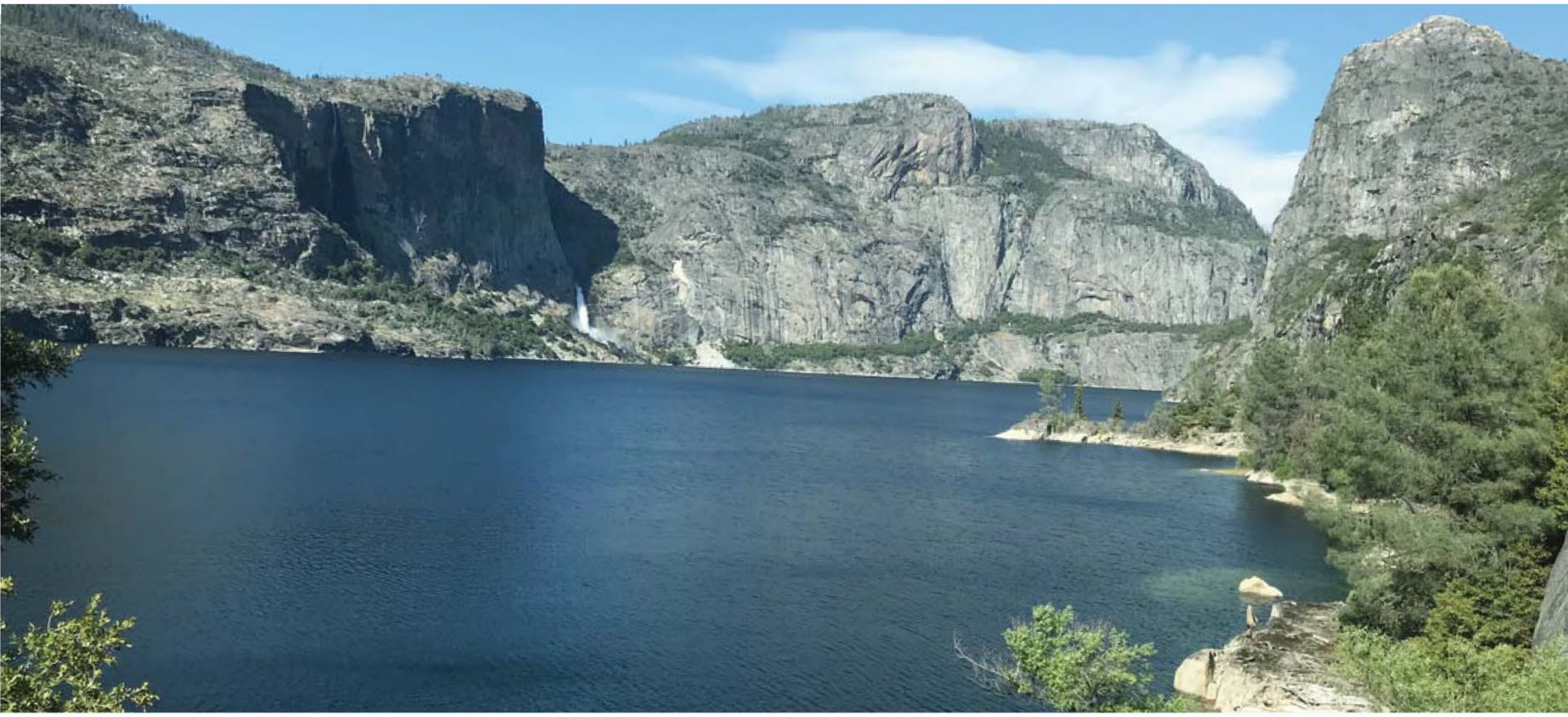
San Francisco
Water Power Sewer
Services of the San Francisco Public Utilities Commission

Evaluation, Prioritization, and Recommendations for Contaminants of Emerging Concern in SFPUC Drinking Water System: 2022 Final Report



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Foreword

In 2008, per Mayor Newsom's direction, the San Francisco Public Utilities Commission (SFPUC) developed a San Francisco Water Quality Protection Plan. An action item from the Plan was to "clarify and revise the monitoring framework for emerging contaminants." In 2011, the proposed SFPUC approach for screening and prioritizing contaminants of emerging concern (CECs) in drinking water was presented in a Nov 1, 2011 memorandum to the Commission.

Specifically, the CEC approach for the SFPUC drinking water system:

- Helps the SFPUC manage contaminants that are not being covered by existing regulations,
- Helps prioritize limited resources on CECs that may be of greater concern to SFPUC, and
- Provides a framework for involving the Commission, stakeholders and the customers in CEC decisions.

A 2013 Report entitled *Screening and Recommended Actions for Contaminants of Emerging Concern (CECs) in SFPUC Drinking Water System* (2013 CEC Report) represented the first implementation of SFPUC's CEC approach and the first evaluation of CECs by the SFPUC Water Quality Division (WQD). The 2013 CEC Report included background information on CECs, the development process, and basic steps of SFPUC's approach to CECs, CEC group descriptions and examples, screening evaluations for the SFPUC system, priorities, and recommendations.

In 2016, a Report on CECs in SFPUC Drinking Water presented CEC monitoring data, screening evaluations, regulatory updates, findings from the scientific studies, recommended actions, and monitoring plan for CECs. In 2019, a progress Technical Memorandum (TM) was provided, which discussed the details on CEC priorities, emerging issues, regulatory developments, a review of recommended actions and monitoring data, the progress made by SFPUC over three years (2016-2018), and a plan for CEC monitoring for the next three years (2019 – 2021).

This Report provides an update to the above referenced documents covering scientific studies in greater detail for years 2016 – 2021 to enable the stakeholders and staff a more in-depth look at the issues of unregulated contaminants in drinking water. All monitoring data collected by the SFPUC on CECs in years 2016 – 2021 are presented. Based on this foundation of scientific information and SFPUC monitoring results, WQD utilized "screening evaluation" table format to organize this complex and extremely broad subject matter to evaluate the "status quo" of presently unregulated drinking water contaminants for our system, proposed priorities, and recommendations for the next cycle 2022 – 2025 and beyond.

Acknowledgments

San Francisco Public Utilities Commission, Water Quality Division*

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Dedication

This Report is dedicated to Gregg E. Olson, P.E. (1968 – 2020)

Gregg E. Olson, P.E., was a long-time engineer with the Water Quality Division (WQD), Engineering Section. Before joining WQD, he worked with US EPA and SFPUC Power Enterprise. He was a Bay Area native from Los Gatos where he spent his childhood years. He obtained his bachelor's degree from University of California at Santa Barbara in Mechanical Engineering, and master's degree in Civil and Environmental Engineering from San Jose State University.

Gregg presented SFPUC's first iteration of the CEC Approach at the American Water Works Association (AWWA) 2014 Annual Conference in Boston. He authored, *"Evaluating and Prioritizing Contaminants of Emerging Concern in Drinking Water"* published in Journal AWWA in December 2017, which has been cited in many other papers around the world. Gregg worked on a wide range of projects, including CEC monitoring, water quality targets, disinfection by-products, total coliform investigations, evaluation of water quality home test kits, nitrification prevention measures, lead and copper control, water quality fact sheets posted on SFPUC's website, and algal toxins monitoring, where he spearheaded evaluations of algal toxins measurement and treatment.

Gregg was a dedicated engineer and coworker you could fully rely on, approaching his work with true scientific curiosity. He was an avid international traveler, sports fan, runner, and golfer. He had a great sense of humor and was very enjoyable to work with. He is greatly missed.

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Executive Summary

This Report presents a six-year review, from 2016 to 2021, on contaminants of emerging concern (**CECs**) in the San Francisco Public Utilities Commission (**SFPUC**) drinking water system, San Francisco Regional Water System (**SFRWS**) and San Francisco Water System (**SFWS**), including:

- source waters (surface and groundwater),
- treated drinking water in SFRWS and SFWS.

CECs are unregulated contaminants that may be detected in water and little may be known about their sources, occurrence, removal during treatment, fate in drinking water distribution systems, and potential risks to human health and the environment. SFPUC Water Quality Division (**WQD**) has developed an approach for evaluating and prioritizing CECs in drinking water to determine the need, if any, for further actions, such as water quality monitoring. The approach also provides a mechanism for documenting CEC information and engaging the customers and other stakeholders on CEC issues. CECs are an important consideration for water utilities in their aim to:

- provide safe drinking water,
- maintain customers confidence in the water supply, and
- prepare for possible future regulations with additional monitoring, treatment optimization, and/or other mitigation measures.

This Report presents the implementation of the approach for CECs in SFPUC drinking water. The objectives of this work are to:

- provide a consistent, proactive, and flexible means of organizing and prioritizing CECs when regulatory guidelines are not available, and
- enhance stakeholder engagement on CEC issues.

In 2016, a Report on CECs in SFPUC drinking water presented the previous in-depth update on the CEC situation including:

- SFPUC monitoring data,
- screening evaluations of 12 groups of contaminants,
- regulatory update,
- findings from the scientific literature at that time, and

- recommended actions and monitoring plan.

In 2019, a Progress Technical Memorandum I was issued, which discussed:

- new/revised CEC priorities,
- emerging issues,
- regulatory developments,
- a review of recommended actions and monitoring data, and the progress made by SFPUC over three years (2016-2018), and
- a plan for CEC monitoring for the next three years (2019 – 2021).

The 2016 and 2019 CEC documents were presented to the SFPUC Citizens' Advisory Committee (**CAC**) and the Commission. This Report provides a current update encompassing years 2016 – 2021.

Approach for CECs in SFPUC Drinking Water

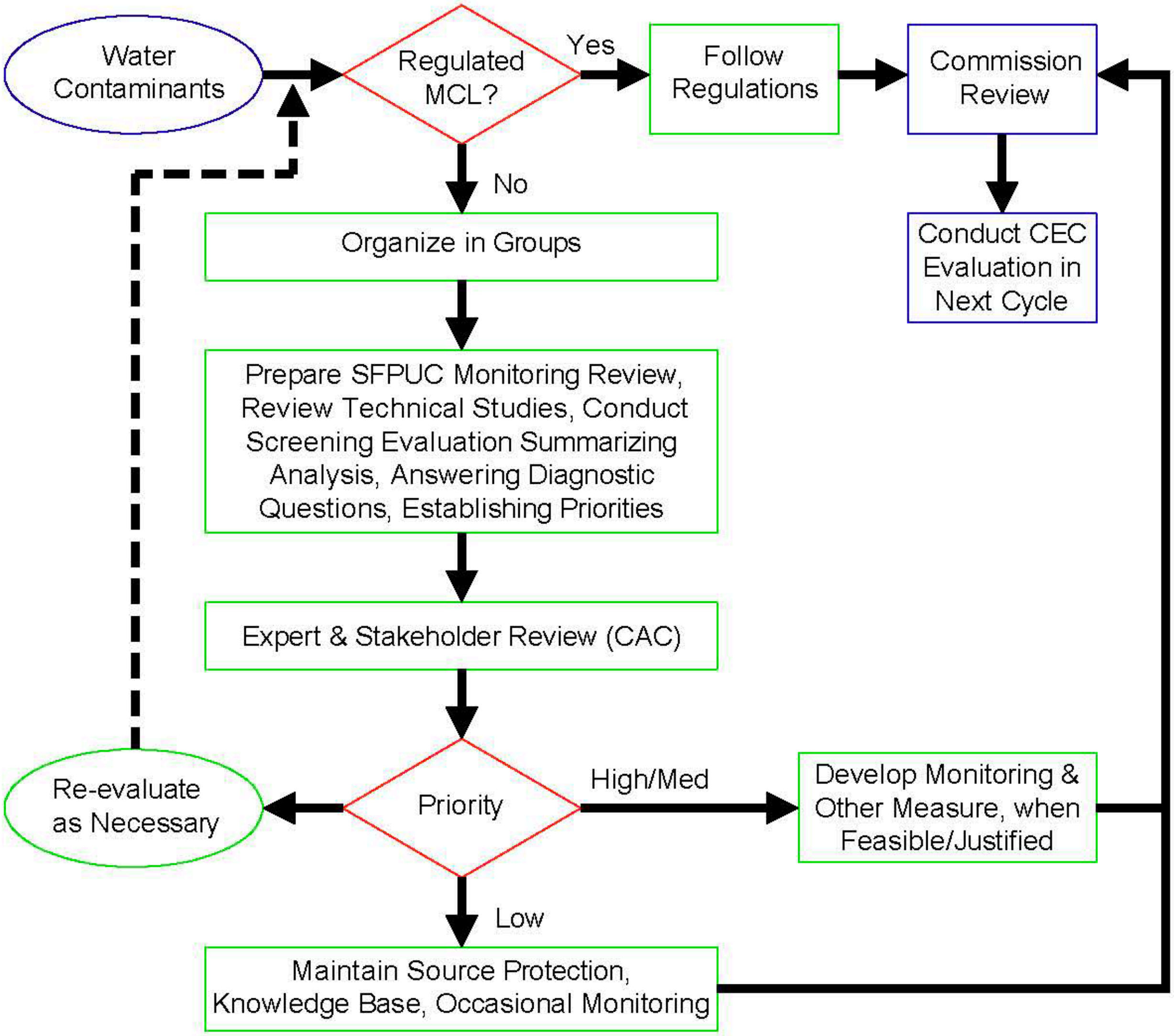
In November 2011, a Technical Memorandum was submitted to the Commission on the proposed approach for CECs in SFPUC drinking water. The approach developed was to group, screen, and prioritize the unregulated CECs to determine the need for further action and was subsequently endorsed by SFPUC Commission in November 2011. This Report is the continuation of the same approach with improvements/refinements. The approach is summarized in **Figure ES-1**. Due to the large number of CECs (hundreds of thousands of unregulated microbial and chemical contaminants) and lack of specific information, the CEC approach utilizes grouping and indicators and is more qualitative compared to regulated contaminants that have numeric water quality criteria. The decisions are based on the latest scientific information and SFPUC monitoring data. Our approach is based on the following steps:

A. From the universe of water contaminants, regulated contaminants are separated and considered under regulatory compliance across the top of **Figure ES-1**.
B. CECs are organized in groups and a review of available SFPUC monitoring data plus a review of scientific studies is conducted by the WQD staff. A screening evaluation table is prepared for each group of contaminants to summarize information and provide basis for establishing priorities and recommended actions.
C. Expert and stakeholder review (Citizens' Advisory Committee, [CAC] and wholesale customers) is conducted next to evaluate the significance and prioritization of various CEC groups or individual CECs for the SFPUC drinking water system.

D. The SFPUC Commission is briefed on the findings, priorities and recommendations for CEC groups. The Report and recommendations are forwarded to the Commission for feedback, as shown on the right-hand side of **Figure ES-1**.

E. Priorities are re-evaluated as necessary as shown by the broken line going back to the front of the evaluation process. Olson et.al (2017) published additional detailed information about our approach as of 2017 that is included in the Resources at the end of this Report.

Figure ES-1. Flowchart of SFPUC's Approach to CECs in Drinking Water



CEC Groups and Screening Evaluations for SFPUC Drinking Water

The SFPUC has very high-quality sources of water yet trace detections of some CECs can occur. The SFPUC approach groups CECs into 10 groups with similar properties and/or common routes of entry into the water system to organize the evaluation process and make the large number of CECs manageable. Each group is screened to determine its priority for SFPUC drinking water. The ten (10) proposed SFPUC CEC groups and their priorities are listed in **Table ES-1**.

All available SFPUC CEC monitoring data for the reporting period (2016 – 2021) along with the analyses are included in this Report, as well as excerpts from peer-reviewed scientific studies to document available scientific information.

The screening evaluation tables of this Report include general information, context of the CEC evaluation for SFPUC (occurrence data, prior experience, customer concerns; etc.), diagnostic questions and answers on health, occurrence, and treatment. This information was obtained from peer-reviewed scientific studies, web searches, available occurrence data, and professional experience. The final section of each Screening Evaluation prioritizes the CEC group, presents implemented actions in the last 6 years and recommends actions for the future. Expert review of the Screening Evaluations was conducted by:

- Dr. R. Rhodes Trussell, Ph.D., P.E., Trussell Technologies Inc., Pasadena, CA.
- Dr. William A. Mitch, Ph.D., P.E., Professor at Stanford University, Civil and Environmental Engineering, Palo Alto, CA.
- Dr. June Weintraub, Sc.E., San Francisco Department of Public Health, San Francisco, CA.
- SFPUC Water Quality Division staff.

The proposed CEC groups and priorities are presented in **Table ES-1**. The changes in priorities of some of the CECs since previous TM update in 2019 are explained below.

Throughout the Report, color was used to help guide the reader through several summary tables and all Screening Evaluations. Red was used for high-priority, green for medium, and blue for low-priority items or contaminants, respectively. Additionally, in the excerpts from the scientific studies for each group of contaminants, the most significant findings were reported in boxes to facilitate review.

Table ES-1. SFPUC Proposed CEC Priorities and Groups for 2022–2025 System

Priority	CEC Groups 2022 – 2025	CEC Examples
1 – High	MICROBIAL WATERBORNE PATHOGENS	*Legionella, Naegleria fowleri, Adenovirus*
2 – Medium	PFAS (Per- and Poly-fluoroalkyl Substances)	29 PFAS on UCMR5.
3 – Medium	Disinfection Byproducts (DBP) NITROSAMINES	NDBA, NDEA, NDMA, NDPA, NDPhA, NDPYR on CCL5
4 – Medium	OTHER DBPs	Iodo-DBP, Brominated-DBP Nitrogenous-DBP chlorate, HAA6Br
5 – Medium	ALGAL TOXINS & HARMFUL ALGAL BLOOMS (HAB)	Total Microcystin, Saxitoxin, Anatoxin-a Microcystis, Anabena, Aphanizomenon
6 – Medium	INORGANICS	Strontium (Sr), Vanadium (V), Manganese (Mn), Chromium (Cr VI)
7 – Medium	ORGANICS	Pesticides, Industrial Chemicals, VOC, SOC, Leachate from Materials (liners, gaskets, etc.)
8 – Low	PPCP/EDC/HORMONES	Pharmaceuticals, Endocrine Disruptors, Hormones, Antibiotics, DEET, Triclosan
9 – Low	MICROPLASTICS & NANOPLASTICS	Polymeric raw materials + additives, (polyethylene, polyvinyl chloride, etc.)
10 – Low	ENGINEERED NANOMATERIALS & NANOPARTICLES	Carbon nanotubes, Buckyballs, titanium dioxide, colloidal silver

Changes to CEC Grouping

Some changes have been made in the grouping of the CEC since 2019 to reflect new research and the evolving nature of the subject matter. Some of the CEC groups, which were listed separately in previous reports are combined under one general group.

- Per- and Polyfluoroalkyl Substances (**PFAS**) – these contaminants will most likely be regulated by the USEPA, hence a new group was created. The previous Report included these contaminants under flame retardants.

- Organics –pesticides, industrial chemicals, and leachate from materials (pipe coatings) are combined under one group as Organics to focus and improve analyses, whereas in the 2016 Report each contaminant group was discussed separately.
- Pharmaceuticals and Personal Care Products (**PPCP**) and Endocrine Disruptor Chemicals (**EDC**) –natural hormones were included in this group, whereas PPCP/EDC and naturally occurring hormones were discussed separately in 2016 Report.
- Microplastics and Nanoplastics – This is a new addition to the CEC groups due to the attention received from public health, California State Water Resources Control Board (**SWRCB**), and research organizations.

CEC Regulatory Developments

Since the 2019 CEC update, PFAS compounds moved from low priority to medium priority in the SFPUC CEC ranking due to new information and the attention received from regulatory agencies. It is expected that MCLs for two PFAS will be promulgated under the Safe Drinking Water Act by 2023; PFAS are also included in the Fifth Unregulated Contaminant Monitoring Rule (**UCMR5**).

USEPA published the UCMR5 on December 27, 2021. UCMR 5 requires sample collection for 30 chemical contaminants between 2023 and 2025 using analytical methods developed by EPA. It includes 29 PFAS compounds and Lithium. The sampling locations will be the entry points to the distribution system.

SWRCB's Division of Drinking Water (**DDW**) issued on March 5, 2021 a revised notification and response level for perfluorobutane sulfonic acid (**PFBS**) of 0.5 parts per billion (ppb) and 5 ppb, respectively.

USEPA published the Draft Fifth Contaminant Candidate List (**CCL5**) on July 19, 2021, which includes 66 chemicals, three chemical groups (PFAS, cyanotoxins, disinfection by-products), and 12 microbes. It is still in draft stage and USEPA will finalize the CCL5 based on the feedback received from the Science Advisory Board along with public comments.

SWRCB re-proposed a new MCL of 10 µg/L for Cr (VI) in March 2022. California does not have an existing MCL for Cr (VI).

The SWRCB DDW has initiated the process of developing revised notification and response levels for manganese because of its possible health effects. To date, manganese is regulated based on aesthetic effects only.

California Office of Environmental Health Hazard Assessment (**OEHHA**) submitted an interim Notification Level (**NL**) recommendation for algal toxins: microcystins, cylindrospermopsin, anatoxin-a, and saxitoxin to SWRCB on May 3, 2021.

Highlights of SFPUC Monitoring and CEC Literature Review

A detailed review of available water quality monitoring data for years 2016 – 2021 and technical literature review was conducted for the respective CEC groups and is presented in the Monitoring and Literature Reviews as well as Screening Evaluation Section of each CEC group. It cites latest findings and information from sources such as Water Research Foundation, American Water Works Association, peer-reviewed journals (published by Elsevier, Springer, American Chemical Society), regulations from USEPA, CA SWRCB, and international regulatory agencies (WHO, Health Canada), etc.

The summary of CECs monitored in SFPUC drinking water is presented in **Table ES-2**.

Table ES-2. Summary of CECs Monitored in SFPUC Drinking Water, 2016-2021

CEC Group	Contaminant(s) Monitored
Emerging Microbial Waterborne Pathogens	Not Monitored in 2016 – 2021*
PFAS (monitored 2019 – 2021)	29 compounds
DBPs, nitrosamines (monitored 2018- 2021)	6 nitrosamines
DBPs, other (monitored 2018 – 2021)	Chlorate Bromochloroacetic Acid Bromodichloroacetic Acid Chlorodibromoacetic Acid Tribromoacetic Acid
Algal Toxins (monitored 2018 – 2021)	Total Microcystins, Anatoxin-a, Saxitoxin, Cylindrospermopsin
Inorganics (monitored 2016 – 2021)	10 contaminants monitored including Cr (VI) and Manganese
Organics monitored for SOC, VOC, Industrial Chemicals, Pesticides (monitored 2016 – 2021)	117 contaminants monitored
Pharmaceuticals/EDC and Natural Hormones (monitored 2020 – 2021)	106 contaminants monitored
Microplastics and Nanoplastics	Not Monitored in 2016 – 2021
Engineered Nanomaterials and Nanoparticles	Not Monitored in 2016 – 2021

* All regulated microbial pathogens were monitored as required

CEC Prioritization and Recommended Actions for SFPUC Drinking Water

The CEC Screening Evaluation helps determine the prioritization of CEC, which is based on the diagnostic questions answered in the screening evaluation tables. A summary table of diagnostic questions and answers grouped in four parts and excerpted from each Screening Evaluation table is shown in **Table ES-3**. The four parts of this analysis are:

- Part A – Health effects from scientific studies in general and likely future US or State regulations.
- Part B – Occurrence in source waters in general and in SFPUC system (based on watershed and source water protection and available SFPUC monitoring data).
- Part C – Occurrence after treatment and distribution at SFPUC (infectivity of pathogens or presence of chemical contaminants) based on effectiveness of treatment in general, assessment of current treatment and available SFPUC monitoring data.
- Part D – CEC prioritization – current assessment at SFPUC based on available scientific information, current treatment and SFPUC monitoring data.

The Screening Evaluations were reviewed by the experts and the stakeholders for the development of the priorities. For high and medium priorities, monitoring and/or mitigation measures were developed. For low priorities, the CEC group will not warrant active monitoring; however, SFPUC will continue its source protection efforts and track new information on the group.

The results of the Screening Evaluations show that waterborne pathogens are still high priority, whereas three CECs have moved from low priority to medium priority – PFAS, Inorganics, and Organics. The six CECs under medium priority are listed below:

- PFAS,
- DBPs – Nitrosamines,
- DBPs other than nitrosamines,
- Algal Toxins,
- Inorganics, and
- Organics (Industrial chemicals, Pesticides, Leachate from pipe material, reservoir floors, treatment plants, troughs, etc.).

Concentrations of chromium (VI) and manganese in groundwater require blending with treated surface water in the City. All results (2016 – 2021) for boron (B), chromium (Cr-VI), manganese

(Mn), molybdenum (Mo), strontium (Sr), vanadium (V) and zinc (Zn) were below published Federal and State guidelines. Levels of bromide (Br) in SFPUC surface waters are very low (< 10 ug/L in Hetch Hetchy supply, and < 20 ug/L for East Bay and West Bay surface waters). Groundwaters can be expected to contain 100 – 1000 ug/L Br. Data for iodide (I) is extremely limited.

PPCP/EDC, Microplastics and Nanomaterials remain low priority CEC groups due to low likelihood of occurrence in SFPUC drinking water at levels of possible health significance as seen from the PPCP/EDC monitoring data. Currently, for Microplastics there is no analytical standard method. Data may be gathered for Nanomaterials by participating in future WRF study or national surveys, when available.

Given limited water supplies in California, reclaimed water use will continue to increase. Since there is a risk that reclaimed water may contain PFAS, PPCP/EDC, DBPs, and possibly other CECs, it is prudent to begin planning for follow-up monitoring in reclaimed waters and/or groundwaters.

CEC contamination of SFPUC surface water sources is unlikely because the reservoirs are in highly protected watersheds. There are no significant municipal or industrial wastewater discharges to SFPUC water sources, which are generally recognized as the principal sources of many CECs in drinking water and can occur in other communities via treated discharges upstream of drinking water intakes. It is unknown to what extent wildfires in the watersheds may contribute to increased disinfection by-products (**DBP**) precursors. Drought cycles are already increasing seasonal total organic carbon (**TOC**) spikes; peak TOC levels result in higher concentrations of regulated DBPs and potentially unregulated DBPs as well.

Table ES-4 presents highlights of proposed recommended actions for CECs in SFPUC drinking water for 2022–2025. More in-depth information can be found in screening evaluation tables for each group of contaminants.

For all CEC groups, maintaining source water protection and optimized water treatment and distribution operations, as well as the continual tracking of new scientific information and any regulatory developments, are recommended.

Table ES-3. Summary of Diagnostic Questions and Answers for the Prioritization of Contaminants of Emerging Concern (CEC) in SFPUC Drinking Water, 2022 – 2025

CEC GROUP Questions	WATERBORNE PATHOGENS	PFAS	DISINFECTION BYPRODUCTS Nitrosamines	DISINFECTION BYPRODUCTS Other	ALGAL TOXINS Harmful Algal Blooms	INORGANICS B, Co, Ge, Mo, Sr, V, Cr(VI), Mn	ORGANICS Pesticides Industrial Chemicals	PHARMA/ EDC Endocrine Disruptors Hormones	MICRO-PLASTICS NANO-PLASTICS	ENG. NANO-MATERIALS NANO-PARTICLES
PART A: HEALTH EFFECTS FROM SCIENTIFIC STUDIES IN GENERAL AND LIKELY FUTURE US OR STATE REGULATIONS										
Do scientific studies indicate potential health impacts in drinking water?	Yes	Possible	Possible	Possible	Yes	Yes	Yes	Unknown	Unknown	Unknown
Regulations or guidelines outside of US?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
US Health Advisories or CA Notification Levels?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Likely regulation? CCL/UCMR? Pending CA Regulation/PHG?	Possible CCL5	Yes UCMR5	Possible CCL5	Possible UCMR4, CCL5	Yes UCMR4, CCL5	Yes Draft CCL5	Possible UCMR4, CCL5	No	No	No
SIGNIFICANT TO PUBLIC HEALTH IN GENERAL?	Yes	Yes	Possible	Possible	Yes	Yes	Yes	Possible	Unknown	Unknown

CEC GROUP Questions	**WATERBORNE PATHOGENS**	**PFAS**	**DISINFECTION BYPRODUCTS** **Nitrosamines**	**DISINFECTION BYPRODUCTS** **Other**	**ALGAL TOXINS** **Harmful Algal Blooms**	**INORGANICS B, Co, Ge, Mo, Sr, V, Cr(VI), Mn**	**ORGANICS Pesticides Industrial Chemicals**	**PHARMA/ EDC Endocrine Disruptors Hormones**	**MICRO-PLASTICS NANO-PLASTICS**	**ENG. NANO-MATERIALS NANO-PARTICLES**
PART B: OCCURRENCE IN SOURCE WATERS IN GENERAL AND AT SFPUC (BASED ON WATERSHED AND SOURCE WATER PROTECTION AND AVAILABLE SFPUC MONITORING DATA)										
Present in other water supplies?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**	**Unknown**	**Unknown**
Present in SFPUC watersheds, surface waters?	**Unknown**	**No**	**No**	**No**	**Yes**	**Yes**	**Yes**	**No**	**Unknown**	**Unknown**
Present in SFPUC groundwater?	**Unknown**	**No**	**No**	**No**	**No**	**Yes**	**Yes**	**No**	**Unknown**	**Unknown**
PART C: OCCURRENCE AFTER TREATMENT AND DISTRIBUTION AT SFPUC (INFECTIVITY OF PATHOGENS OR PRESENCE OF CHEMICAL CONTAMINANTS) BASED ON EFFECTIVENESS OF TREATMENT IN GENERAL, ASSESSMENT OF CURRENT TREATMENT AND AVAILABLE SFPUC MONITORING DATA										
Formed or released during SFPUC treatment?	**No**	**No**	**Yes**	**Yes**	**Possible**	**No**	**No**	**No**	**No**	**No**
Present in treated Hetch Hetchy water?	**No**	**No**	**No**	**Yes**	**No**	**No**	**No**	**No**	**Unknown**	**Unknown**
Present in treated SVWTP (East Bay) water?	**No**	**No**	**Yes**	**Yes**	**No**	**No**	**No**	**No**	**No**	**No**

CEC GROUP Questions	WATERBORNE PATHOGENS	PFAS	DISINFECTION BYPRODUCTS Nitrosamines	DISINFECTION BYPRODUCTS Other	ALGAL TOXINS Harmful Algal Blooms	INORGANICS B, Co, Ge, Mo, Sr, V, Cr(VI), Mn	ORGANICS Pesticides Industrial Chemicals	PHARMA/ EDC Endocrine Disruptors Hormones	MICRO-PLASTICS NANO-PLASTICS	ENG. NANO-MATERIALS NANO-PARTICLES
Present in treated HTWTP water?	No	No	Yes	Yes	No	No	No	No	No	No
Present in treated local (Peninsula and City) groundwater?	Unknown	No	No	Yes	No	Possible	Possible	No	No	No
Formed or released in SFPUC distribution?	Possible	No	Possible	Yes	No	Yes	Yes	No	Unknown	Unknown
PART D: CEC PRIORITIZATION – CURRENT ASSESSMENT AT SFPUC BASED ON AVAILABLE SCIENTIFIC STUDIES, CURRENT TREATMENT AND AVAILABLE SFPUC MONITORING DATA										
Detected in SFPUC drinking water?**	Yes	No	Yes	Yes	No	No	No	No	Unknown*	Unknown*
Could CEC occur in SFPUC drinking water at levels of health significance?	Yes	No	Possible	Possible	No	Possible	Possible	No	Unknown	Unknown
PRIORITY FOR SFPUC	High	Medium	Medium	Medium	Medium	Medium	Medium	Low	Low	Low

*Currently, there is no monitoring standard method.

**Drinking water refers to treated water that is served to customers.

Table ES-4. Highlights of Proposed Recommended Actions for CECs in SFPUC Drinking Water System for 2022– 2025 (for more details, please see Screening Evaluation tables)

CEC Group	Recommended Actions
Microbial Waterborne Pathogens	• Participate in Water Research Foundation Project (5156) on *Legionella* Occurrence in Distribution Systems. • Continue participation in Partnership for Safe Water (PSW) for WTPs and distribution system.
PFAS	• For forest fires, monitor types of retardants in use and application areas. If application is in watersheds, conduct post-fire water quality monitoring. • Conduct repeat groundwater monitoring for PFAS in 6 years.
Disinfection By-Products (DBPs) **Nitrosamines**	• Add NDPhA and NMOR to semi-annual monitoring (on Draft CCL5 list and expert panel recommendation, respectively). • Continue to avoid polymer overfeed, provide free chlorine contact time before chloramination, and minimize detention time in the distribution system.
DBPs **Other than nitrosamines**	• Conduct bromide and iodide monitoring, as well as Total Organic Nitrogen (TON), in SFPUC water sources and other water sources under development and consideration. • Review ongoing haloacetic acids (HAA) results for all HAA9 species to evaluate the effect of groundwater, increased TOC in Hetch Hetchy water supply. • Conduct preliminary monitoring of Total Organic Halide (TOX) at the treatment plants and in the distribution system. • Conduct monitoring of haloacetonitriles (HAN), haloacetaldehydes (HALs), and haloacetamides (HAMs) at the treatment plants and in the distribution system. • Monitor chlorate in drinking water.
Algal Toxins	• Monitor algal toxins with detection levels consistent with new proposed Notification Levels listed by Cal. OEHHA (May 2021) and USEPA in draft CCL5.
Inorganics	• Monitor inorganics listed in USEPA UCMR5 and draft CCL5 (Lithium). • Monitor Cr (VI) and manganese in groundwater and after blending in SFWS.
Organics	• Replace pipeline coal tar lining with cement mortar during system improvements/upgrades.
PPCP/EDC Hormones	• Monitor water reclamation activities in San Francisco Regional Water System (SFRWS) and San Francisco Water System (SFWS).
Microplastics Nanoplastics	• Participate in California SWRCB pilot program to monitor microplastics in SFPUC system.
Engineered Nanomaterials Nanoparticles	• Benchmark through WRF research, national or state surveys when opportunities become available.

RED = High Priority **GREEN = Medium Priority** **BLUE = Low Priority**

Note: For more details, please see screening evaluation tables.

References

Olson G., Wilczak A., Boozarpour M., DeGraca A., Weintraub J., 2017. *Evaluating and Prioritizing Contaminants of Emerging Concern in Drinking Water,* Journal AWWA, 109(12), 54-63.

SFPUC, 2016. *Screening and Recommended Actions for Contaminants of Emerging Concern (CECs) in SFPUC Drinking Water: 2016 Report.*

SFPUC, 2019. *Contaminants of Emerging Concern in Drinking Water, 2019 Progress Technical Memorandum*

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1. Waterborne Pathogens

Microbial CEC are newly recognized pathogens and new strains of known pathogens that may present challenges in drinking water and public health (WHO, 2003). These emerging pathogens have appeared or increased in occurrence, which have been linked to intensive agriculture, increased growth and migration of human populations, climate change (Medema, 2003), and increased use of antibiotics. Infectious diseases caused by pathogenic bacteria, viruses and parasites (e.g., protozoa and helminths) are the most common and widespread health risks associated with drinking water (WHO, 2017).

HIGH PRIORITY FOR SFPUC

Microbial CEC have been linked elsewhere to waterborne disease outbreaks and therefore can impact public health and customer satisfaction.

Implementing a source-to-tap approach is a universally recommended strategy for reducing the concentration of waterborne pathogens in drinking water and controlling their potential risks (Health Canada, 2020). The potential for occurrence in SFPUC drinking water is low due to the use of multiple barriers, source-to-tap approach: watershed protection, filtration of local supplies, applying multiple disinfectants at the treatment plants, maintaining monochloramine in the distribution system, cross-connection and backflow control, sanitary practices during main breaks and construction, etc.

Maintaining microbiological control in premise plumbing systems, especially in large buildings, is a critical component of providing safe drinking water at the consumer’s tap. Important elements of control strategies for plumbing systems include (Health Canada, 2020):

- limiting nutrient levels through an emphasis on system design and materials,
- minimizing areas of low flow/stagnation,
- keeping temperatures of hot- and cold-water systems outside of the ideal range for microorganism growth (e.g., cold water less than 20°C, hot water tank temperature greater than 60°C), and
- reducing the formation and transmission of contaminated aerosols from distal devices.

This section presents: (1) Screening Evaluation Table, which summarizes the findings, diagnostic questions and answers to support priority for this group of contaminants, and implemented and recommended actions, (2) SFPUC Monitoring Review 2016-2021, and (3) Technical Review 2016-2021 of available scientific studies. Items (2) and (3) provide the foundation of available monitoring and scientific information to support the findings, proposed priorities and recommendations in Item (1).

Table 1-1. Screening Evaluation Table for Microbial Waterborne Pathogens

GENERAL INFORMATION ON CEC	
Instructions	This Screening Evaluation may be applied to a CEC group or an individual CEC. The purpose of this section of the Evaluation is to develop background information on the CEC or CEC group.
CEC Name	**Microbial Waterborne Pathogens**
CEC Description Is CEC a group? If individual CEC, which group is CEC part of?	Microbial CEC are newly recognized pathogens and new strains of known pathogens that may present challenges in drinking water and public health (WHO, 2003). These emerging pathogens have appeared or increased in occurrence, which have been linked to intensive agriculture, increased growth and migration of human populations, climate change (Medema, 2003), and increased use of antibiotics
CEC Grouping What is the basis for grouping? *(Grouping factors are: common health effects, treatment, and analytical method, and/or compound co-occurrence)*	Group, although microorganisms are very diverse. Waterborne pathogens have several properties that distinguish them from other drinking-water contaminants (WHO, 2017): • Pathogens can cause acute and chronic health effects. • Some pathogens can grow in the environment. • Pathogens are discrete. • Pathogens are often aggregated or adherent to suspended solids in water, and pathogen concentrations vary in time, so that the likelihood of acquiring an infective dose cannot be predicted from their average concentration in water. • Exposure to a pathogen resulting in disease depends upon the dose, invasiveness and virulence of the pathogen, as well as the immune status of the individual. • If infection is established, pathogens multiply in their host. • Certain waterborne pathogens are also able to multiply in food, beverages or warm water systems, perpetuating or even increasing the likelihood of infection. • Unlike many chemical agents, pathogens do not exhibit a cumulative effect. Implementing a source-to-tap approach is a universally recommended strategy for reducing the concentration of waterborne pathogens in drinking water and controlling their potential risks (Health Canada, 2020).

Examples and Indicators If group, what are notable examples? Are there possible indicator constituents? *(A suitable indicator occurs at quantifiable levels and may co-occur with other CEC, exhibit similar treatment and fate in environment)*	Microbial CEC include: Legionella, *E. coli (O157)*, Mycobacterium Avium Complex (MAC), enterovirus, and others listed on the USEPA CCL5. Monitoring for all pathogens remains impractical and it is not necessary for drinking water utilities to adequately manage risks (Health Canada, 2020). Measurements of single indicator organisms did not correlate with pathogens (only 41%) (Mraz et al., 2021). The detection of pathogenic organisms is not normally associated with the indicator concept, as each pathogen essentially represents only itself and its absence is not an indication of the absence of other pathogens. Instead, regulated microbials or coliphage serve as indicators of fecal contamination and/or distribution system conditions (and not of the presence of unregulated microbial CEC) (Medema, 2003). These regulated microbial indicators include: total coliform, fecal coliform, *E.coli, Giardia, Cryptosporidium,* and heterotrophic plate count (HPC). The following related, non-microbial parameters are also monitored as indicators of treatment and distribution system conditions: turbidity, CxT, chlorine residual, and nitrite. Chlorine residual and nitrite are good indicators for nitrification control and regrowth in chloraminated systems. Regulated and unregulated microbials can be minimized through treatment and best management practices.
Health Advisories Does CEC have a USEPA Health Advisory (e.g., Drinking Water Equivalent Level [DWEL]) or California Notification Level?	There are no CA Notification Levels or USEPA DWELs for unregulated microbials. Updated USEPA Health Advisory Table (USEPA, 2018) lists Legionella, Mycobacteria and viruses. No limit is specified for Legionella; EPA believes that if Giardia and viruses are inactivated, Legionella will also be controlled, under Surface Water Treatment Rule. This concept is not necessarily true for Legionella or any other opportunistic pathogens. The key is maintaining conditions in the distribution system and consumer plumbing that prevent their growth (Dr. Trussell, personal communication).
Regulatory Development Status Is CEC on USEPA Candidate Contaminant List (CCL), Unregulated Contaminant Monitoring Rule (UCMR) list, or California Public Health Goal (PHG) list?	There are 12 unregulated microbials on the draft CCL5 (USEPA, 2021): 1. Adenovirus 2. Caliciviruses 3. *Campylobacter jejuni* 4. Enterovirus 5. *Escherichia coli* (O157) 6. *Helicobacter pylori* 7. *Mycobacterium avium* 8. *Legionella pneumophila* 9. *Mycobacterium abcessus* 10. *Naegleria fowleri* 11. *Pseudomonas aeruginosa* 12. *Shigella sonnei* There are no unregulated microbials on the UCMR5.

CONTEXT OF CEC EVALUATION AT SFPUC	
Instructions	The purpose of this section is to report SFPUC experience with the CEC or CEC Group, including occurrence data for each source water if available.
Purpose Why is evaluation undertaken? What is new about the issue that is considered 'emerging' (e.g., new chemical, new effect)?	Microbial CEC are important due to the acute impact on public health and rapidly developing knowledge about new pathogenic organisms. Treatment and disinfection are optimized for *Giardia*, *Cryptosporidium* and virus inactivation/removal. Distribution system operation is optimized for Revised Total Coliform Rule (RTCR). The likelihood of microbial CEC survival and infection is small. However, the USEPA and the scientific community are concerned about intrusion and regrowth of regulated and unregulated microbial contaminants in distribution system. Of concern are "green" building practices intended to reduce water use that can promote growth of opportunistic premise plumbing pathogens (OPPP) in premise plumbing between utility service lines and customer taps (Edwards, 2015; WRF, Rhoads, 2015). Regulations are based on reducing the spread of pathogens via ingestion that primarily causes diarrheal illness. Expanded routes of transmission include not only ingestion but also inhalation, nasal and contact (dermal, ear, eye, wound, urinary tract) routes. According to CDC, in 2011-2012, premise plumbing respiratory illness outbreaks outnumbered diarrheal outbreaks (Beach, 2016). The CDC acknowledges higher waterborne disease occurrence from plumbing components including pipes, water heaters, shower heads and fixtures than from pathogens passing through a water treatment process. Legionella is responsible for the majority of OPPP outbreaks (WRF, Masters et al., 2018).
Customer Interaction Widespread public concerns? Media coverage?	Due to the acute nature of microbials, any breach of treatment and distribution barriers is likely to impact customer satisfaction and confidence. Media coverage and public concern about waterborne pathogens has always been minimal compared to chemical CEC, except when localized outbreaks become newsworthy.
Expected Outcomes What are the likely benefits of the investigation to SFPUC and its customers?	Tracking regulatory developments, microbial CEC health and technical studies and participating in national surveys, when available and applicable, positions SFPUC to respond to new issues and questions from the public. SFPUC continually improves multi-barrier protections minimizing microbial introduction, regrowth and related risks critical for public health protection.

Occurrence Data (US and SFPUC) What occurrence information is available? Have detections, if any, been confirmed by follow-up sampling and/or QA/QC review?	SFPUC has extensive data on regulated microbials (total coliform, fecal coliform, *E. coli*, *Giardia,* and *Cryptosporidium*). As noted above, regulated microbials can serve as indicators of disinfection adequacy and distribution system conditions (but not necessarily control of specific, unregulated microbials). SFPUC consistently meets the regulatory requirements of the RTCR including ≥ 95% of samples absent for TC per month. Please see Monitoring Review for 2015-2021 Total Coliform statistics for SFRWS and SFWS. From 2003 to 2005, SFPUC conducted a special study of *Legionella* during the conversion from free chlorine to chloramine for residual disinfection. Based on 53 buildings in San Francisco, *Legionella* colonized 60% of the hot water systems before monochloramine conversion versus 4% after conversion (Weintraub, et al., 2008). In June/July 2012, SFPUC sampled two future groundwater wells, CUP 10A (now GSR-SBW) and CUP 11A (now GSR-CRW), for UCMR3 viruses (enteroviruses and noroviruses). Both wells tested absent for viruses.
Supporting Information List key references	LeChevallier Mark W. (2019). Monitoring distribution systems for Legionella pneumophila using Legiolert. AWWA Wat Sci. 2019; e1122. https://doi.org/10.1002/aws2.1122. Mraz et al. (2021). Why pathogens matter for meeting the United Nations' sustainable development goal 6 on safely managed water and sanitation. Water Research 189, 116591. https://doi.org/10.1016/j.watres.2020.116591. NASEM (2020). *Management of Legionella in Water Systems.* Washington, DC: The National Academies Press. https://doi.org/10.17226/25474 USEPA (2021). Technical Support Document for the Draft Fifth Contaminant Candidate List (CCL 5) – Microbial Contaminants. Office of Water (4607M) EPA 815-R-21-007, July 2021. WHO (2017). Guidelines for Drinking-water Quality. FOURTH EDITION INCORPORATING THE FIRST ADDENDUM. Geneva: World Health Organization; 2017. License: CC BY-NC-SA 3.0 IGO. https://www.who.int/publications/i/item/9789241549950 accessed 12/1/2021. WRF, Culotti, A., Packman, A.I. and Kelly, J.R. (2015). Water Research Foundation, *Characterizing the Interactions Between Pathogens and Biofilms in Distribution Systems* [WRF Project #4259], February 2015. WRF, Masters Sheldon, Jennifer L. Clancy, Samantha Villegas, Mark LeChevallier and Zia Bukhari (2018). Customer Messaging on Opportunistic Pathogens in Plumbing Systems. Water Research Foundation, Project #4664.

	WRF, Rhoads, W.J. et al. (2015). *Green Building Design: Water Quality Considerations,* Water Research Foundation, WRF Project #4383 WRF, Seidel, C., Ghosh, A., Tang, G., Hubbs, S.A., Raucher, R. and Crawford-Brown, D. (2014). *Identifying Meaningful Opportunities for Drinking Water Health Risk Reduction in the United States* Water Research Foundation. [WRF Project #4310], May 2014.

DIAGNOSTIC QUESTIONS TO SUPPORT CEC PRIORITIZATION

Instructions	The purpose of the Diagnostic Questions is to determine whether the CEC or CECs Group are significant to SFPUC drinking water and whether they merit further evaluation and/or action. All answers require explanation except those clearly not applicable. The Diagnostic Questions are divided into Health, Occurrence, and Treatment sections. The more questions are answered with a "Yes", the higher the probability that the CEC is a high priority or that a proactive approach should be taken.

HEALTH EFFECTS FROM SCIENTIFIC STUDIES

Question	Answer	Explanation and Comments
Is scientific knowledge on CEC health effects well developed?	**Yes** **No for New**	The USEPA CCL5 list was based on a review of 1,435 pathogens that were narrowed to 12 priorities based on anticipated survival, transmission mechanism, data on waterborne disease outbreaks, occurrence, and health effects. Protocols used in this process are discussed in USEPA (2021). Given that a knowledge-based method was used to develop the microbial CCL5 list, there appears to be adequate scientific knowledge.
Based on current scientific understanding, does the CEC pose potential health risk at the levels typically found in drinking water in the US?	**Yes**	Microbial infection can lead to illness. Waterborne disease outbreaks have been attributed to some unregulated microbials (see next Q&A). For microbials, vulnerable subpopulations are typically at greater risk than the general population. Legionnaires' disease afflicts and kills more people in the United States than any other reportable waterborne disease. (NASEM, 2020) A 2014 study evaluating relative health risk impacts of drinking water contaminants concluded that microbial contaminants pose a larger health risk in US drinking waters than any individual chemical contaminant (WRF, Seidel et al., 2014).

Question	Answer	Explanation and Comments
Adverse health impacts observed in other drinking water systems? **Are public health studies documenting human health impacts (disease or outbreaks) available?**	Yes	The CDC and USEPA maintain a collaborative surveillance system for waterborne disease outbreaks. Many outbreaks have been attributed to unregulated microbial CEC. The most recent summary was published in 2017, and revealed that during 2013–2014, a total of 42 drinking water–associated outbreaks were reported to CDC, resulting in at least 1,006 cases of illness, 124 hospitalizations, and 13 deaths. Legionella was responsible for 57% of outbreaks and 13% of illnesses, and chemicals/toxins and parasites together accounted for 29% of outbreaks and 79% of illnesses. Outbreak surveillance data likely underestimate actual occurrence of outbreaks and should not be used to estimate the actual number of outbreaks or cases of waterborne disease. (CDC, Benedict et al., 2017) SFPUC's partnership with SFDPH includes active surveillance for cryptosporidiosis as well as ongoing tracking of the occurrence of potential waterborne diseases in San Francisco. Although more commonly associated with recreational water exposure, in 2002, two children exposed to Naegleria fowleri in municipal tap water, contracted primary amoebic meningoencephalitis (PAM) and died (PAM has a 98% fatality rate) (Bartrand, 2014). Other fatalities attributed to Naegleria fowleri in tap water have been reported in Louisiana, Virginia, Minnesota and Kansas.
Existing regulations or guidelines outside of US (e.g., WHO, EU)?	Yes	EU Revised Drinking Water Directive (EU 2020a and 2020b) lists Legionella parametric value as < 1000 CFU/L as relevant for the risk assessment of domestic distribution systems. Intestinal enterococci (0/100 mL) and Clostridium perfringens including spores (0/100 mL) are listed as well.
Existing US health advisories or CA notification levels?	Yes	HA Status: Legionella F01, Mycobacteria F99. MCLG zero for Legionella and viruses.
Likely US regulation in the next 10 years? **Is CEC on a regulatory development list, such as CCL?** **Is there a pending regulation or California PHG?**	Possible	There are 12 microbials on the draft CCL5 but it is unknown that any new specific microbials will be regulated in the next 10 years. Possible exceptions would be enterovirus or norovirus for undisinfected groundwater sources, as these two parameters were investigated under UCMR3.

Question	Answer	Explanation and Comments
SUMMARY – SIGNIFICANT TO PUBLIC HEALTH IN GENERAL? (Based on above answers)	Yes	Microbial CECs are considered significant to public health because there have been instances of waterborne disease outbreaks attributed to some of these unregulated CEC.
OCCURRENCE		
Is scientific knowledge on CEC sources/formation well developed?	**Yes** **No for New**	All water sources contain a number of known and unknown microbes, and the conditions under which microbes grow and how growth can be restricted are reasonably well understood. Some microbes (e.g. Naeglaria fowleri, Legionella) favor warmer waters, some are sensitive to chlorine (e.g. Giardia, many viruses), some are best managed with UV disinfection (e.g. Cryptosporidium), some grow more favorably in surface waters, while some grow more favorably in groundwater environments.
CEC presence reported in other water supplies? Are occurrence studies available?	Yes	There are research occurrence studies and data from waterborne disease outbreaks. Please refer to Technical Review (page 1-39 and following).
CEC present in SFPUC watersheds and/or surface waters? Are there complex issues involved in managing CEC ;e.g., point vs. non-point sources?	**Unknown**	SFPUC's protected watersheds are not impacted by wastewater discharges, urban runoff, or agricultural/feedlot runoff. However, the watersheds and source waters contain natural wildlife (e.g., cattle grazing in the East Bay) which contribute microbial contaminants to source waters.
Is the CEC a potential groundwater contaminant?	Yes	Microbial CEC have caused some outbreaks associated with drinking water supplies served by groundwater. Please refer to Technical Review. With respect to groundwater, if wells are not properly sited and constructed, wells can be subject to microbials from leaky sewer lines, septic systems, and/or influences from surface water although there is a siting process to minimize microbial contamination.

Question	Answer	Explanation and Comments
If the CEC is a potential groundwater contaminant, is it highly mobile in the subsurface? *Is* the CEC low-sorbing and resistant to microbial degradation?	**Unknown**	Mobility is dependent on microbe characteristics as well as the subsurface material. For example, waterborne disease outbreaks from *E. coli* in groundwater were linked to fractured bedrock that facilitated the transport of *E. coli* from surface contamination to well intakes (Bloetscher and Plummer, 2011).
Precursor present in SFPUC source waters? *(Including surface waters and groundwaters)*	**No**	Microbial CEC do not have precursors in the chemical sense. However, presence of nutrients, water temperature, oxygenation, pH and other characteristics can determine the rate of microbial growth.
Formed or added during current SFPUC treatment? If so, describe whether the formation or addition of CEC can be controlled.	**No**	Microbial CEC are not formed during treatment.
Formed or added within SFPUC storage or distribution? If so, describe whether the formation or addition of CEC can be controlled.	**Possible**	Intrusion of microbial CEC and regrowth in the distribution are possible. Ensuring the integrity and effective operation of the distribution system is critical for public health protection. Biofilms have been shown to facilitate growth of microbial CEC, such as *E. coli* and *C. jejuni*, under conditions that would otherwise be considered adverse to those organisms (WRF, Culotti, 2015). Reduced water use associated with low flow plumbing fixtures and other water savings could increase residence times, promoting pathogen regrowth. Increased water age has been associated with increased HPC and *Legionalla* growth (WRF, Rhoads, 2015). Maintenance of chlorine residual is effective in controlling Legionella spp. But there are many situations where bacteria can be shielded from the disinfectant, as in a biofilm or amoebae; therefore, complete eradication of the microorganism is difficult (LeChevallier, 2019). Fine sediments deposited over time and accumulated in reservoirs and distribution pipes may provide an environment for regrowth of microbials and may be a concern due to SFPUC's unfiltered source waters.

Question	Answer	Explanation and Comments
Detected in SFPUC drinking water?	Yes	E. Coli is tested extensively throughout the SFPUC water systems for regulatory compliance. Only two E. Coli detections within the SFPUC treated water systems have occurred within the last 10 years – and at unorthodox sample locations (hydrant, blow off) during main disinfections. With the exception of *Legionella*, SFPUC has not routinely sampled for CEC microbials. After the 2004 chloramine conversion, *Legionella* was almost entirely eliminated in bulk water and biofilm samples from 53 buildings.
SUMMARY – OCCURRENCE IN SOURCE AND DRINKING WATER? *(OR SIGNIFICANT POTENTIAL TO OCCUR)* *(Based on above answers)*	Yes	Microbial CEC could occur in source waters (surface water and groundwater) and in the distribution system (if integrity or effective operation is compromised). Waterborne disease outbreaks have been linked elsewhere to unregulated microbials, indicating potential for CEC occurrence in drinking water systems.
TREATMENT		
Is scientific knowledge on CEC treatment/removal well developed?	Yes	Although microbials are a diverse group, they are all susceptible to disinfectants (specific inactivation depends on the disinfectant and pathogen). Monitoring and treatment to control regulated microbials is expected to minimize the occurrence of unregulated microbials. Additionally, distribution system operations to prevent both regulated and unregulated microbial entry and maintaining disinfectant residual are known to minimize microbial occurrence. WHO (2017) presented summary tables and discussion of pathogens transmitted through drinking water.
Likely to pass through current treatment for Hetch Hetchy Supply? Describe any complex issues involved with the treatment/removal of CEC.	No	Tesla Water Treatment Facility provides primary disinfection using UV treatment and chlorine. Though inactivation efficiency is a topic of ongoing research for microbial CEC, disinfection at Tesla is expected to significantly minimize unregulated microbials. In addition, monochloramine is used as a secondary distribution system disinfectant. Several years ago, SFPUC implemented a rigorous set of internal water quality targets for the entire SFRWS and SFWS. They are part of Operations Plans for each treatment and distribution facility and provide drivers of performance to ensure microbial safety well beyond the regulatory requirements.

Question	Answer	Explanation and Comments
Likely to pass through current treatment at SVWTP? Describe any complex issues involved with the treatment/removal of CEC.	**No**	SVWTP provides coagulation, flocculation, sedimentation, filtration, and disinfection using chlorine. Treatment is expected to minimize unregulated microbials. In addition, monochloramine is used as a secondary disinfectant and is monitored throughout the transmission and distribution system. SFPUC participates in a voluntary Partnership for Safe Water (PSW) Treatment Plant Optimization Program at SVWTP. The goal of PSW is to reduce the risk to water consumers from microbial contaminants, such as Cryptosporidium, by reducing filter effluent turbidity. (AWWA, 2021). Additionally, Operations Plan provides internal water quality targets for SVWTP.
Likely to pass through current treatment at HTWTP? Describe any complex issues involved with the treatment/removal of CEC.	**No**	HTWTP provides coagulation, direct filtration and disinfection using ozone and chlorine. Treatment is expected to minimize unregulated microbials. In addition, monochloramine is used as a secondary disinfectant and is monitored throughout the transmission and distribution system. SFPUC participates in a voluntary Partnership for Safe Water (PSW) Treatment Plant Optimization Program at HTWTP (see above and in the Monitoring Review). Additionally, Operations Plan provides internal water quality targets for HTWTP.
Likely to pass through current treatment for groundwater? Describe any complex issues involved with the treatment/removal of CEC.	**Unknown**	Groundwater is disinfected using free chlorine prior to blending with chloraminated surface waters (San Francisco wells) or will be chloraminated at the wellhead prior to blending (Peninsula wells). Disinfection is expected to minimize unregulated microbials.
SUMMARY – LIKELY TO PASS (NOT REMOVED BY) CURRENT TREATMENT? *(Based on above answers)*	**No**	Regulated microbials are effectively removed by existing SFPUC treatment barriers. Though inactivation efficiency of unregulated microbials is a topic of ongoing research, treatment at Tesla, SVWTP, and HTWTP, maintenance of a secondary disinfectant (chloramine) in the distribution system, and continuation of other programs, are expected to significantly minimize microbial CECs. Water reuse projects could be a new source water that needs to be investigated.

CEC PRIORITIZATION – CURRENT ASSESSMENT	
Instructions	This section prioritizes the CEC based upon the information developed in the above Diagnostic Questions as well as in the background information. For high and medium priorities, develop monitoring and/or mitigation measures as appropriate. For low priorities, maintain current measures, track regulatory developments, health/technical studies and reevaluate priority when needed.
Could CEC occur in SFPUC drinking water at levels of possible health significance? *(Based on above Diagnostic Questions)*	**Yes.** Microbial intrusion and regrowth in drinking water are possible.
CEC Prioritization for SFPUC High, Medium, or Low. Provide explanation. *(A high number of "Yes" answers to the Diagnostic Questions indicates a higher priority, and "No" or very few "Yes" answers indicates a lower priority.)*	**HIGH PRIORITY FOR SFPUC** Microbial CEC have been linked elsewhere (though not for SFPUC) to waterborne disease outbreaks and therefore can impact public health and customer satisfaction. The potential for occurrence in SFPUC drinking water is low due to the use of multiple barriers: watershed protection, filtration of local supplies, multiple disinfectants, cross-connection and backflow control, sanitary practices during main breaks and construction, etc. However, microbial CEC are a high priority due to their health significance in general. Infectious diseases caused by pathogenic bacteria, viruses and parasites (e.g., protozoa and helminths) are the most common and widespread health risk associated with drinking water (WHO, 2017).

Implemented Actions Indicate the progress and results of any action items, above, such as implemented in previous cycles of CEC review. Evaluate whether changes to the action plan are required.	• Maintained watershed protection and completed sanitary surveys of the watersheds. • Maintained SWTR and RTCR compliance in SFRWS and SFWS. • Operated the SFRWS and SFWS to meet operational water quality targets. • Continued participation in Partnership for Safe Water at SVWTP and HTWTP. • Joined PSW for SFWS in March 2019. • In 2012, monitored for UCMR3 microbials (enteroviruses and noroviruses) in two regional groundwater wells (untreated, raw groundwater). None were detected. • Continued cross-connection and backflow prevention program. • Several reservoirs and tanks in SFWS are routinely taken out of service seasonally to reduce detention time. • Implemented sanitary construction practices (e.g. pipe caps). • In 2015, increased distribution system residual year-round from 2.3 to 2.8 mg/L total chlorine to address nitrification and to maintain consistent on target disinfectant residual in drinking water. In 2021, increased residual entering the SFRWS and SFWS to 3.4 mg/L to control nitrification during pandemic and low water use. • Continued programs to disinfect pipelines and reservoirs. Sunset Reservoir South was cleaned in 2015. • Posted Legionella Fact Sheet on sfpuc.org web page in Nov. 2019. • Posted Flushing Guidance for Buildings on sfpuc.org web page in June 2020.

Recommended Actions Does the situation merit investing additional resources or has the information gathered so far fulfilled due diligence? Actions could include monitoring and other measures (specified by source water, if necessary).	• Maintain source water protection and optimized multibarrier treatment and distribution operation. • Benchmark through national or state surveys when appropriate. • Continue participation in PSW for SFPUC WTPs to meet turbidity removal standards. • Continue participation in PSW for SFWS distribution. • Continue distribution programs to prevent entry and regrowth of microbial contaminants, including: maintenance of secondary disinfectant residual, cross-connection and backflow control, storage reservoir inspections/mixing/cleaning, disinfections after main breaks/repairs/installations, flushing of pipelines, chloramine and nitrification monitoring, booster station operation, and nitrification prevention and control. • Follow RTCR compliance and investigation requirements. • When feasible, support beyond-the-meter activities, such as, survey of Legionella and other opportunistic pathogens in premise plumbing. • Provide educational materials on large building water quality issues related to water age due to conservation. • Track federal and state regulatory developments, peer-reviewed health/technical studies • Participate in WRF occurrence studies as a utility partner as appropriate. • Participate in WRF occurrence studies (Project # 5156) as a utility partner on *Legionella* in distribution systems.

This evaluation was prepared based on available information (peer-reviewed literature and occurrence data) with the purpose of prioritizing work and informing the public on unregulated CEC. This evaluation will be updated every 6 years or when significant new research or occurrence data on CEC become available that may warrant changing priority and recommendations.

Water Quality Division, SFPUC Monitoring Review 2016-2021

Contaminants of Emerging Concern (CEC) in Drinking Water

Emerging Microbial Waterborne Pathogens

Source-to-Tap Approach. Monitoring water or setting maximum acceptable concentrations for all pathogens that could be present in a drinking water system remains impractical and is not necessary in order for drinking water utilities to adequately manage risks. (Health Canada, 2020)

Implementing a source-to-tap approach is a universally recommended strategy for reducing the concentration of waterborne pathogens in drinking water and controlling their potential risks. Important elements of this strategy include source water protection, treatment and disinfection requirements based on health-based treatment goals for enteric protozoa (Giardia and Cryptosporidium) and enteric viruses, managing microorganism survival and growth in drinking water distribution systems. Maintaining microbiological control in water systems in buildings and residences is also a critical component of providing safe drinking water at the consumer's tap. (Health Canada, 2020)

SFPUC has not monitored for emerging microbial waterborne pathogens in this time frame. Three programs implemented by SFPUC, in addition to complying with all Safe Drinking Water Act federal and state regulations are discussed here. They provide additional barriers to potential unknown microorganisms:

- Best operational practices – water quality targets.
- Voluntary monitoring program Partnership for Safe Water (PSW).
- Regulatory monitoring program Revised Total Coliform Rule (RTCR).

SFPUC Water Quality Targets

SFPUC has implemented several years ago a rigorous set of internal water quality targets for the entire SFRWS and SFWS. The water quality targets are reviewed periodically, usually every year, and incorporated into the facility operations plans. They provide drivers of performance and ensure that we strive for microbial safety well beyond the regulatory requirements. Below is an example of the relevant table from the SVWTP Operations Plan comparing our targets with the SWTR standards. Adherence to SFPUC water quality targets that are more stringent than SWTR standards ensures that the operations is always maintaining better performance than the regulatory compliance standards, as shown below.

Process Control Targets

Process control targets for the SVWTP are presented in Table 1-2. Targets are indicative of optimized processes.

Table 1-2. Process Control Targets at SVWTP

Parameter	CA SWTR Standard[1]	SFPUC Target
Settled Water Turbidity[3]	N/A	≤ 2 NTU
Individual Filtered Water Turbidity (Exceedance Triggers Reporting Requirements)	≤ 1.0 NTU always based on two consecutive 15-minute measurements ≤ 0.3 NTU after first 1-hour basedon two consecutive 15-minute measurements	< 0.3 NTU initial spike ≤ 0.1 NTU within 15 minutes of operation
Individual Filtered Water Turbidity (Exceedance Triggers Removalfrom Service)	≤ 2.0 NTU anytime during first 4-hours ≤ 0.5 NTU at 4-hours into a filter run ≤ 1.0 NTU anytime during first 4-hours more than 10 percent of interruption events in any consecutive 12-month period	< 0.3 NTU initial spike ≤ 0.1 NTU within 15 minutes of operation
Combined Filtered Water Turbidity	≤ 0.3 NTU in at least 95% ofmonthly samples Not > 1 NTU at 4-hour intervals Not > 1 NTU for more than 1 continuous hour Not > 1.0 NTU for more than 8 consecutive hours	≤ 0.1 NTU
Disinfection (CCT Outlet)	≥ 100% of Ct required Not < 0.2 mg/L disinfectant residual for more than 4 hours in any 24- hour period	≥ 120% of Ct required ≥ 1.0 mg/L disinfectant residual at all times[2]
Treated Water Reservoir Outlet	N/A	• 3.2 to 3.4 mg/L total Cl_2 • 8.6 to 9.0 pH units • 0.03 to 0.05 mg/L free NH_3-N • 0.6 to 0.8 mg/L F

[1] Compliance with combined and individual filtered water turbidity requirements of the California Surface Water Treatment Rule (Chapter 17 of the *California Code of Regulations*) is based on continuous monitoring recorded every

15-minutes.

[2] Baseline Cl_2 target and goal can vary on a weekly basis with changes in flow, chlorine demand, and THM formation potential.

[3] Settled water turbidity targets and goals are set to extend filter run length, reduce filter headloss and solids loading onto filters, and ultimately minimize the number of filter backwashes required; operators should always target filtered water turbidity prior to targeting settled water turbidity.

Partnership for Safe Water (PSW)

The Treatment Plant Optimization Program is the original PSW program and was introduced nationally in the United States in 1995. The tools that were developed by the Partnership are based on methods described in the handbook "*Optimizing Water Treatment Plant Performance Using the Composite Correction Program" – EPA/625/6-91/027*. The goal of the treatment program is to:

- Reduce the risk to water consumers from microbial contaminants, such as Cryptosporidium, by reducing filter effluent turbidity. (AWWA, 2021).

The PSW's Distribution System Optimization Program (DSOP), introduced nationally in 2011, is the culmination of more than a decade of research and planning focused on cultivating the knowledge and resources necessary to develop a performance assessment and optimization program for distribution system operations. The Distribution Program is primarily based on *WRF Project #4109, "Criteria for Optimized Distribution Systems"*. The program's objective is to help water service providers deliver high quality water to all users, thus providing an additional level of public health protection. There are three key system integrity categories that are monitored as part of the Distribution System Optimization Program. These categories, along with the optimization criteria by which they are quantitatively represented, include:

- Water quality integrity (disinfectant residual)
- Hydraulic integrity (pressure)
- Physical integrity (main break frequency). (AWWA, 2021).

As of December 2020, The PSW Treatment Plant Optimization Program's subscriber base consisted of 263 utilities with 496 water treatment plants, while approximately 132 utility subscribers with 141 unique distribution systems participated in the DSOP. (AWWA, 2021)

SFPUC participates in both PSW Treatment Plant Optimization Program at SVWTP and HTWTP and Distribution System Optimization Program.

SVWTP. The excerpts below are from the Partnership for Safe Water Annual Report for the SVWTP from June 2021 and June 2020, respectively. These excerpts summarize turbidity performance and show that we are well under the regulatory limits for turbidity:

> "The performance spreadsheets indicate that the goals of the Partnership were achieved in the current year (June 1, 2020 through May 31, 2021). During this period, the average and 95th percentile combined filter effluent turbidities were 0.06 NTU and 0.09 NTU, respectively. By comparison, the average and 95th percentile combined filter effluent turbidities in the previous year (June 1, 2019 through May 31, 2020) were 0.07 NTU and 0.08 NTU, respectively. The average and 95th percentile combined filter effluent turbidities in the previous year (June 1, 2018 through May 31, 2019) were 0.07 NTU and 0.10 NTU, respectively."

HTWTP. Pursuant to the Annual Report Requirements of the Partnership for Safe Water Program (PSW), SFPUC has completed the Performance Assessment and the narrative summarizing completed and scheduled plant improvements and optimization activities. The Performance Assessment summaries were prepared using the PSW's data collection software for the raw and filtered water turbidities and uploaded using the PSW Online Tool. In the past year (June 1, 2020 through May 31, 2021) the Harry Tracy Water Treatment Plant (HTWTP) performed within applicable regulations and did not receive a notice of violation.

> "The performance spreadsheets indicate that the goals of the Partnership were achieved in the current reporting year (June 1, 2020 through May 31, 2021). During this period, the annual average and 95th percentile combined filter effluent turbidities were 0.03 NTU and 0.05 NTU, respectively. By comparison, the average and 95th percentile combined filter effluent turbidities in the previous reporting year (June 1, 2019 through May 31, 2020) were 0.04 NTU and 0.06 NTU, respectively. This demonstrates that the filters performed well continuously and consistently."

> "The performance spreadsheets indicate that the goals of the Partnership were achieved in the current reporting year (June 1, 2019 through May 31, 2020). During this period, the annual average and 95th percentile combined filter effluent turbidities were 0.04 NTU and 0.06 NTU, respectively. By comparison, the average and 95th percentile combined filter effluent turbidities in the previous reporting year (June 1, 2018 through May 31, 2019) were 0.03 NTU and 0.04 NTU, respectively. This demonstrates that the filters performed well continuously and consistently."

PSW Distribution System Optimization Program. SFPUC joined the PSW DSOP in March 2019.

> "For the reporting 2019-20 Period ending May 2020, the SFPUC reported 5497 of 5498 (99.9%) disinfectant residual samples meeting Partnership goal (Total chlorine $\geq$ 0.5ppm), and all TTHM/HAA results within Partnership goals (TTHM < 80ug/L, HAA5 < 60ug/L). For the reporting 2020-21 Period ending May 2021, the SFPUC reported 5356 of 5458 (98.1%) disinfectant residual sample meeting Partnership goal (Total chlorine $\geq$ 0.5ppm), and all TTHM/HAA results within Partnership goals (TTHM < 80ug/L, HAA5 < 60ug/L)."

TCR and RTCR Monitoring

The purpose of the 1989 TCR is to protect public health by ensuring the integrity of the drinking water distribution system and monitoring for the presence of microbial contamination. Total coliforms are a group of related bacteria that are (with few exceptions) not harmful to humans. EPA considers total coliforms a useful indicator of other pathogens for drinking water. Total coliforms are used to determine the adequacy of water treatment and the integrity of the distribution system. To comply with the monthly MCL for total coliforms (TC), PWSs must not find coliforms in more than five percent of the samples they take each month to meet EPA's standards. The purpose of 2013 RTCR is to increase public health protection through the reduction of potential pathways of entry for fecal contamination into distribution systems. https://www.epa.gov/dwreginfo/revised-total-coliform-rule-and-total-coliform-rule (accessed 1/29/2022).

SFPUC monitors for RTCR in SFRWS and SFWS. Table 1-3 presents the summary of RTCR annual monitoring for the years 2015 – 2021 to show the multi-year trend of monitoring results (regulatory compliance of less than 5% TC positives is determined monthly). The very low background level of Total Coliform positive samples remained at about 0.1% samples annually for both SFRWS and SFWS. The two exceptions were year 2015 and 2020 in SFRWS, when %TC positives were 0.92% and 0.49%, respectively. Explanation for these two above background values in 2015 and 2020 in SFRWS is provided in Table 1-3. The values of indicator microorganisms in the last 7 years presented in Table 1-3 show stable performance of the drinking water system in terms of providing microbial protection of drinking water.

Table 1-3. Summary of Total Coliform Rule Annual Monitoring for SFRWS and SFWS, 2015-2021.

Year	No. TC Samples	No. TC Positive Samples	% TC Positive Samples Calculated Annually (a)
San Francisco Regional Water System			
2015	1850	17	**0.92% (b)**
2016	2028	2	0.10%
2017	2100	3	0.14%
2018	2077	1	0.05%
2019	2071	2	0.10%
2020	2023	10	**0.49% (c)**
2021	2009	1	0.05%
San Francisco Water System			
2015	4000	5	0.13%
2016	3959	3	0.08%
2017	4036	2	0.05%
2018	4044	4	0.10%
2019	3936	1	0.03%
2020	3975	3	0.08%
2021	3918	2	0.05%

(a) Compliance is calculated monthly. Here to show a multi-year trend was calculated annually.

(b) Occasional spurious TC positives at SA#2 and SA#3 Baden due to flow direction changes (of no health concern) resolved by moving sample points downstream, based on a study conducted by WQD in coordination with SWRCB.

(c) Occasional TC positives in the summer of 2020 that resolved themselves.

In addition to programs discussed above:

- SFPUC implemented sanitary construction Best Management Practices in Dec 2015 focusing on controls at pipe storage yards, construction staging areas, and clean installation practices.
- The SFPUC has an aggressive nitrification prevention program to prevent water stagnation in large, oversized reservoirs and reduce water age and travel times within the water conveyance network. This helps to sustain total chlorine residuals at the far ends of the distribution system.

- The changing water use patterns caused by business shutdowns due to COVID pandemic in 2020-2021, has prompted SFPUC to take drastic operational changes within the distribution system to keep water fresh.

Water Quality Division, Technical Review 2016-2021

Contaminants of Emerging Concern (CEC) in Drinking Water

Emerging Microbial Waterborne Pathogens

Review of Regulatory Status, Health, Occurrence and Treatment Studies, and Recommendations

It is widely recognized that microbiological risks are considered a top priority in drinking water management and that the microbiological quality of drinking water should never be compromised. (Health Canada, 2021).

Waterborne pathogens have several properties that distinguish them from other drinking-water contaminants (WHO, 2017):

- Pathogens can cause acute and chronic health effects.
- Some pathogens can grow in the environment.
- Pathogens are discrete.
- Pathogens are often aggregated or adherent to suspended solids in water, and pathogen concentrations vary in time, so that the likelihood of acquiring an infective dose cannot be predicted from their average concentration in water.
- Exposure to a pathogen resulting in disease depends upon the dose, invasiveness and virulence of the pathogen, as well as the immune status of the individual.
- If infection is established, pathogens multiply in their host.
- Certain waterborne pathogens are also able to multiply in food, beverages or warm water systems, perpetuating or even increasing the likelihood of infection.
- Unlike many chemical agents, pathogens do not exhibit a cumulative effect.

The basis for grouping is co-occurrence, ability to cause infection, and treatment. Although microbials are a diverse group with individual occurrence, inactivation, and infection behavior, they are all susceptible to disinfectants, albeit at different efficacies. Compliance with existing microbial regulations should also control many unregulated microbials, such as regulations to control turbidity, inactivate/remove bacteria, viruses, Giardia and Cryptosporidium, and provide residual disinfectant and monitoring. There may be exceptions, however, where certain microbial CEC are relatively resistant to disinfection. For example, adenoviruses are more stable than fecal indicator bacteria and other enteric viruses during UV treatment (Jiang, 2006). Viruses are easily inactivated by chlorine whereas Cryptosporidium is resistant to chlorination.

Watershed protection, water treatment, and distribution system operations to prevent CEC entry and maintain disinfectant residual provide critical public health protection and help minimize occurrence of all members of this group.

Besides treatment-resistant microbes, ongoing concerns remain about other emerging and reemerging microbial contaminants such as Naegleria fowleri, Legionella spp., norovirus, and mimivirus in water supplies.

Significant advances in molecular methodology within the last decade have facilitated a better understanding of the ecology, pathogenicity, genetic diversity, and biofilm/community behavior of these organisms. Regulatory determination processes begin by including emerging contaminants on the Contaminant Candidate List (CCL) every five years, followed by prioritizing them in the Unregulated Contaminant Monitoring Rule (UCMR) to collect robust national occurrence data. Research gaps include standardized detection, identification, and inactivation methods through the treatment plant to the point of use, incorporation of molecular methods in compliance monitoring, and determining public notification procedures for such nontraditional contaminants. (Albert and Nayak, 2019)

Risk Communication. Utilities need to develop strategies to proactively communicate microbial contamination risks related to drinking water supplies or systems. Such communication should be based on scientifically sound information after hazard identification and assessment has been conducted. Successful risk communication strategies provide timely, clear, complete information regarding the types of microbial contaminants, their health risks, and actions taken to reduce or remove them. (Albert and Nayak, 2019)

This review conducted as part of the SFPUC 6-year CEC update focused on the latest technical literature published since last detailed review in 2016. Information published and posted for consultation by the regulatory and advisory agencies was reviewed. Second, open access sources were searched and reviewed: published by the American Water Works Association, Water Research Foundation and International Water Association. Where possible, other open access sources were reviewed as listed in the bibliography. The purpose is to support SFPUC prioritization of work and recommendations for unregulated microbial CECs based on latest information.

GENERAL INFORMATION

Reviews by the Regulatory and Advisory Agencies

USEPA Draft Microbial CCL5. USEPA carried forward all microbes listed on the CCL 3 to the Fourth Draft CCL (CCL 4). USEPA listed the 12 highest-ranked pathogens in the Draft CCL 5 (see Table 1-4). A comparison to previous CCLs follows (Table 1-5). All the microbes nominated for the CCL 5, except for Salmonella enterica, Aeromonas hydrophila, and Hepatitis A, were listed on the Draft CCL 5. Salmonella enterica, Aeromonas hydrophila and Hepatitis A did not produce sufficient composite scores to place them on the Draft CCL 5. Although Salmonella enterica and Hepatitis A have numerous WBDOs, the route of exposure was not explicitly waterborne. Non-tuberculous Mycobacterium (NTM) and Mycobacterium (species broadly found in drinking water) were nominated for the CCL 5 and were not listed on the Draft CCL 5 as a group; instead, they were listed as Mycobacterium avium and Mycobacterium abscessus, two species of NTM that are found in drinking water. (USEPA, 2021)

Table 1-4. The Draft Microbial CCL 5 (USEPA, 2021)

Microbial Name	Microbial Class
Adenovirus	Virus
Caliciviruses	Virus
Campylobacter jejuni	Bacteria
Escherichia coli (O157)	Bacteria
Enteroviruses	Virus
Helicobacter pylori	Bacteria
Legionella pneumophila	Bacteria
Mycobacterium abcessus	Bacteria
Mycobacterium avium	Bacteria
Naegleria fowleri	Protozoa
Pseudomonas aeruginosa	Bacteria
Shigella sonnei	Bacteria

The microbial universe was defined as any pathogen that causes human disease. The microbial CCL 5 Universe was developed based upon previous CCL, CCL 3 and the CCL 4 Universes. (USEPA, 2021)

The 12 exclusion criteria were used to evaluate the five microbial groups (bacteria, viruses, fungi, helminths, and protozoa) but each criterion did not necessarily apply to every group. Some evaluation criteria would never be used to exclude microbes in a group because of fundamental characteristics of the microbes in that group. For example, Criterion 5: Microflora indigenous to the gastrointestinal tract, skin, and mucous membranes was not used to evaluate viruses and helminths. (USEPA, 2021). As the pathogens are screened through the 12 criteria, a pathogen needs to only meet one criterion to be excluded from moving on to the PCCL. Based upon this screening exercise conducted on 1,435 pathogens in the microbial CCL universe 1,400 pathogens were excluded from consideration while 35 pathogens passed on to the PCCL. USEPA used scoring protocols to rank pathogens on the PCCL to produce a Draft CCL. US EPA listed the 12 highest-ranked pathogens in the Draft CCL 5. Protocols used in this process are discussed in USEPA (2021).

Table 1-5. The Final CCL3, CCL4 and Draft CCL 5 for Microbes (USEPA, 2021)

Microbe	Final CCL 3	Final CCL 4	Draft CCL 5 (1)
Adenovirus	X	X	X
Caliciviruses	X	X	X
Campylobacter jejuni	X	X	X
Enterovirus	X	X	X
Escherichia coli (O157)	X	X	X
Helicobacter pylori	X	X	X
Legionella pneumophila	X	X	X
Mycobacterium abcessus			X
Mycobacterium avium	X	X	X
Naegleria fowleri	X	X	X
Pseudomonas aerugionosa			X
Shigella sonnei	X	X	X

(N) Hepatitis A and *Salmonella enterica* were listed on CCL 3 and CCL 4 but are not listed on CCL 5.

Health Canada Guidance for Waterborne Pathogens of Potential Human Health Concern. Health Canada completed its review of waterborne pathogens of potential human health concern and distributed for consultation. (Health Canada, 2020). The document focuses in detail on the following pathogens: (1) Waterborne enteric pathogens – Campylobacter spp., Enteric pathogenic Escherichia coli (E. coli) and Shigella spp., Helicobacter pylori, Salmonella spp., Yersinia spp., and (2) Waterborne naturally-occurring pathogens – Aeromonas spp., Legionella spp., Mycobacterium spp., Pseudomonas spp., Naegleria fowleri, and Acanthamoeba spp. Health Canada (2020) document contains detailed information about these microbial CECs.

World Health Organization. WHO (2017) has published first addendum to its 2017 Guidelines for Drinking-Water Quality (GDWQ), which included updated discussion of microbial hazards associated with drinking water and emerging issues. An excerpt from Chapter 7 Microbial Aspects is appended to this review. The GDWQ, 4th edition, incorporating the 2nd addendum, was to be published by mid-2021.

European Union Revised Drinking Water Directive. On 16 December 2020, the European Parliament formally adopted the revised Drinking Water Directive. The Directive entered in force on 12 January 2021, and Member States will have two years to transpose it into national legislation. The Directive laid down the essential quality standards at EU level. A total of 48 microbiological, chemical and indicator parameters must be monitored and tested regularly. In general, World Health Organization's guidelines for drinking water and the opinion of the Commission's Scientific Advisory Committee are used as the scientific basis for the quality standards in the drinking water. (EU, 2020a). The revised Drinking Water Directive (EU, 2020b) will modernize the 20 year old Drinking Water Directive (98/83/EC)

ANNEX I, MINIMUM REQUIREMENTS FOR PARAMETRIC VALUES USED TO ASSESS THE QUALITY OF WATER INTENDED FOR HUMAN CONSUMPTION (EU, 2020b):

- Part A Microbiological Parameters lists intestinal enterococci – parametric value set at 0/100 mL, and Escherichia coli (E. coli) – parametric value set at 0/100 mL,
- Part C Indicator parameters includes Clostridium perfringens including spores at 0/100 mL (this parameter shall be measured if the risk assessment indicates that it is appropriate to do so), Colony count 22o C (No abnormal change), and Coliform bacteria at 0/100 mL,
- Part D, Parameters relevant for the risk assessment of domestic distribution systems, lists Legionella parametric value as < 1000 CFU/L. Actions could be considered even when the value is below the parametric value, e.g. in cases of infections and outbreaks. In such cases, the source of infection should be confirmed and the species of Legionella should be identified. (EU, 2020b).

Monitoring and Indicator Organisms

Indicator Organisms. Water and wastewater utilities have traditionally used indicator organisms to serve as surrogate organisms to point out the presence of certain pathogens in water and sanitation systems. However, some studies have shown that the measurements of single indicator organisms do not correlate with pathogens. Mraz et al. (2021) assembled a dataset containing 540 cases from studies that investigated relationships between pathogens and indicators. After assessing the pathogen-indicator relationships, it was found that only 223 (41.3%) of them were correlated. Similarly, no single indicator organism correlated with the pathogens studied in reclaimed water, suggesting that additional monitoring of pathogens is fundamental to protect public health. (Mraz et al., 2021).

The indicator concept has its origin in the fecal-to-oral route of disease transmission common for cholera, typhoid fever, salmonella, polio, hepatitis, rotavirus, Campylobacter etc., and most indicators, particularly coliforms (E. coli), were seen as indicators of exposure to human feces. Presently, our concerns have expanded to zoonotic protozoa like Giardia and Cryptosporidium and opportunistic agents like Legionella, MAC; for all these old indicators are less relevant. (Dr. Trussell, personal communication. NRC, 2004)

Why Pathogens Matter? It is important to consider pathogens and not only rely on indicators when making decisions regarding water and sanitation. The calculated probabilities of risk of infection are statistically significantly higher when using treatment/persistence information for pathogens versus using persistence data for indicator species. Considering only fecal indicator groups when assessing treatment efficiencies of sanitation and drinking water treatment systems may provide a scenario with a falsely reduced risk. Process indicators, treatment indicators, or indicators of mobility and fate, used to assess treatment or disinfection efficacy, or surface and subsurface microbial transport, should include representative organisms from the four key pathogen groups when appropriate. (Mraz et al., 2021)

Pathogen presence and persistence are important to understand in the water and sanitation sector in order to develop more realistic interventions to avert the risk of disease to the public and sanitation workers. New tools and resources that consider pathogens are available to support sanitation decision making through the WHO. Indicator species do not tell the whole story for the safety of sanitation systems, which is why pathogens matter. (Mraz et al., 2021).

Microbial quality of water is usually monitored by measuring microorganisms using indicator organisms such as Escherichia coli. However, over-reliance on indicator bacteria to determine the sanitary and public health safety of treated drinking water has its own challenges, including the fact that other pathogens like enteroviruses and protozoa are more resistant to disinfection than E. coli, such that a zero count of E. coli does not essentially indicate the absence of other microorganisms.

Fungi. Heterotrophic plate count is the only indicator method for fungi as it is used to indicate changes in microbial concentration that show entry or regrowth in treated drinking water. The problem, however, is that there is no regulatory value with the heterotrophic plate count, leading to a conclusion of compliance that is defined as a "no abnormal change", which may ultimately not indicate the presence or absence of fungi. The available methods may not be reliable to detect and/or quantify all the waterborne pathogens including fungi that are also known to resist disinfection. (Mhlongo et al., 2019).

The WHO has an international obligation of issuing guidelines, setting of recommendations, and requirements for testing and monitoring of drinking water quality. A preventative approach that only monitors the quality of treated drinking water, the Water Safety Plans was endorsed by the WHO. The plan considers factors that may contribute to endangering the quality of water from the source of water to the end user. While the WHO did not include fungi in the routine battery of microbiological parameters used to determine the quality of treated drinking water, it has labelled fungi as nuisance organisms because of taste and odor problems. (Mhlongo et al., 2019)

Legionella Monitoring. A new culture method Legiolert was developed and is targeted specifically for recovery and enumeration of Legionella pneumophila, the pathogen responsible for >97% of Legionella pneumonia cases. Legiolert offers many advantages over traditional culture method using buffered charcoal yeast extract (BCYE) agar methods: ease of use; minimal equipment; lower initial cost to set up and lower cost per sample; faster time to results; larger volumes analyzed (increased sensitivity); focus on L. pneumophila, which is the significant species causing Legionnaires' disease; and ability of more labs to do testing, for example, water utility labs that have the Legiolert platform for coliform testing. (McCuin et al., 2021)

Due to the application of culture independent methods, there has been increasing evidence that viable but non culturable (VBNC) legionellae are present in water systems at concentrations that are up to several logs higher than obtained by standard culture methods. Nowadays, there are culture independent methods at hand that can in principle distinguish between living and dead Legionella cells and that are ready to be used in routine laboratories. However, further improvements are necessary for a more reliable and robust determination of viability. (Kirschner, 2016).

The VBNC state is either considered to be a long-term survival strategy of mostly gram-negative bacteria with a specific program of differentiation, or the VBNC state is seen as an injured state from which the cells may recover or possibly die. In this state, bacteria stop growing on standard media but maintain certain characteristics of viable cells, such as metabolic activity, membrane integrity and, most controversially discussed, virulence. (Dietersdorfer et al., 2018)

Culture-based standard techniques may underestimate number of active cells. Legionellae are common inhabitants of engineered water systems, where they live mostly associated with biofilms, and the survival of legionellae is closely linked to the presence of free-living amoebae. Legionellae not only survive amoebal digestion but also use the nutritional resources of the host to replicate within the host and persist in adverse environmental conditions and/or in the presence of disinfectants. Nutrient depletion is the goal of many treatment strategies to limit biofilm formation in drinking water systems (DWS). Thus, DWS are likely to have oligotrophic biofilms that contain starved VBNC legionellae. Standard surveillance of DWS and outbreak investigations are commonly performed using culture-based standard techniques. In such cases, the VBNC legionellae undetected would be an underestimation of the real number of active cells and the source of clinical cases of legionellosis might remain unknown. (Dietersdorfer et al., 2018)

Although, in the present study, we observed that starved VBNC Legionella infected amoebae, primary human macrophages and THP-1 macrophages, the legionellae did so with reduced efficacy because of the reduced number of active cells and because the remaining active cells were harmed in the starvation microcosms. However, it is known that passage through amoebae enhances Legionella pathogenicity. Consequently, if environmental conditions change, after several passages through amoebae a pathogenic population of Legionella that is likely to colonize DWS may arise. (Dietersdorfer et al., 2018).

Microbial Source Tracking. Finding and eliminating source water contamination, especially fecal contamination, is a top priority for utilities and regulators. Microbial source tracking (MST) methods have proved useful in supporting regulatory determinations, such as total maximum daily loads, for various water bodies. Although fecal indicator bacteria, such as fecal coliforms, are commonly used to determine levels of fecal contamination in water, they can’t identify the source(s) of contamination. MST has been applied to identify nonpoint sources of fecal contamination. In addition, MST methods have been used to assess the risk from sources of fecal contamination. For example, some MST methods also provide context as to whether the contamination is of human or nonhuman origin. (Albert and Nayak, 2019).

Pathogen Risk Assessment for Potable Reuse. Communities around the world are looking for sustainable water supply alternatives to address increasing water scarcity and stretched water resources. Advancements in water treatment technologies and research have significantly increased opportunities for adopting potable reuse. Pathogen control for public health protection is the primary consideration for all potable reuse projects. Some individual states have set log reduction targets based on an annual risk assumption of 1 in 10,000. Quantitative microbial risk assessments have shown that risks associated with potable reuse vary considerably, and it is recommended to further assess site-specific risks such as pathogen influent concentrations, treatment process trains, failure response time, and infectivity models for risk characterization. (Albert and Nayak, 2019).

Antibiotic Resistance. The increased global emergence and dissemination of antibiotic-resistant microorganisms is a growing public health threat and an economic burden. It is extremely concerning that antibiotic-resistant bacteria (ARB) aren't only isolated from nosocomial settings such as hospitals and doctors' offices but are known to have environmental reservoirs, mainly in areas with anthropogenic influence. The role of such environmental reservoirs in the spread of antibiotic resistance is poorly understood. (Albert and Nayak, 2019)

Antibiotics and other Agents in Potable Reuse. The presence of antibiotics and other agents in domestic wastewater can provide a favorable environment for ARB and is therefore a critical consideration for utilities planning to adopt potable reuse as a water supply option. Pilot studies have demonstrated that the configuration of water reuse treatment processes has a direct impact on reduction/inactivation of ARB and antibiotic resistance genes (ARGs). Further research is needed to develop real-time or near-real-time monitoring tools to determine the efficacy of reducing/removing ARB and ARGs during wastewater treatment. (Albert and Nayak, 2019)

Clinically relevant antimicrobial resistant bacteria, genetic resistance elements, and antibiotic residues (so-called AMR) from human and animal waste are abundantly present in environmental samples. This presence could lead to human exposure to AMR. The potential risk of infection by AMR bacteria through the consumption of drinking water gives rise to the public's questions and concern. This is especially a concern in areas in which water reuse projects are being developed and implemented. (Wuijts et al., 2017).

HEALTH

Bacteria

E. coli and Shiga Toxins. Shiga toxin (Stx), produced by some serotypes of E. coli belonging to the enterohemorrhagic E. coli (EHEC) pathotype, is one of the most potent bacterial toxins known. In the United States (USA) alone, it is estimated that Shiga toxin-producing E. coli (STEC) causes more than 265,000 infections, 3,600 hospitalizations and 30 deaths annually. STEC is mostly associated with foodborne illness but STEC has also been documented as the causative agent of important waterborne outbreaks in Japan, in Fife, Scotland and in Canada. In the USA, major outbreaks have been reported in Missouri, Wyoming and New York. (Crespo-Medina, 2020).

At present, six E. coli pathotypes collectively known as diarrhoeagenic E. coli are recognized as clinically important. Verotoxigenic E. coli (VTEC), or Shiga toxin-producing E. coli (STEC), are characterized by the production of verocytotoxins (Stx1, Stx2) similar to AB5-type Shiga toxins which include enterohaemorrhagic E. coli (EHEC) strains. Following ingestion and (intestinal) colonization, verotoxins may form attaching and effacing enteric lesions in the host manifesting as gastrointestinal disease. Over 400 VTEC serotypes have been identified, a subset of which have been linked to clinical cases. Globally, O157 is the serotype most commonly associated with human cases and outbreaks with additional serogroups (i.e., non-O157) increasingly reported as pathogens of emerging clinical importance. VTEC enteritis comprises a wide range of symptoms from mild uncomplicated infection in healthy adults to severe haemorrhagic diarrhea and colitis among vulnerable sub-populations. Potential sequalae include haemolytic uraemic syndrome, renal failure, and thrombotic thrombocytopenic purpura, all of which can prove fatal in a minority (3-10%) of cases. VTEC transmission is often zoonotic, occurring via the fecal-oral route, with cattle the most frequently reported animal reservoir, but also potentially including other domesticated animals and wildlife. The organism is characterized by a relatively small infectious (threshold) dose (ID 50 < 100 cells), with human infection in developed regions typically associated with consumption of contaminated water or food. (Chique et al., 2021).

Legionella. In developed countries, legionellae are one of the most important water-based bacterial pathogens. Legionellae are ubiquitously present at low concentrations in natural aquatic ecosystems. Due to their sessile mode of life and their preference for temperatures above 25 C, man-made engineered water systems often select for legionellae, if they are not adequately managed. (Kirschner, 2016)

Known risk factors for Legionella disease (LD) include increasing age, being male, smoking, chronic lung disease, diabetes, and various conditions associated with immunodeficiency. There are no reported cases of interhuman transmission and the environment may represent the only source of infection. The incidence of the disease has been significantly increasing in recent years. In the USA, a 192% increase in the national incidence of LD has been observed, rising from 3.9 cases per million in 2000, to 11.5 cases per million in 2009. (De Filippis et al., 2017).

Although L. pneumophila is a ubiquitous environmental microorganism, the real risk to public health is represented by its concentration. A high Legionella load in some microenvironments, such as hot water distribution systems that produce aerosols, might pose a strong risk of contracting the disease. In this study, about 14.4% of the examined samples showed a concentration of Legionella >10,000 CFU/L. In agreement with Italian guidelines, such contamination level, even in the absence of cases of disease, requires the immediate implementation of appropriate disinfection measures. (De Filippis et al., 2017).

Legionellosis is a respiratory infection caused by bacteria in the Genus Legionella. Currently, there are approximately 50 species of Legionella consisting of 70 serogroups, but Legionella pneumophila serogroup 1 is responsible for about 95% of the Legionnaires' disease cases in the U.S. The severity of legionellosis (the disease caused by Legionella) varies from a mild fever (called Pontiac fever) to a more serious pneumonia (called Legionnaires' disease) that can affect anyone, but principally affects those who are more susceptible due to age, illness, immunosuppression, or other risk factors, such as smoking. (Masters et al., 2018). In general, Legionella levels less than 1 cfu/mL are considered lower risk, and levels greater than 1 cfu/mL could require some remedial action, with higher levels (>100 cfu/mL) leading to immediate actions. These guidelines are intended to apply only to water systems being used by healthy individuals and are not necessarily protective for people who are 32aters-compromised. Guidelines with lower trigger values could be used when high risk populations are encountered (e.g., hospitals, nursing homes, etc.). (Masters et al., 2018).

While L. anisa is rarely responsible for causing Legionnaires' disease, its cohabitating species are of particular concern, for example, L. pneumophila serogroups 1 and 6. L. pneumophila is an intracellular pathogen, capable of transitioning through a multiphasic lifecycle. In the simplest biphasic cycle, Legionella differentiates between an intracellular, replicative life phase and an extracellular, transmissive life phase. (June and Dziewulski, 2018).

Mycobacteria. Mycobacterium avium complex (MAC). MAC is a subgroup of the nontuberculous mycobacteria. Mycobacterium spp. Are commonly observed in healthcare-setting water distribution systems. MAC consists of gram-positive bacteria, widespread in the environment, and opportunistic pathogens. Transmission to humans, particularly to those who are immunocompromised, may result in progressive lung disease or respiratory failure. (June and Dziewulski, 2018).

Elizabethkingia. Members of the genus Elizabethkingia are Gram-negative, non-motile, non-fermenting, aerobic bacteria: Elizabethkingia meningoseptica, Elizabethkingia anophelis, Elizabethkingia miricola, and Elizabethkingia endophytica. All species of the genus are commonly found in the environment (soil, water, and plants). In particular, E. anophelis is abundant in the midgut of the mosquito Anopheles gambiae. The microorganism may colonize hospital environment, is highly persistent to decontamination measures, thus contaminating medical solutions and devices. Recent studies have proposed that hospital water supply systems possibly act as a reservoir, being responsible for long-term transmission of the microorganism in the hospital environment. E. meningoseptica mainly causes healthcare-associated infections in immunocompromised patients as well as neonatal meningitis and sepsis. Infections caused by E. meningoseptica are often very severe, displaying high death rates. The existing comorbidities and immunosuppression of these patients in combination with the multidrug-resistant profile of the microorganism contribute to the fatal outcome of the infection. E. anophelis has been widely known since the outbreak in Wisconsin, USA, that was attributed to the microorganism, which accounted for 67 cases and 18 deaths from 01.11.2015 to 11.01.2017. E. anophelis usually causes pneumonia and bacteremia with high rates of mortality. The study denoted the presence of Chryseobacterium meningosepticum (presently E. meningoseptica) in hemodialysis water and dialysate at a frequency of 14.9% in renal units in Greece. (Kyritsi et al., 2018)

Protozoa

Pathogenic free-living amoebae (PFLA) including Acanthamoeba spp., Balamuthia mandrillaris and Naegleria fowleri are known to produce rare but serious human and animal infections. For example, pathogenic Acanthamoeba spp. Cause blinding keratitis often connected with improper use of contact lenses as well as a fatal brain infection known as granulomatous amoebic encephalitis (GAE) in patients with weaker immune systems. Out of the 20 different genotypes (T1-T20), several have been implicated in human and animal infections, albeit T4 genotype is more frequently associated with infections. In contrast, N. fowleri produces primary amoebic meningoencephalitis (PAM), typically affecting healthy children and young adults. Comparable to pathogenic Acanthamoeba spp., Balamuthia mandrillaris is a causative agent of GAE that is known to affect both immunocompromised and healthy people. Pathogenic amoebae enter the body via skin lesions and/or the nasal cavity and disseminate via haematogenous spread or travel along the neuroepithelial route to reach the central nervous system to produce infection (Gabriel et al., 2019).

Naegleria fowleri. Naegleria fowleri, commonly known as the “brain-eating ameba” is a free-living ameba found in warm freshwater and soil. N. fowleri infections typically occur from swimming in polluted freshwater lakes or streams, however, several cases have been associated with inadequately disinfected tap water. Sources of tap water risk include rinsing the sinuses through the nose or cleansing the nose through religious practices with contaminated water. It is recommended that water be boiled (and cooled) before use in such practices (Masters et al., 2018).

Acanthamoeba. One of the most common amoebae, Acanthamoeba is a microscopic, free-living amoeba found naturally in dust and soil, fresh and salt-water sources, as well as building plumbing, heating, air-conditioning, and humidifier systems. Although rare, infection of Acanthamoeba can become severe, infecting the eye (Acanthamoeba keratitis), brain and spinal cord (Granulomatous encephalitis) and can spread throughout the entire body (disseminated infection). Acanthamoeba keratitis (AK) is an eye infection caused from poor hygiene practices of contact lens wearers and can potentially lead to blindness caused by infection of the eye. Contact lens wearers should never rinse the lens or cases with tap water. Acanthamoeba can form dormant cyst which are highly resistant to disinfections and temperature. Additional guidance is provided by the EPA (https://www.epa.gov/dwstandardsregulations/danger-using-tap-water-contact-lenses) and the CDC (https://www.cdc.gov/parasites/acanthamoeba/index.html). (Masters et al., 2018).

Fungi and Mycotoxins

Direct contact of contaminated water with damaged human tissue or inhalation of bioaerosols can cause skin irritations and a variety of diseases. It has been reported that showering and sink washing spreads fungi present in hospital water systems into the air as bioaerosols; they remain in the air for a long time and cause opportunistic infections such as fusariosis. In recent years, studies in hospitals have focused on Aspergillus fumigatus and its effect on patients with suppressed immune system diseases, such as diabetes, cancer, and AIDS. It is known that members of the genera Aspergillus, Penicillium, and Fusarium are important mycotoxin producers. Aspergillus flavus, which is known to produce aflatoxins (B2 and G2), has been isolated from a coldwater storage tank. Previous studies indicated that the production of mycotoxin in water is low; the concentration of mycotoxin may increase because of long-term storage of water in reservoirs. Small amounts of mycotoxins in the human body, a result of long-term consumption of contaminated water, might lead to health problems. The production and importance of mycotoxin in water environments are still poorly known. Fungi generally produce slowly progressing chronic infections. Nonetheless, people with suppressed immune systems might experience fatal, acute infections. In particular, the air we breathe contains Aspergillus, Penicillium, Cladosporium, Alternaria, and Fusarium, which may cause aspergillosis, allergic rhinitis, anaphylactic pneumonia, chronic bronchitis, and asthma. The frequency of cases of these infections has been increasing. Fungi, which are predominantly present in the soil and air, can adapt to live in man-made water systems. (Kadaifciler and Demirel, 2018).

Waterborne filamentous fungi are known to act as pathogens or allergens that have adverse impacts on human health, and mostly on immune-compromised patients. Fungal infections are a challenge to cure as fungal cells are eukaryotic, just like human cells. Fungal infections were quite low from the late 1950s and early 1960s, yet over the past two decades, fungal infections have dramatically increased as they are easily diagnosed. Most of the fungi are dematiaceous fungi responsible for causing a number of cutaneous and subcutaneous infections including invasive and contagious infections. A significant proportion of waterborne illnesses related to fungi are likely to go undetected by the communicable disease surveillance and reporting systems. The possible health impacts caused by fungi in treated water are still not well documented. Fungi have been implicated in a number of diseases causing allergies, respiratory illness, cutaneous infection and life-threatening meningitis. Alternaria sp., Cladosporium sp., Aspergillus sp., Penicillium sp. And Fusarium sp. Have been linked to allergies and respiratory illness. Cryptococcus and Candida cause meningitis, with the Candida species responsible for cutaneous infections. Taste and odour problems in water are caused by Aspergillus sp., Acremonium sp., Phialophora sp. And Penicillium sp. Fungi such as Rhizopus, Fusarium, Alternaria, Aspergillus and Penicillium produce mycotoxins that are harmful to public health as these mycotoxins are carcinogenic and have the ability to impair the immune system. Mycotoxins of great concern for public health include aflatoxins, ochratoxins, trichothecenes, zearalenone, fumonisins, tremorgenic toxins, and ergot alkaloids. The types of infections caused by mycotoxigenic fungi depend on the type of mycotoxin, the concentration and length of exposure; as well as age, health, and sex of the exposed individual. The absence of toxigenic fungi in treated drinking water may not provide assurance that the water is free of mycotoxins, as mycotoxins may persevere long after the fungi has died. Mycotoxins have serious and chronic effects on humans and animals, as many of them are believed to be carcinogenic, cytotoxic, mutagenic and may lead to immunosuppressive complexes. (Mhlongo et al., 2019)

Mycotoxins. Mycotoxins are fungal poisons that are produced as secondary metabolites by the mycelial structure of filamentous fungi as well as spores. Not all fungi produce mycotoxins, as most mycotoxin producing species are filamentous ascomycetes, basidiomycetes and Deuteromycetes with Penicillium, Aspergillus and Fusarium being the most mycotoxin-producing genera. These mycotoxins do not have any biochemical implications in fungal growth and their development. Fungal growth and mycotoxin production are the consequence of an interaction among the fungus, the host and the environment. The right combination of these factors determines the amount of colonization of the substrate, the type and amount of mycotoxin produced. The synthesis of any particular mycotoxin depends not only on the species but also on the strain. Although the chemical structures of mycotoxins vary significantly, they are generally low molecular mass organic compounds. Mycotoxigenic fungi have been reported in treated drinking water. While mycotoxin concentrations can be low in water because of dilution, water retention in storage tanks, the long distances water travels in distribution systems, depletion of chlorine residual and the resistance of some of the fungi to disinfection can cause mycotoxin concentrations to increase to unsafe amounts in drinking water. Parameters such as temperature and pH also encourage growth and persistence of fungi in water. (Mhlongo et al., 2019).

Yeasts. Yeasts are eukaryotic microorganisms classified in the kingdom fungi and are divided into two phylogenetic groups, i.e. ascomycetes and basidiomycetes. Yeasts commonly occur in water, animals, plants, soil and insects. Interest was further fueled by the advent of human immunodeficiency virus (HIV) co-infectious or opportunistic infections by some yeasts species infecting immunocompromised individuals. Most of these patients that are compromised are those in therapeutic technology including organ transplants and anticancer therapies or have certain disease conditions such as malignancy and HIV. (Monapathi et al., 2000).

Most invasive yeast infections are frequently caused by pathogens from the genera Candida and Cryptococcus. Candidiasis is one of the common opportunistic infections caused by Candida species. C. albicans is the most prevalent causal species. The following non-Candida albicans species also known to cause candidiasis include: C. glabrata, C. parapsilosis, C. tropicalis, C. krusei and C. auris. Human cryptococcal infections are primarily caused by Cryptococcus neformans and C. gattii. Cryptococcosis is one of the leading causes of mortality in adults living with HIV in sub-Saharan Africa. Rare non-Candida and non-Cryptococcus species are also associated with yeast infections. Trichosporon species (Trichosporon asahii, T. faecale) cause invasive trichosporonosis in patients with haematological malignancies and other medical conditions associated with immunocompromised people. Opportunistic pathogenic Rhodotorula species (R. mucillaginosa, R. glutinis and R. minuta) cause infections with high mortality rates in haematologic patients particularly on central venous catheters. The following uncommon clinical yeast species have also been reported as opportunistic pathogens: Clavispora 36aters36es, Cyberlindnera fabianii, Debaryomyces hansenii, Kluyveromyces marxianus, Meyerozyma guilliermondii, Pichia kudriavzevii, Saccharomyces cerevisiae, Torulaspora delbruecki and Yarrowia lipolytica. The abovementioned pathogenic yeast species have been isolated from freshwater water environments. (Monapathi et al., 2000).

OCCURRENCE

Opportunistic pathogens reported in premise plumbing (OPPP) include Legionella pneumophila, MAC, and other bacteria, e.g. Pseudomonas aeruginosa, and Aeromonas hydrophila, and amoebae, e.g. Naegleria fowleri, Acanthamoeba spp., but could also include pathogenic fungi, and virulence and antimicrobial genes in biofilms. (LeChevallier et al., 2016).

Legionella is the Leading Waterborne Outbreak Agent. The CDC acknowledges higher waterborne disease occurrence from plumbing components including pipes, water heaters, shower heads and fixtures than from pathogens passing through a water treatment plant into the drinking water distribution system (Masters et al., 2018). Among the various OPPPs (e.g., Legionella, Mycobacterium, Pseudomonas, Aeromonas, free living amoebae etc.), Legionella is responsible for the majority of OPPP outbreaks and all waterborne outbreaks.

Waterborne disease and outbreaks associated with drinking water continue to occur in the United States. CDC collects data on waterborne disease outbreaks submitted from all states and territories through the National Outbreak Reporting System. (CDC, Benedict et al., 2017)

A 12-year study of waterborne outbreaks in the US, 1991 to 2002, found that the specific causes of several of the outbreaks were due to unregulated CECs, including: 12 norovirus outbreaks, 11 *E. coli* O157:H7 outbreaks, 9 *Shigella* outbreaks, 7 *Campylobacter jejuni* outbreaks, 6 *Legionella* outbreaks, and 3 *Salmonella* (non-Typhoid) outbreaks (Craun, 2006).

During 2007-2008, there were 36 drinking water-associated outbreaks in the US, causing 4,128 illnesses and 3 deaths (CDC, Brunkard et al., 2011). Twenty-six of these outbreaks (approximately 70%) were attributed to pathogens listed on the CCL3 and CCL4. In 2008, an estimated 1,300 cases of illness were related to a single *Salmonella* (non-Typhoid) outbreak in Colorado resulting from a WDS deficiency in an untreated groundwater system. In 2007-2008, 60% of waterborne outbreaks were associated with a source water protection, WTP or WDS deficiency and 44% were associated with PWS (CDC, Brunkard, 2011).

Surveillance for Waterborne Disease Outbreaks Associated with Drinking Water, United States, 2013–2014.

During 2013–2014, a total of 42 drinking water–associated outbreaks were reported to CDC, resulting in at least 1,006 cases of illness, 124 hospitalizations, and 13 deaths. Legionella was responsible for 57% of outbreaks and 13% of illnesses, and chemicals/toxins and parasites together accounted for 29% of outbreaks and 79% of illnesses. Eight outbreaks caused by parasites resulted in 289 (29%) cases, among which 279 (97%) were caused by Cryptosporidium and 10 (3%) were caused by Giardia duodenalis. Chemicals or toxins were implicated in four outbreaks involving 499 cases, with 13 hospitalizations, including the first outbreaks associated with algal toxins. Outbreak surveillance data likely underestimate actual occurrence of outbreaks and should not be used to estimate the actual number of outbreaks or cases of waterborne disease. (CDC, Benedict et al., 2017)

Continued public health surveillance is necessary to detect waterborne disease and monitor health trends associated with drinking water exposure. When drinking water is contaminated by infectious pathogens, chemicals, or toxins, public health agencies need to provide rapid detection, identification of the cause, and response to prevent and control waterborne illness and outbreaks. Effective water management programs in buildings at increased risk for Legionella growth and transmission can reduce the risk for disease from drinking water pathogens. (CDC, Benedict et al., 2017)

Viruses

The most important waterborne enteric viruses belong to the families Caliciviridae (Norovirus), Picornaviridae (Enterovirus and Hepatitis A virus) and Adenoviridae (Adenovirus). These viruses are often excreted at high titres in the feces (and occasionally, at lower concentrations, in urine) of infected humans. They have also been detected from virtually all types of water: wastewater, seawater, fresh waters, groundwater and drinking water and have been associated with drinking and recreational water outbreaks (LaRosa et al., 2020).

Conversely, enveloped viruses, are structurally dissimilar to the enteric (non-enveloped) viruses and are believed to behave differently in water environments. This group of viruses includes families such as Orthomyxoviridae (es. Influenza viruses), Paramyxoviridae (measles virus, mumps virus, respiratory syncytial virus, etc.), Herpesviridae, Coronaviridae and several other viruses. Among the enveloped viruses, coronaviruses (CoV) (order Nidovirales, family Coronaviridae, subfamily Coronavirinae) are single-stranded RNA viruses. (LaRosa et al., 2020)

Occurrence of Viruses. Since human enteric viruses are present generally at relatively low concentrations in environmental water samples, it is essential to sample by concentrating the viruses into smaller sample volumes to enhance the usefulness of detection assays. The development and application of methods for concentrating viruses have contributed significantly to the detection of diverse viruses using culture- or molecular-based assays. One of the major findings of recent investigations based on qPCR is seasonal profiles of viral concentration in water environments.

For instance, it was found that human caliciviruses, i.e., noroviruses (NoVs) and sapoviruses (SaVs) typically exhibit a relatively clear seasonal trend; specifically, their concentrations tend to be higher in colder months, which is an epidemic period for those viruses in many countries located in temperate regions. As opposed to human caliciviruses, other human enteric viruses, such as adenovirus AdVs, enterovirus Evs, and Aichi virus 1 (AiV-1), have been reported to exhibit relatively constant concentration in sewage over a year without showing a clear seasonal trend. NoVs are a major cause of waterborne gastroenteritis outbreaks and are abundant in environmental settings, such as river water, seawater, and shellfish waters. SaVs are also a cause of acute gastroenteritis in humans and cases are becoming more prevalent worldwide. AiV-1 has been proposed as a causative agent of gastroenteritis in humans, potentially transmitted by fecal-oral routes through contaminated food or water. In addition to these well-known human enteric viruses, several types of recently recognized human viruses, bocaviruses, cardioviruses, circoviruses, cosaviruses, picobirnaviruses, and salivirus also have been identified from environmental water samples. This suggests that these emerging viruses, which are suspected to be associated with human diseases, could potentially be transmitted through water. Circulation of viruses between contaminated environmental water and human populations is a key issue. On one hand, water can be contaminated by humans, and on the other hand, water can be a route of infection to humans. Wastewater contains viruses shed from all populations, regardless of their health status; therefore, monitoring viruses in wastewater and environmental water bodies that receive effluents from WWTPs could be an appropriate approach for determining the actual prevalence and molecular epidemiology of gastroenteritis viruses in a given geographical region rather than clinical studies. (Haramoto et al., 2018).

The episodic prevalence of viral nucleic acid across the majority of public water sources, all major water supply aquifers, and a range of typical microbial risk settings in both urban and rural areas, indicate potentially widespread seasonal viral risks in groundwater used for drinking in the United Kingdom. The public water sources that were sampled all have suitable treatment measures in place for the provision of safe drinking water before supply. However, there are likely to be other sites, notably private water sources, where water treatment is insufficient and public health risks from viruses may be present. To manage potential groundwater virus contamination via water safety plan (WSP) risk assessments, larger scale studies are required to further understand key risk factors within catchments, for example viral sources and relative loading, subsurface transport, viral persistence, and viral viability. Sampling for viruses should be focused during periods of groundwater recharge, when they are most likely to occur, if investigating viral risks at a source. The lack of co-occurrence amongst viral targets suggests a widespread suite of viruses would be more suitable than investigating a single indicator target, such as adenoviruses, in untreated groundwater. Bacterial indicator organisms do have value to assess whether a viral risk is present: a source with an absence of indicators in regularly collected historical data is unlikely to be at risk of virus contamination. (Sorensen et al., 2021)

Survival of Viruses. The survival rate of viruses in environmental waters is affected by various conditions, as temperature and pH. Many viruses are stable and can survive for long periods in groundwater or drinking water, as hepatitis A virus, for which 99% inactivation takes about 56 days. For adenovirus type 41 it is up to 304 days at 4 C in water. In addition, some viruses, like adenovirus, are resistant to UV disinfection, which is commonly used in drinking water treatment plants (Wang et al., 2020).

Coronaviruses (CoVs). Prior to COVID-19, interest in this topic was very low owing to the common belief that enveloped viruses cannot survive for extended periods in water. However, the assumption that SARS-CoV-2 is not involved in environmental circulation cannot be accepted without better knowledge, as highlighted by the detection of SARS-CoV-2 RNA in wastewater by six different global research groups. The family of Coronaviridae includes strains that infect humans with a wide range of clinical symptoms, from those associated with the common cold to potentially lethal respiratory syndromes. Other Coronaviridae strains infect birds and mammals. Although the main route of transmission of these viruses is via droplets and close contacts, the possible environmental spread via water, bioaerosols, and food should not be neglected. In fact, the fecal elimination of coronavirus is well-known and has been confirmed for SARS-CoV and SARS-CoV-2. The potential fecal-oral transmission was recently highlighted. (La Rosa et al., 2020) Moreover, possible transmission through bioaerosols from toilet flushing was demonstrated in Hong Kong for the SARS epidemic cluster. Although these studies are fragmentary and not directly comparable, they indicate that human coronavirus and surrogates are less resistant than non-enveloped viruses in water environments, that their survival is generally reduced in waters with organic and microbial pollution, and that viral inactivation increases with increasing temperatures. Recent studies confirm the lack of standardized concentration methods for enveloped viruses and the need to use the same method in order to be able to compare results from different studies. (Carducci et al., 2020).

CoVs are a large family of viruses causing a spectrum of disease ranging from the common cold to more severe diseases as Middle East Respiratory Syndrome (MERS-CoV) and Severe Acute Respiratory Syndrome (SARS-CoV). The recent outbreak of coronavirus disease 2019 (COVID-19) has become a public health emergency worldwide. SARS-CoV-2, the virus responsible for

COVID-19, is spread by human-to-human transmission via droplets or direct contact. However, SARS-CoV-2 (as well as other coronaviruses) have been found in the fecal samples. (LaRosa et al., 2020)

As predicted by many experts, the COVID-19 will last irregularly or seasonally for a long period, and SARS-CoV-2 is very likely to coexist with human beings. Therefore, establishing the immunological barrier to SARS-CoV-2 is essential. At present, all countries around the world are actively developing vaccines against COVID-19 for herd immunity, the threshold of which can be achieved only with a high vaccination rate of 60−70% of the population. Some experts have alleged that herd immunity to COVID-19 is probably impossible. Accordingly, before herd immunity can be achieved, SARS-CoV-2 surveillance in water environments is significant in preventing the wide outbreak of the COVID-19 pandemic. (Meng et al., 2021)

Coronaviruses in Water Environments. The data available suggest that:

- CoV seems to have a low stability in the environment and is very sensitive to oxidants, like chlorine;
- CoV appears to be inactivated significantly faster in water than non-enveloped human enteric viruses with known waterborne transmission;
- Temperature is an important factor influencing viral survival (the titer of infectious virus declines more rapidly at 23-25 C than at 4 C);
- There is no current evidence that human coronaviruses are present in surface or ground waters or are transmitted through contaminated drinking-water;
- Further research is needed to adapt to enveloped viruses the methods commonly used for sampling and concentration of enteric, non-enveloped viruses from water environments. (LaRosa et al., 2020).

It has been found that most fecally transmitted viruses are highly persistent in the aquatic environment. SARS-CoV is an enveloped virus and more likely to be inactivated than non-enveloped viruses. However, enveloped viruses have similar persistent rates compared to those of nonenveloped ones in dark water environments as determined by viral decay constants. Additionally, the persistence of SARSCoV-2 RNA is significantly longer than that of other closely related coronaviruses. For example, SARS-CoV-2 RNA is present in wastewater for 7 days, longer than human coronavirus (HcoV) 229E (∼2 days). The long persistence of SARS-CoV-2 in water leads to the non-neglectable significance of its potential transmission in water environments. Researchers have found that the time that SARS-CoV-2 persists is different in wastewater (>7 days) and groundwater (>10 weeks). Additionally, enveloped SARS-CoV-2 possibly has stronger mobility in the underground aquifer systems and viral adsorption on soil is crucially affected by pH, ion strength, and soil properties, posing challenges in virus detection and control. (Meng et al., 2021)

Bacteria

E. Coli and Shiga Toxins. The aim of this study was to investigate the occurrence of Shiga toxin-encoding genes (STX1 and STX2) from total coliform (TC) and E. coli positive samples from small community water systems in Puerto Rico. After aliquots for TC and E. coli analyses were removed, the remnant volume of the samples was enriched, following a protocol developed for this study. Fifty-two per cent of the samples tested by multiplex PCR were positive for the presence of the STX genes; this percentage was higher in raw water samples. The STX2 gene was more abundant. Testing larger volumes of the samples increase the sensitivity of the assay, providing an alternative protocol for the detection of STEC that might be missed by the TC assay. This study confirmed the presence of STX encoding genes in source and distributed water for all systems sampled and suggested STEC as a potential health risk in small systems. (Crespo-Medina, 2020)

E. coli Groundwater Transmission. However, over the past decade, a newfound emphasis has been placed on the importance of groundwater as a transmission pathway for waterborne enteric infection. VTEC strains have been reported in groundwater supplies and linked with multiple groundwater-related outbreaks. For example, the Walkerton (Ontario, Canada) multietiological outbreak was positively associated with a contaminated municipal groundwater supply, causing 2300 acute clinical cases and 7 deaths, with E. coli O157:H7 identified as one of two pathogens responsible. (Chique et al., 2021). Overall, a VTEC to “generic” E. coli sample detection ratio of 15/152 (9.9%) was derived from reviewed investigations, providing a baseline for VTEC in E. coli contaminated groundwater sources. (Chique et al., 2021).

Legionella species. Water is the natural reservoir for Legionellae, and the bacteria are found worldwide in many different natural and manmade aquatic environments, such as cooling towers; water systems in hotels, homes, ships, and factories; respiratory therapy equipment; fountains; misting devices; and spa pools. The greatest concern is where water is aerosolized into small droplets; for example, with showers, humidifiers, fountains, etc. Since 2000, legionellosis has been on the rise, and approximately 5,000 cases of Legionella are reported each year in the United States, however, the exact incidence of disease is difficult to determine since the symptoms can be similar to the common cold. Normal, healthy people are at low risk for contracting legionellosis, but the probability of infection increases in the elderly, particularly for men. An infection is also typically associated with some other underlying factor (Masters et al., 2018).

Surveillance for Waterborne Disease Outbreaks Associated with Drinking Water, United States, 2013–2014

The most commonly reported outbreak etiology was Legionella (57%), making acute respiratory illness the most common predominant illness type reported in outbreaks in 2013-2014. Legionella continues to be the most frequently reported etiology among drinking water–associated outbreaks. All of the outbreak-associated deaths reported during this surveillance period as well as all of the outbreaks reported in hospital/health care settings or long-term care facilities, were caused by Legionella. A review of 27 Legionnaires' disease outbreak investigations in which CDC participated during 2000–2014 identified at least one water system maintenance deficiency in all 23 investigations for which this information was available, indicating that effective water management programs in buildings at increased risk for Legionella growth and transmission (e.g., those with more than 10 stories or that house susceptible populations) can reduce the risk for Legionnaires' disease. Although Legionella was detected in drinking water, multiple routes of transmission beyond ingestion of contaminated water more likely contributed to these outbreaks, such as aerosolization from domestic or environmental sources. (CDC, Benedict et al., 2017)

The transmission of Legionella takes place by inhalation of contaminated aerosols which can be produced by air conditioning systems, cooling towers, whirlpools, spas, ice machines, dental devices, shower heads, hotel fountains. (De Filippis et al., 2017). The bacteria were found in one-third of the facilities and in one-fourth of the samples analyzed, again clearly indicating the limited efficacy in controlling Legionella colonization in recreational facilities.

A total of 679 samples were analyzed: 53 from the source water, 50 from the plant effluent, and 576 from the distribution system. L. pneumophila was detected in three of five source water samples only at utility 7 and was not detected in untreated samples at any of the other utilities. One of three positive source water samples contained both serotype 1 and serotype 2-14, while the other two positive source water samples contained only serotype 2-14 strains of L. pneumophila. L. pneumophila serogroup 1 is the strain most commonly associated with waterborne disease outbreaks in the United States. The low frequency of detection is not surprising as the average source water temperatures ranged from 2 to 24 C, which is below the optimal growth threshold for L. pneumophila. Source water total coliform and heterotrophic plate count (HPC) levels showed good source water quality, with levels well below the criteria for source water used as a potable water supply (LeChevallier, 2019). L. pneumophila was not detected in any of the treated plant effluent samples, in part because average free chlorine residuals ranged between 0.8 and 1.7 mg/L and total chlorine residuals ranged between 1.8 and 4.1 mg/L for the five utilities that practiced chloramination. In addition, all total coliform samples were negative, and HPC levels were typically nondetectable. (LeChevallier, 2019)

A follow-up monitoring was conducted in a second round of testing during the summer and early fall months when water temperatures averaged 23 C (averages ranged from 14 to 29 C). A total of 669 samples were analyzed during the study: 50 source water samples, 46 from the plant effluent, and 573 from the distribution system. L. pneumophila was detected in two source water samples and not detected in any of the treated plant effluent samples. L. pneumophila was detected in 14 distribution system samples, 13 from free chlorinated systems and one from a chloraminated system. All occurrences of L. pneumophila were observed when water temperatures were >18 C. (LeChevallier, 2019b)

Control of Legionella. Generally, maintenance of a chlorine residual in potable water systems is effective for controlling Legionella spp., but there are many situations where the bacteria can be shielded from the disinfectant (as in a biofilm or amoebae cyst), and therefore, complete eradication of the organism is difficult. (LeChevallier, 2019)

Concentrations of L. pneumophila were <10 MPN/100 mL except when chlorine residuals were less than 0.1 mg/L. Based on the results of this study, it is recommended that water utilities maintain at least a 0.1 mg/L chlorine residual, particularly when water temperatures are >18 C. (LeChevallier, 2019b)

Legionella grows inside amoebae that normally grow in biofilms on the inside of pipes. Legionella growth occurs when the water temperatures range from 20 to 45 C (68 to 113 F). (LeChevallier, 2020)

Increased Risk of Legionellosis. According to CDC, cooling towers and plumbing within large buildings (such as hospitals or hotels) are the most likely sources for infection, but other sources include hot tubs, industrial equipment, and decorative fountains. Risk of illness from Legionella predominantly occurs when their concentration is high (>50,000/L). (LeChevallier, 2020)

Mycobacteria. Mycobacterium avium is ubiquitous in the environment and has been found in soil, house dust, water (wastewater, surface and groundwater water, and drinking water), animals, and poultry. M. avium grows slowly, but is resistant to disinfectants, and can withstand exposure to temperatures of 50oC (125oF) for 60 minutes. M. avium can survive chlorine concentrations 500-times higher than Escherichia coli. People at greater risk are older men with reduced lung function due to smoking or occupational dust exposure; tall, slender older women; and AIDS patients. (Masters et al., 2018)

Control of MAC. Raising hot water heaters to 55oC (130oF), installing filters with poresize less than 0.2 micrometers and periodically draining and refilling hot water heaters are good practices to minimize M. avium risk. (Masters et al., 2018)

Other strains of Mycobacteria collectively called “non-tuberculous Mycobacteria” (NTM) are pervasive environmental organisms found in lakes, soil, milk, and wild animals. Estimates based on hospital admissions show that the prevalence of NTM infections are increasing at a rate of between 8% and 10% annually with approximately 30,000 cases in the United States alone. The majority of Mycobacterium spp. Infections in the United States are caused by M. avium. (Masters et al., 2018)

Pseudomonas aeruginosa. Pseudomonas aeruginosa is found in water and soils and can be regularly found on the surfaces of plants and some animals. The bacterium almost never infects an uncompromised person, but is most commonly associated with patients with severe burns, cystic fibrosis, cancer and AIDS patients who are immunosuppressed. When grown on surfaces, such as pipes, the biofilms provide increased protection and survival. (Masters et al., 2018)

Control of P. aeruginosa. P. aeruginosa can be controlled by a variety of disinfectants but may require temperatures greater than 50oC (125oF) for effective control. Therefore, special care should be taken to reduce biofilm development through minimizing dead ends forming stagnant water, flexible hoses, and poor temperature control. (Masters et al., 2018)

There are no drinking water standards for Pseudomonas aeruginosa but France has recommended levels be less than 1 CFU/100 mL for water used in health care facilities. Similarly, in the United Kingdom P. aeruginosa is expected to remain undetected in premise plumbing water from health care facilities. (Masters et al., 2018)

Staphylococcus aureus. Staphylococcus aureus is widely recognized as the major leading community based bacterial agent in the world. It is worth highlighting its importance as a human pathogen, due to its ability to cause infections as well as its capacity to adapt to diverse environmental conditions and multiple antimicrobial resistance. Also, S. aureus forms biofilms, which enhances its persistence in water systems and its resistance to antibiotics and disinfectants (Santos et al., 2020)

This study evaluated the water quality of drinking water fountains and mist makers in four municipal parks of Sao Paulo for 13 months. Although all samples met bacteriological water quality criteria according to Brazilian regulations, the absence of residual chlorine (<0.1 mg/L) was observed. These data were significantly correlated with the frequency of S. aureus that was found in 25.2% of the samples. The mecA gene was detected in 36.7% of the isolates demonstrating its potential for resistance to several antimicrobials. Furthermore, 27.3% isolates carrying the mecA gene had methicillin-resistant Staphylococcus aureus (MRSA) phenotypic potential. (Santos et al., 2020)

Staphylococcus aureus Surveillance. The presence of S. aureus with characteristics of microbial resistance in water for human consumption is an unprecedented finding. Hence, conducting surveillance for opportunistic bacteria, such as staphylococci in drinking water, is reasonable to take control measures and to protect human health, especially in public places with high attendance. (Santos et al., 2020)

Aeromonas. Most human diseases reported for the genus Aeromonas are associated with A. hydrophila, A. veronii and A. caviae. Aeromonas occur naturally in a wide variety of environments including fresh and salt water, treated and raw sewage water, plumbing systems, fish, shellfish, domestic animals, raw meat and vegetables. Infections associated with typically include people with immunocompromised or other underlying illnesses, young children, and the elderly. Aeromonas can be controlled through maintenance of an effective disinfectant residual and can be inactivated at temperatures greater than 50oC (125oF). (Masters et al., 2018).

Waddlia chondrophila. Waddlia chondrophila is an obligate intracellular bacterium belonging to its own family, Waddliaceae, and to the order Chlamydiales. From its first detection in bovine fetal tissues to date, evidence regarding its involvement as an agent of human miscarriages, is likely implicated as an agent of lower respiratory tract infection (bronchiolitis, bronchitis, pneumonia) since Waddlia chondrophila DNA was identified in respiratory tract samples from children with pneumonia (Augusti et al., 2018).

Previous survey carried out in Spain was able to detect W. chondrophila in well water but not in domestic drinking water. Now, this work demonstrates, in a different geographic area (France), that hot water systems from nondomestic networks can be colonized by this pathogen. It is well known that these types of systems, with low levels or absence of disinfectant, can easily support the proliferation of FLA and their endosymbionts (i.e. Legionellae). The data from this work demonstrate that W. chondrophila can colonize hot water systems from non-domestic networks with higher prevalence than Legionellae. Similar to other members of the Chlamydiales order, W. chondrophila may use FLA for its proliferation and it is not surprising to find it in artificial water systems, such as hot water networks. In these systems, the low levels of residual chlorine, water recirculation, and the existence of dead ends can promote FLA growth and that of their endosymbionts. (Augusti et al., 2018).

Elizabethkingia. A total of 457 tap water samples from 11 hospitals of Northern and Central Greece were analyzed at the Laboratory of Hygiene and Epidemiology of the University of Thessaly, Greece. All samples were collected without disinfecting the tap before sample collection. Only three out of 243 isolates were identified as Elizabethkingia spp. This corresponds to three samples out of 457, collected from two hospitals out of eleven. The first isolate was classified as E. meningoseptica, the second, originating from the same hospital was identified as E. miricola, while the third strain was also identified as E. meningoseptica. The concentrations of the microorganism in the water samples were 2 cfu/100 mL, 16 cfu/100 mL, and 5,120 cfu/100 mL, respectively. Given the severity of the infection in hospitalized patients, the multidrug-resistant profile, the persistence of the microorganism in the environment, and the unknown way of transmission and pathogenesis, E. anophelis may be a cause of nosocomial infection in Greece. In that respect, infectious diseases specialists should actively search for the pathogen both in clinical and environmental samples. (Kyritsi et al., 2018)

Protozoa

Among all examined water bodies in northwestern Poland, Toxoplasma gondii parasitic protozoan DNA was detected in 19.4% (7/36) of them: four lakes, two rivers and one pond. Two cases of double contamination were reported: T. gondii with Cryptosporidium parvum and T.gondii with potentially pathogenic Acanthamoeba T4 genotype. (Adamska, 2018).

The occurrence of free-living amoebae (FLA) in Peninsular Malaysia was evaluated by Gabriel et al. (2019). Of 250 samples, 142 (56.8%) samples were positive for presence of amoebae. Recreational water showed higher prevalence of amoebae than tap water. PCR for the plating assays revealed the presence of Acanthamoeba in 91 (64%) samples and Naegleria in 99 (70%) of samples analyzed. All samples tested were negative for B. mandrillaris. In contrast, the centrifugation method was less effective in detecting amoebae as only one sample revealed the presence of Acanthamoeba and 52 (29%) samples were positive for Naegleria. PCR assays were specific and sensitive, detecting as few as 10 cells. These findings show the vast distribution and presence of FLA in all 11 states of Peninsular Malaysia. (Gabriel et al., 2019).

Blastocystis is an intestinal, anaerobic protozoan parasite, which can be isolated from humans, animals, and the environment. The presence of Blastocystis sp. Cysts in the water samples indicates the possibility of fecal contamination of the water resources by humans or animals. It was proposed that Blastocystis sp. Not only remains alive in water with temperatures of 4 and 25 oC, but also it seems that it may resist conventional chlorine treatment. Several confirmed and most probable waterborne outbreaks due to Blastocystis sp. Have been reported from Nepal, Italy, China, and Morocco. There are reports demonstrating transmission of Blastocystis sp. From drinking water to humans. (Nemati et al., 2021)

Fungi

Bacteria and Fungi Interaction. Bacteria and fungi exist and interact in many environments as they often share a common substrate. Fungal interactions with bacteria range from disorderly polymicrobial assemblies to closely related symbiotic associations of fungal hyphae and bacterial cells. Bacteria are responsible for the initial construction of biofilms while fungi colonize pre-established bacterial biofilms, which is a form of commensalism, as one benefits while the other is unaffected, due to different ecological requirements of the two organisms. Fungi and bacteria are believed to positively use their competitive interactions during fungal decomposition of organic matter. Fungi produce most enzymes because they have higher biomass and bacteria benefit from the enzymatic capacity of fungi, in particular when it comes to enzymes involved in degrading plant polymers. However, some fungal species tend to suppress bacterial growth through production of antibacterial substances, for example, penicillin from the fungus Penicillium notatum. Understanding the interactions between bacteria and fungi in water will give an insight as to whether the presence of certain bacterial species in water can be used as an indicator of its fungal content. To date, no conclusive correlation has been found between indicator organisms such as E. coli and other coliforms to fungi in treated drinking water systems. This is because fungi can resist disinfection while coliform bacteria would be eradicated. This lack of correlation between coliforms and fungi presence in drinking water distribution systems may mean that there is a possibility for bacteriologically safe water to contain some pathogenic fungi. More indicators of process efficiency are required rather than the reliance on the “old style” E. coli as an indicator. However, a point worth noting is that fungi often colonize pre-established bacterial biofilms and, as such, the correlations for biofilms are not necessarily the same as for water samples. (Mhlongo et al., 2019).

The most prevalent fungi in treated drinking water are Acremonium sp., Alternaria sp., Aureobasidium sp., Aspergillus sp., Chaetomium sp., Cladosporium sp., Epicoccum sp., Exophiala sp., Fusarium sp., Geotrichum sp., Mucor sp., Paecilomyces sp., Penicillium sp., Phialophora sp., Phoma sp., Rhizopus sp., Trichoderma sp. And Verticillium sp. Most of the fungal genera described in the studies are dematiaceous fungi which are capable of secreting melanin or melanin-like pigment in their cell walls. This makes them thick-walled species with hydrophobic spores, which give them the advantage to resist water treatment. These persistent fungi normally originate from soil, wood and decomposing plant material, which explains why they end up in raw water. Cladosporium sp., Penicillium sp., Fusarium sp., Penicillium sp., Aspergillus sp., Phoma sp., Epicoccum sp., Trichoderma sp., Acremonium sp., Exophiala sp., Alternaria sp. And Phialophora sp. Are capable of producing mycotoxins and other secondary metabolites that produce toxic chemicals, which impair water quality and become a threat to humans and animals. (Mhlongo et al., 2019)

Water samples were collected from 86 different man-made water systems, including 49 homes, 13 shopping centers, and 24 hospitals, directly connected to municipal water supplies in the city of Istanbul, Turkey. The mean fungal concentrations found in the water samples were 98 CFU/100 mL in shopping centers, 51 CFU/100 mL in hospitals, and 23 CFU/100 mL in homes. The dominant fungal species were identified as Aureobasidium pullulans and Fusarium oxysporum. Aflatoxigenic Aspergillus flavus and ochratoxigenic Aspergillus westerdijkiae were only detected in the hospital water samples. Alternaria alternata, Aspergillus clavatus, Aspergillus fumigatus, and Cladosporium cladosporioides were also detected in the samples. The highest isolation frequency of fungi was recorded for water samples collected from hospitals (100%), followed by shopping centers (84.6%) and homes (79.5%). The lowest number of fungal species was isolated from the shopping centers (eight species), while the highest number of fungal species was isolated from the homes (32 species). The genera Penicillium (10 species) and Aspergillus (8 species) had higher species diversity than the other genera. The following genera were represented by only one species each: Alternaria, Botryosphaeria, Byssochlamys, Coprinopsis, Gibberella, Paecilomyces, and Periconia. However, the most prevalent fungal species were Aureobasidium pullulans (808 CFU/100 mL) and Fusarium oxysporum (809.9 CFU/100 mL). A. pullulans was isolated from homes, hospitals, and shopping centers, while F. oxysporum was isolated from homes and shopping centers. In addition, several other fungi were identified such as Alternaria alternata, Aspergillus clavatus, Aspergillus fumigatus, Cladosporium cladosporioides, and Exophilia sp. Free chlorine (0-3 ppm) was identified in 7.6% of the shopping centers, 12.5% of the hospitals, and 46.9% of the homes. The mean temperature of the water samples was 23 C, pH 6.7-7.7. The current study highlights that water from shopping centers and hospitals contains more fungi than domestic waters. (Kadaifciler and Demirel, 2018).

When fungi enter the water distribution system, they can be harbored in stratified reservoirs that generate stagnation, dead zones, depletion of residual disinfectants and biofilm formation. These conditions, together with chemical-physical characteristics like high turbidity and temperature, pH, total organic carbon (TOC) and dissolved oxygen (DO), are favorable to microbial growth, making these environments at potential risk of water quality degradation by fungi. Fungi have been shown to enter the water distribution system in many ways that may be unavoidable such as mains interruptions, installations and maintenance. Others may include treatment breakthrough, water storage problems and cross connections. Many water companies have encountered operational and technical challenges that have, at times, led to consumer complaints because of fungi related problems. Fungi also produce secondary metabolites that exude organic acids which contribute to microbiological corrosion in water pipes. This corrosion inhibits proper disinfection as accurate concentrations of chlorine residual in the treated distribution water system are altered. (Mhlongo et al., 2019)

Fungi in Groundwater. Aquifer systems have been studied to investigate the presence of different microbial groups and their potential roles in nutrient cycling by employing both culture dependent and culture-independent high throughput methods. However, most of such studies with the focus on geomicrobiology in subsurface aquifer systems have targeted prokaryotes (bacteria and archaea). The potential presence, activity and ecological importance of microbial eukaryotes, such as fungi have largely been overlooked with only a few studies specifically targeting fungi in pristine carbonate-rock aquifers. The study took advantage of the groundwater monitoring wells of the Hainich formation near the Hainich National Park in Thuringia, Germany. The observed fungal communities primarily belonged to three phyla: Ascomycota, Basidiomycota and Chytridiomycota. Perceived dynamics in the composition of living fungal communities were significantly shaped by the concentration of ammonium in the moderately agriculturally impacted aquifer system. (Nawaz et al., 2018).

Yeast. From studies conducted, the following yeast genera have been isolated from water distribution systems and tap water: Candida, Clavispora, Cryptococcus, Debaromyces, Meyerozyma, Pichia, Rhodotorula, Trichosporon and Yarrowia. The following Candida species, namely C. albicans, C. glabrata and C. parapsilosis were isolated from bottled, mineral and tap water from municipal supplies. In another study yeasts species such as Candida tropicalis,Yarrowia lipolytica and Rhodotorula sp. Were isolated from tap water. Ubiquitous opportunistic pathogenic yeasts Candida parapsilosis and Rhodotula mucilaginosa were isolated from tap water and hot aerosols from dishwashers. Yeasts in drinking water distribution systems are known to act as pathogens. Their occurrence in drinking water can pose a health threat to consumers with direct daily contact such as drinking and showering. From clinical tests, for microorganisms to cause an infection, the number of colony-forming units (CFU)/ml in the bloodstream should be defined. In bloodstream infection, Candida CFU/ml In the first 50% positive blood culture had <1 CFU/ml of circulating organisms. For candidemia, classified as high-grade and low-grade candidemia, >25 CFU/10 ml and <10 CFU/10 ml of blood, respectively, were defined. (Monapathi et al., 2000).

The diversity of yeasts in groundwater is comparable to that of surface water and comprise of genera Candida, Clavispora, Cryptococcus, Geotrichum, Pichia, Rhodotorula, Saccharomyces, Trichosporon and Yarrowia. However, groundwater is dominated by black yeasts. Most yeasts are mesophilic and grow best at temperatures between 20 and 30 C. Human pathogens grow well at 37 C, the normal internal temperature of the human body. Yeasts species that grow at this particular temperature may have pathogenic potential as opportunistic species for humans. Yeasts prefer a slightly acidic medium with optimum pH between 4.5 and 5.5. Furthermore, yeasts can grow aerobically on particular carbon compounds such as alcohols, organic acids and amino acids as their sole energy source stipulated that increased dissolved oxygen and dissolved organic matter in aquatic environments favor yeast growth. Yeasts can also utilize a wide range of nitrogen compounds as nitrogen sources. Some nitrogen containing compounds such as amino acids and ammonia can also be used by yeasts as carbon sources. (Monapathi et al., 2000).

The USEPA did look at the addition of microsporidia in drinking water regulations although it was later withdrawn from its Contaminant Candidate List. Sweden is the only country that currently includes specific measures for the monitoring of micro-fungi in treated drinking water. The Swedish Drinking Water Guidelines specify a criterion of 100 CFU of micro-fungi per 100 mL in treated water (Mhlongo et al., 2019).

Occurrence of Pathogens in Premise Plumbing

Unique characteristics of premise plumbing, such as a high ratio of surface area to volume, longer stagnation periods, and low disinfection residual, create ideal conditions for the persistence of opportunistic premise plumbing pathogens (OPPPs) such as Legionella pneumophila, Mycobacterium avium complex, and other nontuberculous mycobacteria and Pseudomonas aeruginosa. These organisms have adapted to low nutrient and oxygen levels, are resistant to low levels of disinfectants, and are capable of biofilm formation and growth in phagocytic free-living amoebae. The heterogeneity of premise plumbing with respect to pipe materials, fixture types, and water temperatures and velocities adds challenges to OPPP monitoring.

Human exposure to OPPPs happens through aspiration and inhalation of contaminated water. Susceptible populations include young children, patients in hospitals and long-term care facilities, and immunocompromised individuals. Risk analysis efforts are confounded by variability in individual susceptibilities and in the virulence of these pathogens. There are significant research gaps in the understanding of OPPP ecology and epidemiology as well as the impact of disinfection methods and the contribution of the premise plumbing microbiome to OPPP persistence. Public education campaigns are needed to emphasize building owners' responsibilities in maintaining and monitoring premise plumbing water quality. (Albert and Nayak, 2019).

Ability to form a biofilm within temperature range (26-40 C) is associated with the optimum growth temperature of different microbial species. At the optimal temperature for growth, cell numbers increase rapidly. The introduction of nutrients (to simulate contamination) increased biofilm formation. The study confirmed the possibility of biofilm formation on the surfaces of hydrotherapy equipment. The isolated and identified microorganisms were very diverse. No common pathogens were identified among the isolates. All isolates were classified as opportunistic pathogen, which can cause infections in humans with weakened immunity systems. For this reason, it is necessary to regularly monitor equipment, facilities and installations and also water use in spas. (Jarzab and Walczak, 2017)

Exposures to aerosols from water fixtures in the indoor environment are considered for multiple scenarios and human susceptibilities to identify the most important factors driving the risk estimate. These results can help to provide context for Legionella spp. Concentration measurements and identify potential data gaps for larger-scale risk prioritization and modeling efforts. Showers were the driving indoor exposure risk compared to sinks and toilets. Critical concentrations depended on the dose response model (infection vs clinical severity infection, CSI), risk target used (infection risk vs disability adjusted life years [DALY] on a per-exposure or annual basis), and fixture type (Hamilton et al., 2019).

TREATMENT

Risk Assessment for WTPs. None of the pathogens were detected at concentrations that pose a significant risk when plants are operated as designed. Matrix spike recovery studies indicated widely variable recoveries for Cryptosporidium and Giardia among the plants and very low recovery of enteric viruses. QMRA and statistical analyses indicate that ongoing, routine monitoring would not contribute to improved risk estimation for any of the study plants. This is largely because all of the plants are designed and operated to provide pathogen removal/reduction well above that required to meet microbial risk objectives given conservative estimates of source water pathogen concentrations. This is particularly true for bacterial and viral pathogens, whose removal, in most cases, was beyond the ability of the QMRA tool to calculate. (WRF, Bartrand et al., 2017a; 2017b) QMRA was run “in reverse“ to determine plant-specific source water pathogen concentrations that would pose benchmark level risks given the treatment in place at the plant. Such an a priori use of QMRA in assessing and managing microbial risks can avoid expenses for pathogen analyses that would not contribute to meaningful risk management.

Research literature is available for many microbial CECs on effectiveness of disinfectants such as chlorine or ultraviolet (UV) disinfection (e.g., Bloetscher and Plummer, 2011). For example, *E. coli* O157 is inactivated by chlorine at doses well below those typically used in drinking WTP. *H. pylori* is readily inactivated by chlorine and UV light. *Naegleria fowleri* cysts required higher UV doses than *Cryptosporidium parvum* oocysts (Bartrand, 2014). Exposure of 13 mW-s/cm^2 UV light was needed for 2-log inactivation of *Naegleria fowleri* trophozoite, and 63 mW-s/cm^2 was needed for cysts. Ozone is a more effective chemical disinfectant than chlorine for *Naegleria fowleri* inactivation.

Viruses

Coronaviruses. Water disinfection was only addressed by one study, which analyzed the resistance of SARS-CoV and phage f2 seeded into 100-ml domestic sewage to different chlorine solutions. During a 30 min disinfection assay, SARS-CoV was completely inactivated with 10 mg/L chlorine or 20 mg/L chlorine dioxide, while phage f2 needed a higher chlorine concentration (40 mg/L) and was not completely inactivated even by 40 mg/L chlorine dioxide. (Carducci et al., 2020) It follows that the current water disinfection practices (drinking water, wastewater, water from swimming pool), effective against non-enveloped viruses and bacteria, are expected to be effective also towards enveloped viruses such as coronaviruses. (LaRosa et al., 2020)

Bench scale of a coagulation-filtration system previously optimized using three different coagulants (zirconium, chitosan and polyaluminium chloride) in reducing BcoV and other viruses (Hepatis A virus, bovine norovirus and MS2). Diluted and undiluted water samples (400-ml) from water treatment plants were spiked with viral mixtures. After the addition of coagulants, centrifugation and filtration steps, the supernatant and filtrate were analysed for quantification. A combination of flocculation and filtration led to a decline in viral presence from 10 to 70% depending on the type of virus, coagulant and presence of natural organic matter: BcoV was reduced more (mean 4 Log10) in undiluted water by all the three coagulants than in diluted water. In this last example, chitosan performed the best. (Carducci et al., 2020).

Inactivation of SARS-CoV-2 in chlorinated swimming pool water was dependant on free chlorine and pH levels with increased inactivation at higher free chlorine and lower pH. We show that 30 s contact time at room temperature with water of a pH of no more than 7.4 and free chlorine above 1.5 mg l⍰ 1 (ppm) resulted in at least a 3-log10 reduction in viral titre within 30 s. These levels are within the recommendations for swimming pools from June 2021 to July 2021 of the pandemic in the UK of at least 1.5 ppm free chlorine at pH 7.0, 2.0 ppm at pH 7.4 and 2.7 ppm at pH 7.6 (2020). The newly revised UK guidelines that swimming pools at pH 7.2 – 7.4 should have a minimum free chlorine level of 2.0 ppm is also supported by our observation that 1.5 ppm is adequate at pH 7. (Brown et al., 2021)

The main methods of inactivating SARS-CoV-2 in a wastewater environment include the following. (1) SARS-CoV-2 is more vulnerable to ultraviolet (UV) (254 nm) exposure than is non-enveloped virus, and the exposure time for effective inactivation is just several seconds. (2) The thermal effect for the inactivation of SARS-CoV-2 is confirmed effectively at 70oC in 5.7 min. (3) Chemical disinfection quenched viral infectivity within a short exposure time as the most effective and economical solution. Thus, a large number of disinfectants (chlorine disinfectants, hypochlorous acid, ozone, etc.) have been applied to inactivate SARS-CoV-2 in wastewater. At present, chlorine disinfectants are most widely used, as free chlorine could effectively inactivate SARS CoV-2 by destroying the proteins on its envelope. (Meng et al., 2021)

Removal of Viruses by Membrane Filtration. This study showed a substantial removal of most viruses from raw water treated with conventional methods and additional barriers at two Swedish DWTPs. Larger viruses were efficiently removed by UF. However, genomes of some smaller viruses, as HEV and some bacteriophages and plant viruses, were detected after UF and UV treatment. Although UV has been shown to reduce the infectivity on recombinant HEV1/HEV3 virus adapted to cell cultures, the inactivation efficiency for wild type HEV is not known. The HEV strains in this study could enter the water supply network despite that all standards were fulfilled for routine monitoring of small particles in the outlet water at the DWTPs. The pores in the UF membranes used are smaller than those recommended by the

Swedish authorities, which have stated that membranes with pore size 100 nm can be a used microbial barrier, and the Norwegian guide for barrier analyses recommend 40 nm nominal pore size for UF. These larger pore sizes would probably not remove smaller viruses as efficiently as the membranes in this study. Common human viruses with fecal/oral spread that may not have been removed by larger pores are e.g. norovirus (38-40 nm), rotavirus (45 nm) and adenovirus (90-100 nm). Several other viruses with fecal/oral spread are as small as HEV, about 30 nm in diameter, and may pass through the membranes, as those belonging to the Picornaviridae family, for example hepatitis A virus, enterovirus, Aichivirus and parechovirus. This should be considered during outbreaks of these viruses in the community. However, the retention of viruses by UF may not only depend on virus size but also on other physiochemical factors of the viral capsid influencing the flocculation of the virus during purification at the DWTPs. The results from this study indicate that the current methods are sensitive for reducing almost all larger viruses and most of the smaller size viruses in water. Although HEV was found in treated water before disinfection at the DWTPs and in tap water, the amount per L tap water was comparable low. Therefore, the risk of infection by consumption of the drinking water is probably negligible. However, further studies on viral infectivity and lowest infectious dose are needed. (Wang et al., 2020)

This study showed that even if the number of viruses were reduced 3-4-log10 at the two DWTPs, there were sequences representing many different virus families, including HEV, in the effluent after UF and in tapwater. The total number of viral reads in tap water was about 0.1% of that in raw water, but for HEV it was 2.2%. Despite this, the risk for getting infected by viruses in these concentrations in the drinking water is probably negligible. However, there may be a risk of transmission during outbreaks with large number of infected persons excreting high concentrations of small fecal/oral transmitted viruses. The virome and reduction of many different small RNA and DNA viruses in water could be monitored using an indicator virus, as gokushovirus, which was found in all water samples. Further studies are necessary to investigate the viability of the viruses identified in water. To achieve better understanding of the efficiency of virus removal and inactivation there may be a need for routine monitoring for viral indicators in waters at the DWTPs and in the distribution network. This knowledge will help tracking possible transmissions of viruses from raw water to tap water, and thereby ultimately reduce potential risks of viral infections from drinking tap water during outbreaks. (Wang et al., 2020)

Bacteria

Legionella. Legionella is regulated under the SWTR with a maximum contaminant level goal (a nonenforceable guideline) of zero Legionella organisms for drinking water. The rule specifies a treatment technique for Legionella control (e.g., filtration and maintenance of a detectable disinfectant residual), and therefore, monitoring for Legionella is not required. Although analytical methods existed for Legionella detection, the USEPA determined that testing was impractical to implement, particularly for small systems. Water utilities are reluctant to monitor for Legionella, particularly because there are no USEPA or CDC guidelines for responding to positive results. (LeChevallier, 2019b).

Nutrient Limitation. Nutrient limitation in water distribution systems includes reducing nutrients during water treatment, corrosion control, and preventing nitrification. Enhanced coagulation and biological filtration (e.g., rapid sand filtration for groundwater treatment and biological active carbon filtration and/or slow sand filtration for surface water) are important for removal of organic nutrients. Controlling corrosion of iron pipes in the distribution system prevents iron from being released in the water system, which can influence the growth of L. pneumophila because iron is an essential nutrient for L. pneumophila. Finally, when the chlorine-to-ammonia ratio (4.5:1) is not properly managed in chloraminated drinking water, nitrification can occur, resulting in enhanced biofilm biomass, which can lead to increasing numbers of host protozoans for L. pneumophila. (LeChevallier, 2020).

In some structures, a repeated treatment has been required to remove Legionella by changing the cleaning mode in order to increase its effectiveness. In our practical experience, we have observed that the most effective solution has been using in combination two treatments of decontamination: hyper-chlorination and heating to 60 deg C, especially for the complex water distribution systems. (De Filippis et al., 2017). The results obtained show a possible association between the presence of Legionella and high values of HPC at 37 deg C. This might suggest the use of this parameter as a preliminary assessment of the possible presence of Legionella. Therefore, high values of HPC (> 1000 CFU/mL) at 37 deg C may also suggest searching for Legionella, particularly in those cases where there is a high risk for the population to become ill. (De Filippis et al., 2017).

Outbreaks in Complex Plumbing Systems. Legionella poses a minor risk for most healthy individuals. Outbreaks are usually related to the more complex plumbing systems in larger buildings rather than single-family houses. For these reasons, homeowners should not be concerned about the risk of legionellosis. However, for homes with at risk populations or homeowners who would like to take additional precautions, various options are available to reduce Legionella risk. (Masters et al., 2018)

Regular maintenance is a simple task that, when done often, can minimize risk of Legionella. Such maintenance includes simple cleaning of shower heads and faucet aerators. Flushing the hot water tank on a regular basis may also mitigate risk, but this should be done with caution and performed by a qualified plumber. (Masters et al., 2018). Maintaining the water heater at an appropriate temperature can help reduce the likelihood of Legionella growth in the plumbing system. Hot water heaters should store water at least 60 C (140 F) and distribute water at 50 C (122 F) or higher, but to minimize the risk of scalding, thermostatic mixer valves should be fitted as close as possible to outlets. Point of use water filters, such as those that are installed at the kitchen faucet, can be especially useful when at risk patients are in need of additional layers of protection, as these filters can be installed at the point where water comes out of the tap. It is very important that the filters be changed according to the manufacturer's recommendations because if left for prolonged periods of time, Legionella can grow on the filters and actually degrade water quality. Humidifiers create aerosols by design, and if not properly maintained can be a mechanism for the growth and transmission of Legionella. Due to this, humidifiers must be closely examined in any Legionella control plan. Multi-dwelling facilities differ from single-family homes in that they may have the following features that can increase the risk of bacterial growth and transmission:

1. Hot tubs/Jacuzzis/spas
2. Pools and shower facilities
3. Indoor or outdoor fountains or water features
4. Central water heaters and distributed water lines/pipes
5. Cooling towers
6. Water reservoir tanks
7. Humidifiers
8. Solar water systems.

Therefore, facility operators should have standard operating procedures for the routine maintenance and sanitation of these features. (Masters et al., 2018).

The Centers for Disease Control, CDC, has created a toolkit for large buildings to ensure the safety of staff and the public. The CDC toolkit can help to identify areas of concern where Legionella might grow and be transmitted. The toolkit includes practical resources to help ensure a comprehensive and effective system that holds to industry standards. https://www.cdc.gov/Legionella/downloads/toolkit.pdf.

Health care facilities pose a special situation for managing Legionella risk due to the increased number of people who may be susceptible to infection. For this reason, it is important for health care facilities to create a water management plan in accordance with the CDC Toolkit. https://www.cdc.gov/Legionella/downloads/toolkit.pdf. (Masters et al., 2018)

The CDC toolkit (CDC 2017) can be used to create a building water management program to reduce the risk of Legionnaires' disease in building water systems and devices. The plan should identify areas of concern where Legionella might grow, increasing the risk of an outbreak. This toolkit includes practical resources to help ensure a comprehensive and effective system that meets industry standards.

The EPA Report, titled Technologies for Legionella Control in Premise Plumbing Systems: Scientific Literature Review, https://www.epa.gov/sites/production/files/2016-09/documents/Legionella_document_master_september_2016_final.pdf characterizes the effectiveness of different technologies used to control Legionella growth in premise plumbing systems. Particularly, it focuses on premise plumbing systems of large buildings, such as hotels, hospitals, schools, and other buildings with complex plumbing infrastructure. The document summarizes information on several Legionella control technologies, including:

1. Risk management approaches (including temperature control)
2. Chlorine
3. Monochloramine
4. Chlorine dioxide
5. Copper-silver ionization
6. Ultraviolet light
7. Ozone

The document also provides information on other control technologies often used for emergency remediation such as superheat-and-flush, shock chlorination and point-of-use filtration. (Masters et al., 2018). Although Legionella pneumophila is responsible for the most outbreaks of opportunistic premise plumbing pathogens (OPPP), there are many other microbes of concern that can grow in building water systems. Most of the procedures outlined for control of Legionella (e.g., cleaning, flushing, water management plans, etc.) will also be useful in reducing the occurrence and concentration of these other OPPPs.

Free Chlorine versus Chloramine. The disinfectant type and total chlorine residual (TClR) were investigated to understand their influence on the detection and concentrations of the five pathogens in potable water. Samples (n=358) were collected from point-of-use taps (cold or hot) from locations across the United States served by public water utilities that disinfected with chlorine or chloramine. Each species of bacteria responded differently to the disinfection type, concentration, and temperature. There was no unifying condition among the water characteristics studied that achieved microbial control for all. Legionella pneumophila and L. pneumophila serogroup 1 (Sg1) (causing legionellosis) and Mycobacterium avium, Mycobacterium intracellulare, and Mycobacterium abscessus (causing pulmonary NTM disease) were quantified in water samples taken at locations across the United States. When all chlorine- and chloramine-treated water samples were considered, L. pneumophila and L. pneumophila Sg1 were detected at similar rates (26% [CL] versus 22% [CLM] for L. pneumophila and 9% [CL] versus 5% [CLM] for L. pneumophila Sg1). M. avium and M. abscessus were detected (22% and 17%) significantly more frequently at locations where chloramine was used as the disinfectant. Detections of the three Mycobacterium spp. Ranged from 9 to 22%. (Donohue et al., 2019)

Increased relative abundance of *Legionella*, *Escherichia* and *Mycobacterium* following monochloramine primary disinfection observed in lab-scale and full-scale WDS have been attributed to differential resistance of microorganisms to monochloramine (Chiao, 2014; WRF, Rhoads, 2015).

Chlorine versus Chloramine. M. avium and M. abscessus were detected significantly more frequently in chloramine-treated water samples than in chlorine treated samples. All the pathogens showed no significant difference in detection frequency in hot-water or cold-water tap samples whether from chlorine- or chloramine-treated water sources. There were significantly fewer L. pneumophila CE per liter detected in samples from chloramine-treated water than in chlorine-treated samples. (Donohue et al., 2019)

This was also true for samples collected from cold water compared to those collected from hot water. The median concentrations for L. pneumophila Sg1 and for the three Mycobacterium species were not significantly different based on the two disinfectant types. Among the mycobacterium species, M. intracellulare concentrations were significantly greater in chloramine-treated systems than in chlorine-treated systems in cold-water samples. Neither chlorine nor chloramine eliminated pathogenic Legionella or Mycobacterium organisms in the water samples tested. Although L. pneumophila and L. pneumophila Sg1 were detected at about the same frequency in systems that disinfected with chloramine or chlorine, chloramine significantly reduced the median concentration of L. pneumophila compared to chlorine-treated samples for both the cold- and hot-water samples plus all samples combined. On the other hand, M. avium and M. abscessus were detected significantly more frequently in water samples from systems that disinfected with chloramine than from those using chlorine, but the median concentrations were not significantly different for chloramine-treated water samples versus chlorine-treated water samples. The median concentrations of L. pneumophila Sg1 were significantly lower only in cold-water samples from utilities that used chloramine compared to those that used chlorine. (Donohue et al., 2019).

A novel chlorine-resistant bacterium identified as Gordonia was isolated from the drinking water supply system of Jinan City, China. The authors examined the resistance and inactivation of the isolate by investigating cell survival, changes in cell morphology, and the permeability of cell membranes exposed to chlorine. After 240 min chlorine exposure, the chlorine residual was greater than 0.5 mg/L and the final inactivation was about 3 log reduction, which showed that the Gordonia strain had high chlorine tolerance. Gordonia JN724 exposed to 0.38 mg/L of chlorine dioxide for 5 min produced more than 2 log inactivation. UV irradiation was effective in Gordonia JN724 inactivation. When the UV dosage increased to 40 mJ /cm2, approximately 4 log 10 (i.e., 99.99%) removal was detected. Complete inactivation (about 5 log 10) was practically reached after exposure to UV fluences of 80 mJ/cm2. The UV dose-response curve for Gordonia JN724, which was similar to that of other organisms inactivated by UV. Gordonia JN724 can be effectively inactivated by ClO2 and UV treatments, which suggests that they may serve as alternative approaches for the control of chlorine-resistant microorganisms. Meanwhile, water treatment plants using chlorine disinfection should be aware of the existence of chlorine-resistant microbes and consider different disinfection methods based on their own unique needs. (Lu et al., 2020)

Copper and Silver as a Biocide. Different types and strains of bacteria have different sensitivities to copper and silver biocidal effects. Gram-negative bacteria, including Salmonella enterica, Escherichia coli (E. coli), and Legionella spp., demonstrate a greater sensitivity to ion disinfection than gram-positive bacteria. This is suggested to be due to inherent physical and biological differences. Gram-negative bacteria possess a thin, single peptidoglycan-layered cell wall and an outer layer to the cell membrane. They also possess a periplasm (matrix between the inner and outer membranes in gram negative bacteria), have high lipopolysaccharide content, and do not contain teichoic acids. Gram-negative bacteria have little inherent physical resistance to the action of copper and silver ions. (June and Dziewulski, 2018).

Gram-positive bacteria, including Enterococcus hirae, Staphylococcus aureus, and some Clostridium and Bacillus spp., demonstrate a greater tolerance to ion disinfection than gram-negative bacteria. Gram-positive bacteria have a thick, multilayered peptidoglycan layer within the cell wall. They do not possess an outer cell membrane layer, periplasm, or lipopolysaccharide content. However, gram-positive bacteria do contain teichoic acids, polymers that achieve a positive electrostatic charge and deter positively charged biocidal activity. (June and Dziewulski, 2018).

For most organisms, copper is a biologically essential element. Copper acts also as an antimicrobial agent, meaning the copper product possesses the ability to eradicate 99.9% of most bacteria within 2 h. Low copper concentrations are rate limiting; there is an activity threshold beyond which excess copper concentrations yield no added benefit. This is notable for maintenance of metal treatment and understanding potential resistance management. Pure copper demonstrated significantly greater inhibition of gram-positive E. hirae than either cuprite or tenorite, with pure copper and cuprite demonstrating toxicity. The observed slower release of ions in copper oxides associated with a lowered antimicrobial activity indicated that free copper ions are essential for biocidal activity. Oxidizing conditions will maintain antimicrobial characteristics on the surface. However, other water quality variables, such as phosphates added for corrosion control by many water utilities, can bind metal ions and reduce the ability of copper and silver to kill Legionella. (June and Dziewulski, 2018).

Legionella is resilient in a wide range of water conditions, surviving both slightly acidic and slightly basic environments. While pH alterations of premise water may not prove detrimental to the organism, they can influence treatment efficacy. Treatment at an Ohio hospital proved ineffective for L. pneumophila control despite reaching and maintaining target ion concentrations (0.27 mg/L of copper and 0.03 mg/L of silver). Water quality sampling revealed the pH of the water to be between 8.5 and 9.0. Elevated pH levels (i.e., >7) resulted in a significant decline in log-reduction (6-log to 1-log) provided by the copper ions in treatment. In contrast, the silver ions maintain biocidal capacity under almost all pH conditions, suggesting that Legionella control under elevated pH may still be offered by the silver ions. (June and Dziewulski, 2018).

At low concentrations of halides, silver maintains the ability to bind to bacteria and exert biocidal effects; at moderate levels of halides, silver is precipitated (e.g., silver chloride [AgCl]); at high concentrations of halides, the silver compounds become bioavailable again as anions (e.g., AgCl2-). Formation with anions such as sulfate, phosphate, and carbonate will have a similar precipitation effect on aqueous cuprous and cupric species, thereby limiting the amount of available copper for disinfection. Higher concentrations of halides in solution have also been associated with increased silver toxicity to bacteria. A suggested mechanism for such toxicity increase is that of increased organism membrane permeability when bound to chloride.

The authors have reviewed the scientific literature on the biocidal and defensive mechanisms and identified possible data gaps that, if filled, could help make this method a reliable tool or useful component of a multi-barrier approach for Legionella control. Possible approaches for improving CSI efficacy and reliability include increasing the dissolved oxygen and sodium content of the water, applying copper and silver ions in combination with other disinfectants, and using copper and silver ions at higher temperatures. Water system operators considering treatment should review water chemistry and the potential benefits and drawbacks of treatment specific to their system when selecting any onsite technology. The potential public health protection benefits of treatment, particularly in healthcare facilities in which the most vulnerable populations reside, justify the need for further examination of improving the efficacy of CSI and other treatment systems. (June and Dziewulski, 2018)

Protozoa

Trophozoites of free-living amoebae are typically sensitive to disinfection (while the cysts are not), so the maintenance of a stable disinfectant residual (like chloramines) may have more impact on shifting the life stage from trophozoite (where intracellular pathogens can proliferate) to the cyst stage where intracellular growth does not occur. (LeChevallier et al., 2016).

Fungi

Fungi can grow attached to a substrate and colonize filters in water treatment plants giving them a good opportunity to resist water treatment. If fungi survive sedimentation and flocculation, rapid sand filtration does not become an effective treatment for fungi as these filters have been shown to partially remove microorganisms, especially fungi that end up in the distribution system. Fungi and bacteria have the ability to become dormant in order to survive when conditions are no longer conducive. This is the phenomenon with the melanised thick-walled fungal species that are more resistant to water treatment and disinfection. Different fungal species vary in their resistance to disinfection. Penicillium and Aspergillus species are more resistant to chlorine disinfection than the Cladosporium and Phoma species. Ozone and UV radiation are more capable in the destruction of many pathogenic organisms than chlorine. Ozone inactivates fungal species by causing an irreversible cellular damage. There are resistant species to ozone like Trichoderma viride that is slightly affected only in elevated concentrations and Penicillium spinulosum, which is the most resistant due to its hydrophobic surface. Fungi with pigmented spores such as Aspergillus and Penicillium have better defense against radiation and are not responsive to UV treatment. The radiation cannot destroy fungal species even in slightly turbid water as the fungi tend to be harbored within the particles and escape disinfection. Furthermore, disinfection methods by exposing some species of fungi to UV light may seem futile as strongly melanised spores of Aureobasidium pulullans and Aureobasidium melanogenum have shown resistance to elongated radiation interactions. Fungi are more resistant to chlorine inactivation than the commonly used indicator organism E. coli. Monitoring and keeping the amount of fungi under surveillance after water treatment and in distribution systems is fundamental in guiding against harm to human health, and also to improve the aesthetic quality of water in relationship to taste and odor. This can also include the need to evaluate the removal of secondary metabolites by drinking water treatment processes. (Mhlongo et al., 2019)

PRIORITIZATION AND RECOMMENDATIONS

Source-to-Tap Approach. A priority focus on drinking water process management, for example, through the implementation of a source-to-tap or water safety plan approach, is the recommended strategy by Health Canada (2020) for water utilities to manage potential risks. Important elements of this strategy include:

- Source water protection (where feasible);
- Optimized treatment performance for turbidity and natural organic matter removal;
- Proper application of disinfection technologies;
- Performance/verification testing using multiple operational parameters and water quality indicators;
- A well-designed and well-maintained distribution system; and
- Maintenance of an effective disinfectant residual.

Water treatment plant. When properly designed and operated, physical removal and disinfection technologies commonly used in drinking water treatment are very effective in reducing or inactivating the waterborne pathogens described in this document. Current treatment requirements are based on health-based treatment goals for enteric protozoa (Giardia and Cryptosporidium), and enteric viruses. This is because of their importance as causes of waterborne disease, high infectivity, difficulty of removal through water treatment, and high disinfectant resistance. The physical removal and disinfection requirements for the waterborne pathogens discussed here are less than or equivalent to those for enteric protozoa and enteric viruses. As a result, surface water and groundwater under the direct influence of surface water systems that meet the guidelines for enteric protozoa and enteric viruses (minimum 3-log removal and/or inactivation and minimum 4 log removal and/or inactivation, respectively), are capable of controlling these pathogens. Groundwater systems that meet the guidelines for enteric viruses (minimum 4-log removal and/or inactivation) are capable of controlling of these pathogens. Health Canada (2020)

Drinking water distribution system. Even with treatment technologies in place, microorganisms can enter drinking water distribution systems as a result of inadequate treatment or through post-treatment contamination via intrusions, cross-connections or during construction or repairs. Biofilms and loose deposits in drinking water systems provide habitats that can support the survival, growth and dissemination of pathogenic microorganisms, particularly opportunistic pathogens (e.g., Legionella). Key distribution system operational and maintenance practices include (Health Canada, 2020):

- Use of proper construction materials;

- Treatment optimization to minimize the amounts of nutrients, scaling and corrosion within the system;
- Managing water age and controlling the effects of temperatures where possible;
- Maintaining an effective disinfectant residual;
- Preventing the entry of contamination (e.g., pressure maintenance, preventing cross-contamination/backflow, hygienic 64aters64es during mains constructions and repairs); and
- Keeping the distribution system clean (e.g., use of appropriate flushing and cleaning techniques).

Minimum Disinfectant Concentration

Many states have replaced USEPA’s “detectable” requirement with a numerical value for the minimum residual concentration, and 24 states have established numerical values for minimum residual disinfectant. Of these, 20 states require a minimum residual ≥0.2 mg/L for free and/or total chlorine throughout the system, and four states have established numerical minimums of <0.2 mg/L. Thirteen states have set higher minimums for total chlorine than for free chlorine, ranging from 0.5 to 1.5 mg/L. Regardless of the regulatory requirements for minimum residuals, water suppliers should select system-specific target and trigger levels for distribution system residuals for operational purposes. (Furatian et al., 2021)

Premise plumbing. Maintaining microbiological control in premise plumbing systems, especially in large buildings, is a critical component of providing safe drinking water at the consumer’s tap. Important elements of control strategies for plumbing systems include (Health Canada, 2020):

- Limiting nutrient levels through an emphasis on system design and materials;
- Minimizing areas of low flow/stagnation;
- Keeping temperatures of hot and cold water systems outside of the ideal range for microorganism growth (e.g., cold water less than 20°C, hot water tank temperature greater than 60°C); and
- Reducing the formation and transmission of contaminated aerosols from distal devices.

It is also important to highlight that in management strategies for complex water systems, many control measures are interrelated. Changes in the microbiological diversity of drinking water systems can occur with changes in materials or operational procedures. Understanding the effects of changes in water management operations on drinking water ecology is necessary to minimize unintended consequences such as creating conditions that favour the growth (i.e., enrichment) of specific microbiological groups. Health Canada (2020)

Further Selected Recommendations from Literature Review

Maintenance of a disinfectant residual is a primary control strategy for managing risks from emerging pathogens, but little data is available on the levels necessary for control in distribution and plumbing systems. (LeChevallier et al., 2016)

Disinfectant Residual Goals. Most well-run water utilities set internal performance goals; across North America, they typically strive to maintain a minimum disinfectant residual of 0.2 mg/L in all parts of the distribution system. The voluntary Partnership for Safe Water program, for example, requires that all member systems use secondary disinfection and that optimized systems meet these residual disinfectant goals throughout the distribution system (LeChevallier, 2020):

≥0.20 mg/L and ≤4.0 mg/L for free chlorine

≥0.50 mg/L and ≤4.0 mg/L for chloramines

≥0.20 mg/L and ≤0.80 mg/L for chlorine dioxide

These goals are to be achieved for 95% of routine readings each month, and individual routine sample sites should not have consecutive residual readings less than the residual disinfectant goal. Additionally, well-run systems specifically target areas that are known to experience low disinfectant residuals because of the nature of the pipe materials (e.g., unlined cast-iron mains), long detention times, or water quality characteristics (e.g., organic matter, inorganic chemicals, pH, temperature). In these cases, routine flushing, replacement of old mains, improvement of the circulation within the distribution system, or improvements in treatment processes can be implemented to increase the stability of the disinfectant residual. (LeChevallier, 2020).

Messaging for Building Water Systems. It is recommended that water utilities and others in the sector develop and implement proactive messaging for building water systems and their associated hazards as a critical way to manage OPPP risks. Larger, more complex plumbing systems associated with commercial buildings such as hotels, resorts, offices, hospitals, schools, and universities (collectively called commercial, industrial, institutional, or CII) are more likely than homes to have OPPP outbreaks. (Masters et al., 2018)

Hospital Showers. Well-developed biofilms were physically removed from the internal surface of shower hoses collected in four locations in England and Scotland. Samples revealed the presence of sequences related to Exophiala 65aters65es, Fusarium fujikuroi and Malassezia restricta. These organisms can be associated with the environment and healthy skin, but also with infection in compromised and 66aters-competent hosts and occurrence of dandruff. Domestic showering may result in exposure to aerosols of bacteria and fungi that are potentially pathogenic and toxigenic. Use of disinfectants, or regular replacement of hoses, where 66aters-compromised persons are present was recommended (Moat et al., 2016). The UK Department of Health suggests that flexible hoses should not be used in high-risk situations. It has been demonstrated that the concentration of airborne of filamentous fungi, including Fusarium and Aspergillus species, was significantly reduced by washing water-related surfaces in hospital bathrooms immediately prior to showering.

Use for Nasal Rinsing. Because there is no guarantee that even the most vigilant drinking water system can completely eliminate N. fowleri, the public should take additional precautions when using tap water for nasal or sinus rinsing. Water used for nasal or sinus rinsing should undergo additional treatment at the point of use, which can include boiling for 1 min and cooling before use, filtering using a filter labeled as absolute pore size of 1 micrometer or smaller, disinfecting with chlorine bleach, or using water that is purchased sterile or distilled. (Cope et al., 2019).

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2. Per-and Polyfluoroalkyl Substances (PFAS)

PFAS are organic chemicals containing chlorine, bromine, and/or fluorine (halogens) that are used in firefighting or applied to products to impart fire resistance. PFAS also commonly referred to as perfluorinated chemicals or PFCs, are a group of anthropogenic chemicals that resist heat, oil, and water, which make them extremely useful for a wide variety of products, including non-stick coating, textiles, and firefighting foam. They are very stable in the environment and can be found in plants and animals used for human consumption (WRF, 2019).

Surveys conducted by the CDC show that most people in the United States have been exposed to some PFAS, which can accumulate in the body over time. Current scientific research suggests that exposure to high levels of certain PFAS may lead to adverse health outcomes (USEPA, 2021b). More than 3000 PFAS are on the global market.

MEDIUM PRIORITY FOR SFPUC

PFAS contaminants are considered medium priority. PFOA and PFOS are undergoing rulemaking under the Safe Drinking Water Act, with final rules expected to be promulgated in 2023.

PFAS do not occur and are not expected to occur in SFPUC source waters or drinking water, based on available monitoring data and the fact that SFPUC watersheds and source waters are not impacted by significant wastewater and industrial discharges or urban runoff. Future recharge of reclaimed wastewater will need to be monitored to ensure that groundwater is not affected.

This section presents: (1) Screening Evaluation Table, (2) SFPUC Monitoring Review 2016-2021, and (3) Technical Review 2016-2021 of available scientific studies.

Table 2-1. Screening Evaluation Table for PFAS

GENERAL INFORMATION ON CEC	
Instructions	This Screening Evaluation may be applied to a CEC group or an individual CEC. The purpose of this section of the Evaluation is to develop background information on the CEC or CEC group.
CEC Name	**Per-and Polyfluoroalkyl (PFAS) Substances** PFAS – The emphasis is given to Per-and polyfluoroalkyl (PFAS) substances, because this CEC group is on USEPA's high priority list to phase out its use in industrial and consumer products.
CEC Description Is CEC a group? If individual CEC, which group is CEC part of?	PFAS are organic chemicals containing chlorine, bromine, and/or fluorine (halogens) that are used in firefighting or applied to products to impart fire resistance. PFAS also commonly referred to as perfluorinated chemicals or PFCs, are a group of anthropogenic chemicals that resist heat, oil, and water, which make them extremely useful for a wide variety of products, including non-stick coating, textiles, and firefighting foam. They are very stable in the environment and can be found in plants and animals used for human consumption (WRF, 2019).
CEC Grouping What is the basis for grouping? *(Grouping factors are: common health effects, treatment, and analytical method, and/or compound co-occurrence)*	CEC Group. The basis for the grouping is common sources/uses. For the purpose of this Screening Evaluation, this group includes two types: (1) flame retardant materials/coatings, and (2) fire extinguishing fluids and foams. Some subgroups within Types 1 and 2 also have common health effects or analytical methods. Grouping and evaluating PFAS with similar characteristics together, rather than individually, will help EPA to more efficiently evaluate existing data and support more informed decisions about data gaps and needs (USEPA, 2021i).

Examples and Indicators If group, what are notable examples? Are there possible indicator constituents? *(A suitable indicator occurs at quantifiable levels and may co-occur with other CEC exhibit similar treatment and fate in environment)*	Examples are found on UCMR5, and Draft CCL5 lists. The UCMR5 was published on December 27, 2021. UCMR 5 requires sample collection for 30 chemical contaminants between 2023 and 2025 using analytical methods developed by EPA and consensus organizations. Includes 29- Per- and Polyfluoroalkyl Substances (USEPA, 2021d). Please see the literature review for the list of 29 – Per-and Polyfluoroalkyl substances. Some are listed below.
Health Advisories **Does CEC have a USEPA Health Advisory (e.g., Drinking Water Equivalent Level [DWEL]) or California Notification Level?**	States have initiated their own efforts to implement lower enforceable standards (Alfredo et.al. 2021): • New York currently establishing the lowest for PFOS at 10 ng/L. • Michigan's proposed levels recently became enforceable in August 2020 at 8 ng/L for PFOA and 16 ng/L PFOS. • California has the lowest NL concentrations of 5.1 ng/L and 6.5 ng/L for PFOS and PFOA, respectively. • Illinois passed HA levels for four PFAS to include PFOA at 2 ng/L. Illinois did not include PFOS in these HA guidance levels.
Regulatory Development Status **Is CEC on USEPA Candidate Contaminant List (CCL), Unregulated Contaminant Monitoring Rule (UCMR) list, or California Public Health Goal (PHG) list?**	Yes. Three PFAS were on the CCL3 and CCL4 and 7 (including 5 perfluorochemicals) were on UCMR3. UCMR5 includes sample analysis using a newer analytical method (EPA Method 533), collecting occurrence data on an additional 11 individual PFAS incorporating an additional suite of PFAS (AWWA, 2020). UCMR5 includes 29 PFAS (USEPA, 2021d). In March 2021, EPA published Regulatory Determinations for Contaminants on the Fourth Contaminant Candidate List which included a final determination to regulate perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) in drinking water. The Agency is now developing a proposed NPDWR for these chemicals. As EPA undertakes this action, the Agency is also evaluating additional PFAS and considering regulatory actions to address groups of PFAS. (USEPA, 2022)

CONTEXT OF CEC EVALUATION AT SFPUC	
Instructions	The purpose of this section is to report SFPUC experience with the CEC or CEC Group, including occurrence data for each source water if available.
Purpose Why is investigation undertaken? What is new about the issue that is considered 'emerging' (e.g., new chemical, new effect)?	PFAS have been detected in all types of waters throughout the world including surface, ground, tap and bottled waters, wastewater, industrial waste, rivers, and lakes with concentrations ranging from below detection limits to µg/L in some cases (WRF, 2019). Surveys conducted by the CDC show that most people in the United States have been exposed to some PFAS, which can accumulate in the body over time. Current scientific research suggests that exposure to high levels of certain PFAS may lead to adverse health outcomes (USEPA, 2021b). More than 3000 PFAS are on the global market for intentional uses in different consumer, commercial, and industrial products and the chemical identities of many are yet unknown (USEPA, 2021a, Wang et.al., 2017).
Customer Interaction Widespread public concerns? Media coverage?	PFAS has been gaining widespread attention due to its potentially harmful health effects. USEPA has implemented a comprehensive risk management and phase out plan under the Toxic Substances Control Act. (USEPA, 2022a)
Expected Outcomes What are the likely benefits of the investigation to SFPUC and its customers?	Information collected as part of this investigation will be valuable to understand occurrence, health concerns, and sources of PFAS in SFPUC drinking water. Two PFAS will soon be regulated under the Safe Drinking Water Act.
Occurrence Data in US and SFPUC What occurrence information is available? Have detections, if any, been confirmed by follow-up sampling and/or QA/QC review?	Reliable analytical methods are available for many types of flame retardants, including PBDEs (e.g. EPA Methods 527 and 1614), perfluorochemicals (EPA Method 537), TCEP, and TCPP. Occurrence information for SFPUC is available from monitoring performed as part of UCMR2, UCMR3, a 2006 AwwaRF study in previous CEC Report. In 2019 – 2021, SFPUC voluntarily monitored PFAS compounds listed currently in UCMR5 at multiple locations in groundwater wells, surface water and drinking water in SFRWS and SFWS. All results were non-detect, below 2 ng/L and 5 ng/L. Please see Table 2-2 in Monitoring Review for detailed information.
Supporting Information List key references.	California OEHHA, 2020. Fact sheet – Flame Retardants. https://www.p65warnings.ca.gov/fact-sheets/flame-retardants. Accessed on 1/7/22. SWRCB, 2021. Drinking Water Resources, Public Water System PFAS Information and Resources. https://www.waterboards.ca.gov/pfas/drinking_water.html. Accessed on 12/21/21.

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DIAGNOSTIC QUESTIONS TO SUPPORT CEC PRIORITIZATION

Instructions	The purpose of the Diagnostic Questions is to determine whether the CEC or CEC Group are significant to SFPUC drinking water and whether they merit further evaluation and/or action. All answers require explanation except those clearly not applicable. The Diagnostic Questions are divided into Health, Occurrence, and Treatment sections. The more questions are answered with a "Yes", the higher the probability that the CEC is a high priority or that a proactive approach should be taken.

HEALTH EFFECTS FROM SCIENTIFIC STUDIES

Question	Answer	Explanation and Comments
Is scientific knowledge on CEC health effects well developed?	**Yes**	Scientific studies have shown that exposure to some PFAS in the environment may be linked to harmful health effects in humans and animals, including endocrine and thyroid disruption, impacts to the immune system, reproductive toxicity, cancer, and adverse effects on fetal and child development and neurologic function (NIEHS, 2016). More than 3000 PFAS are on the global market for intentional uses in different consumer, commercial, and industrial products, and the chemical identities of many are yet unknown (USEPA, 2021a, Wang et.al., 2017).
Based on current scientific understanding, does the CEC pose potential health risk at the levels typically found in drinking water in the US?	**Possible**	There is enough evidence about the health effects of PFOA an PFOS in drinking water to support development of an MCL for these two PFAS. (USEPA, 2022) Evidence for health effects of other PFAS at drinking water levels is not conclusive.

Question	Answer	Explanation and Comments
Adverse health impacts observed in other drinking water systems? Are public health studies documenting human health impacts (disease or outbreaks) available?	Yes	Numerous health studies support the importance of regulating PFAS in drinking water. Current scientific research has shown links between oral exposure to studied PFAS chemicals and adverse health effects, including prenatal and postnatal development, cancer, liver effects, immune effects, and other effects (e.g., cholesterol changes). (USEPA, 2022b)
Existing regulations or guidelines outside of US (e.g., WHO, EU)?	Yes	Canada. The MAC in DW for PFOA is 200 ng/L, PFOS is 600 ng/L (Health Canada, 2018a, 2018b). A Screening Value in drinking water of 20 ng/L is established for PFNA (Health Canada, 2020). EU. Standards were introduced on 12 January 2021: a limit value of 100 ng/L for a sum of 20 individual PFAS, as well as a limit value of 500 ng/L for total PFAS concentration (EC, 2020; ECHA, 2021). Australia. The Australia Department of Health has established a health-based drinking water quality value of 70 ng/L, the sum of the concentrations of PFOS and PFHxS. Based on human health considerations, the concentration of PFOA in drinking water should not exceed 560 ng/L (ADWG, 2021).
Existing US health advisories or CA notification levels?	Yes	EPA will move as quickly as possible to issue updated health advisories for PFOA and PFOS in 2022 that reflect the newest science and input from the Science Advisory Board. (USEPA, 2022) States have initiated efforts to implement advisories and enforceable standards (Alfredo et.al. 2021): • New York currently establishing the lowest for PFOS at 10 ng/L. • Michigan's 2019 proposed levels became enforceable in August 2020 at 8 ng/L for PFOA and 16 ng/L PFOS. • California has NLs of 5.1 ng/L and 6.5 ng/L for PFOS and PFOA, respectively. • Illinois passed HA levels for four PFAS to include PFOA at 2 ng/L. Illinois did not include PFOS in these HA guidance levels.

Question	Answer	Explanation and Comments
Likely US regulation in the next 10 years? **Is CEC on a regulatory development list, such as CCL?** **Is there a pending regulation or PHG in California?**	**Yes**	EPA is developing a proposed PFAS National Primary Drinking Water Regulation for publication in Fall 2022. The Agency anticipates issuing a final regulation in Fall 2023 after considering public comments on the proposal. (USEPA, 2022)
SUMMARY – SIGNIFICANT TO PUBLIC HEALTH IN GENERAL? **(Based on above answers)**	**Yes**	Exposure to PFAS is associated with known health effects (though drinking water is not a principal exposure route). Health-based concentration guidelines for drinking water are available for some PFAS.
OCCURRENCE		
Is scientific knowledge on CEC sources/formation well developed?	**Yes**	In the United States, PFAS have been detected in the ng/L range or lower in surface waters including lakes, and rivers. PFAS have also been detected in ground waters in the ng/L range or lower (Dickenson et.al., 2016). WHO documents PFAS contamination of drinking water of 21 municipalities in the Veneto region of Italy. Industrial activity in the area has polluted both surface waters and ground water, as well as the drinking water of approximately 127,000 citizens. Monitoring conducted of the Veneto Region found PFOS in 63-100 % of the locations sampled and PFOA in 100 % of the sites (EEA, 2019, WHO, 2017).
CEC presence reported in other water supplies? Are occurrence studies available?	**Yes**	In a 2011 survey of brominated and chlorinated flame retardants in German rivers, TECP, TCPP and TDCPP were the only flame retardant detected (Sacher, 2011). Occurrence of PFAS in drinking water system in US are published by USEPA in its UCMR3 data set. Please see Technical Review section for the data published by USEPA.

Question	Answer	Explanation and Comments
CEC present in SFPUC watersheds and/or source waters? Are there complex issues involved in managing the CEC (e.g., point vs. non-point sources)?	No	Most recent comprehensive PFAS monitoring conducted in 2019 – 2021 in raw (surface and groundwater) and drinking water. All results were non-detect. Please see the detailed Table 2-2 in SFPUC Monitoring Review. The Tiltill Fire in the HH Watershed (July 2021) that burned 2,300 acres had no known WQ impacts. SFPUC coordination exists between HHWP and Cal Fire regarding the use of fire retardants in the watersheds. Santa Clara Unit Complex Fire (Aug– Sept 2020) post-fire monitoring was conducted for the Calaveras and San Antonio watersheds with no significant contaminants detected.
Is the CEC a potential groundwater contaminant?	Yes	In general, flame retardants can occur in groundwaters impacted by wastewater or industrial use/spills of flame retardants. For example, TCEP occurred in 12% of groundwaters (n = 25) in a survey of untreated US drinking water sources (Focazio et al., 2008). The EWG has identified and mapped 206 military sites in the U.S. where drinking water or groundwater is contaminated with PFAS, at levels that exceed the USEPA's health guideline. PFAS contamination on military installations is widespread because for nearly 50 years, the DOD has used firefighting foam that contains PFAS chemicals (EWG, 2019).
If the CEC is a potential groundwater contaminant, is it highly mobile in the subsurface? **Is the CEC low-sorbing and resistant to microbial degradation?**	Yes	PFAS are mobile and can be transported through rainwater run-off and enter surface water or seep through the soil and migrate into large groundwater aquifers (USEPA, 2021g). Mobility depends on the compound. Some flame retardants are not likely to be mobile because they are highly sorbing in soils (e.g. PBDEs: USEPA, 2010), whereas others (e.g. PFOS, PFOA, TCEP) are highly mobile in groundwater (USEPA, 2014; Sacher, 2011).
Precursor present in SFPUC source waters? **(Including surface waters and groundwaters)**	No	PFAS were not detected in SFPUC's source water, groundwaters or drinking water in SFRWS and SFWS (MDL 2 or 5 ng/L).

Question	Answer	Explanation and Comments
Formed or added during current SFPUC treatment? **If so, describe whether the formation or addition of CEC can be controlled.**	No	PFAS are not formed or added during treatment. One exception may be bromochloromethane, because in addition to being a flame retardant, bromochloromethane is a disinfection byproduct. However, it has not been detected in annual treatment plant effluent sampling since 1999 (< 0.5 ug/L).
Formed or added within SFPUC storage or distribution? **If so, describe whether the formation or addition of CEC can be controlled.**	No	PFAS are not formed or added during storage or distribution.
Detected in SFPUC drinking water?	No	PFAS have not been detected in SFPUC drinking water. Monitoring was conducted by SFPUC, most recently in 2019 – 2021 at 2 or 5 ng/L detection limits.
SUMMARY – OCCURRENCE IN SOURCE OR DRINKING WATER? (OR SIGNIFICANT POTENTIAL TO OCCUR) (Based on above answers)	No	Based on available monitoring data for SFPUC and the fact that SFPUC watersheds and source waters are not impacted by wastewater discharges, industrial pollution, or urban runoff, flame retardants (Types 1 and 2) do not occur and are not expected to occur in source water or drinking water. Groundwater monitoring in 2019-2021 has not detected PFAS.

TREATMENT		
Question	**Answer**	**Explanation and Comments**
Is scientific knowledge on CEC treatment/removal well developed?	**No**	Some processes, such as anion exchange (AIX), GAC, NF, and RO have been evaluated at the bench scale and showed promise in the removal of some of these chemicals. (WRF, Dickenson et.al., 2016). As part of its rulemaking for the MCL for PFOA and PFOS, EPA is evaluating different treatment technologies that can reduce PFAS. (USEPA, 2022b)
Likely to pass through current treatment for Hetch Hetchy Supply? Describe any complex issues involved with the treatment of CEC.	**No**	PFAS are poorly or only somewhat removed during drinking water treatment. Therefore, if present, they are likely to pass through current SFPUC treatment. Most recent comprehensive monitoring in SFPUC surface, groundwater and drinking water indicated PFAS were not present. All results were non-detect.
Likely to pass through current treatment at SVWTP? Describe any complex issues involved with the treatment of CEC.	**No**	PFAS are poorly or only somewhat removed during drinking water treatment. Therefore, if present, they are likely to pass through current SFPUC treatment. Most recent comprehensive monitoring in SFPUC surface, groundwater and drinking water indicated PFAS were not present. All results were non-detect.
Likely to pass through current treatment at HTWTP? Describe any complex issues involved with the treatment of CEC.	**No**	PFAS are poorly or only somewhat removed during drinking water treatment. Therefore, if present, they are likely to pass through current SFPUC treatment. Most recent comprehensive monitoring in SFPUC surface, groundwater and drinking water indicated PFAS were not present. All results were non-detect.

Question	Answer	Explanation and Comments
Likely to pass through current treatment for groundwater? Describe any complex issues involved with the treatment of CEC.	**No**	PFAS are poorly or only somewhat removed during drinking water treatment. Therefore, if present, they are likely to pass through current SFPUC treatment. Most recent comprehensive monitoring in SFPUC surface, groundwater and drinking water indicated PFAS were not present. All results were non-detect.
SUMMARY – LIKELY TO PASS (NOT REMOVED BY) CURRENT TREATMENT? *(Based on above answers)*	**No**	PFAS are poorly or only somewhat removed during drinking water treatment. Therefore, if present, they are likely to pass through current SFPUC treatment.

CEC PRIORITIZATION – CURRENT ASSESSMENT	
Instructions	This section prioritizes the CEC based upon the information developed in the above Diagnostic Questions as well as in the background information. For top priorities (high and medium priorities), monitoring and/or mitigation measures should be developed if feasible and justified. For low priorities, the CEC will not warrant action items beyond continued source protection and tracking of new information.
Could CEC occur in SFPUC drinking water at levels of possible health significance? *(Based on above Diagnostic Questions)*	**No.** PFAS do not occur and are not expected to occur in SFPUC source waters or drinking water, based on available monitoring data and the fact that SFPUC watersheds and source waters are not impacted by significant wastewater and industrial discharges or urban runoff.

CEC Prioritization for SFPUC High, Medium, or Low. Provide explanation. *(A high number of "Yes" answers to the Diagnostic Questions indicates a higher priority, and "No" or very few "Yes" answers indicates a lower priority.)*	**MEDIUM PRIORITY FOR SFPUC** PFAS contaminants are considered medium priority. PFOA and PFOS are undergoing rulemaking under the Safe Drinking Water Act, with final rules expected to be promulgated in 2023.
Implemented Actions Indicate the progress and results of any action items, above, such as implemented in previous cycles of CEC review. Evaluate whether changes to the action plan are required.	• Maintained source water protection. • In 2019 – 2021, SFPUC voluntarily conducted comprehensive follow-up monitoring to initial 2012 and 2013 monitoring of PFAS in raw (surface and groundwater) and drinking water at lower detection limits. All results were below the detection limit. • During the Rim Fire in August 2013, chemical data on plane-applied flame retardants were reviewed and exclusion zones around reservoirs were delineated and this information was communicated to all pertinent parties. WQD ensured that PFAS were not applied in the watershed. • Coordination exists between HHWP and Cal Fire regarding the use of fire retardants in the watersheds. • The Tiltill Fire in the HH Watershed (July 2021) that burned 2,300 acres had no known WQ impacts.
Recommended Actions Does the situation merit investing additional resources or is the information gathered so far sufficient to have fulfilled due diligence? Actions could include monitoring and other measures (specified by source water, if necessary).	• Maintain source water protection. • For forest fires retardants, monitor types of retardants in use and application areas. If fire retardants known to contain PFAS are applied in watersheds, consider conducting post-fire water quality monitoring. • Conduct UCMR5 monitoring for PFAS for surface and drinking water. • Conduct repeat groundwater monitoring in 6 years. • Track federal and state regulatory developments. • Track pertinent information and peer-reviewed publications.

This evaluation was prepared based on available information (peer-reviewed literature and occurrence data) with the purpose of prioritizing work and informing the public on unregulated CECs. This evaluation will be updated every 6 years or when significant new research or occurrence data on CECs become available that may warrant changing priority and recommendations.

Water Quality Division, SFPUC Monitoring 2016 – 2021

Contaminants of Emerging Concern (CEC) in Drinking Water

PFAS – Per- and Polyfluoroalkyl Substances

Although PFAS is an area of focus for federal and state regulators, these CEC groups are unlikely to present in SFPUC's protected watersheds and source waters, which are not impacted by significant wastewater and industrial discharges or urban runoff. This priority will change, however because of likely regulation in the near future.

CCL3 and CCL4 parameters included: Halon 1011, PFOS, and PFOA. Therefore, it has been tested annually at all source waters, Alameda East, SVWTP effluent, and HTWTP effluent since 1999. All measurements have been **non-detect** (<0.5 ug/L).

Type 1 – Fire retardant materials/coatings

The five flame retardants tested under UCMR2 (BDE-47, BDE-99, HBB, BDE-153, BDE-100) were all **non- detect**, with detection limits of 0.3 ug/L, 0.9 ug/L, 0.7 ug/L, 0.8 ug/L, and 0.5 ug/L, respectively. The UCMR2 testing involved quarterly monitoring from March 2008 to December 2008 at Harry Tracy Water Treatment Plant (HTWTP) effluent, Irvington Portal, and Mocho Shaft.

Two flame retardants, TCEP and TCPP, were investigated under the 2006 AwwaRF study (Snyder et al., 2008) onendocrine disrupting compounds (EDCs) and pharmaceuticals, which included SFPUC waters as part of a nationalsurvey. This involved one-time sampling at the following location IDs: HTWTP_RAW, HTWTP_EFF_POST, andSA#2_SAN_PEDRO. Both contaminants were **non-detect** (<50 ng/L).

TCEP was also **non-detect** in a one-time SFPUC sampling for select CECs in June/July 2012 of raw surface waterreservoirs (Hetch Hetchy, San Antonio, Calaveras, and San Andreas), treated water from each treatment facility (Alameda East Portal, Sunol Valley Water Treatment Plant (SVWTP), and HTWTP), and raw groundwater from two test wells.

Type 2 – Fire extinguishers

CCL3 and CCL4 parameters included: Halon 1011, PFOS, and PFOA. There are 358 LIMS records for Halon1011 (bromochloromethane). Bromochloromethane, though unregulated, is part of the VOC test method (EPA Method 524). Therefore, it has been tested annually at all source waters, Alameda East, SVWTP effluent, and HTWTP effluent since 1999. All measurements have been **non-detect** (<0.5 ug/L).

Bromochloromethane was tested under UCMR3 with detection limits of 60 ng/L. Testing involved quarterly monitoring in 2013 at the following location IDs: CS#2_BADEN and SA#2_BADEN. All samples were non-detect.

In June/July 2012, SFPUC sampled for CECs (including unregulated flame retardants) in source waters, finished waters, and two groundwater wells. Fire retardants were not detected.

For Type 1 and 2 retardants, watersheds and source waters are not impacted by wastewater discharges, industrial pollution, or urban runoff, and thereforeno occurrence of these compounds is expected. Occurrence information for SFPUC is available from monitoring performed as part of UCMR2, UCMR3 and the 2006 AwwaRF study; flame retardants were not detected.

SFPUC conducted PFAS monitoring as part of special SFPUC CEC Monitoring (2012) and under UCMR3 (2013). PFOS, PFOA, and other perfluorochemicals were evaluated in the one-time SFPUC sampling for select CECs in June/July 2012 described above for Type 1 and were **non-detect**. In addition, PFOS and PFOA were monitored quarterly in 2013 under UCMR3, as described for bromochloromethane. All samples were non-detect. Detection limits were 0.04 µg/L for PFOS and 0.02 µg/L for PFOA.

In 2013, SFPUC conducted UCMR3 quarterly monitoring at CS#2 Baden, SA#2 Baden for the following industrial chemicals: perfluorooctanesulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorononanoic acid (PFNA), perfluorohexanesulfonic acid (PFHxS), perfluoroheptanoic acid (PFHpA). **All data were non-detect**.

In 2012/2013, the detection levels for PFOA and PFOS were 14 ppt and 13 ppt, respectively. Therefore, another round of monitoring at lower detection levels, EPA Method 537 with DL of 2 ppt, was recommended to demonstrate that PFOA and PFOS are below CA NLs (SFPUC, 2019).

In 2019 – 2021, SFPUC voluntarily monitored the raw (surface and groundwater) and treated water for the presence of PFAS compounds listed currently in UCMR5. All results were non-detect. The results are attached in Table 2-2 (at the end of this document), which shows comprehensive scope of SFPUC monitoring for these CECs. Eighteen (18) PFAS listed in Table 2-2 were monitored using USEPA SM 537.1, whereas 24 PFAS listed were monitored using USEPA SM 533.

Given limited water supplies in California, reclaimed water use will continue to increase. Currently, a reclaimed water facility is under construction at SFPUC's Oceanside Water Pollution Control Plant (OSP), which will be used for irrigation purposes and possibly to recharge groundwater in the future like Orange County in the Los Angeles area. Since there is a risk that reclaimed water contains PFAS, it is prudent to begin planning for monitoring of PFAS in groundwater.

Table 2-2. Results of SFPUC for Monitoring PFAS – USEPA 537.1 (last updated 2/17/2022)(1)

Sample Type		SFPUC System	Location	Date	PFOS	PFOA	PFDA	PFDOA	PFHpA	PFHxS	PFHXA	PFNA	9CL-PF3ONS	PFUnA	ADONA
					Perfluoro octanesulfonic acid	Perfluoro octanoic acid	Perfluoro decanoic acid	Perfluoro dodecanoic acid	Perfluoro heptanoic acid	Perfluoro hexanesulfonic acid	Perfluoro hexanoic acid	Perfluoro nonanoic acid	9-Chloro hexadecafluoro-3-oxanone-1-sulfonic acid	Perfluoro undecanoic acid	4,8-Dioxa-3H-perfluorononanoic acid
Raw	Groundwater	SFWS	SFGW-LMW	10/2/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SFGW-GCW	8/13/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SFGW-SSW	10/2/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SFGW-WSW	10/2/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SFGW-NLW	9/15/20	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SFGW-SWW	9/15/20	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SF Zoo Well	10/2/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
		SFRWS	GSR-BSW	6/24/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			GSR-CBW	9/16/20	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			GSR-FSW	9/16/20	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			GSR-HBW	9/17/20	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			GSR-MSW	1/6/22	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			GSR-MYW	9/17/20	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			GSR-PDW	9/16/20	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
		PWF	PWF-Well A	10/30/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			PWF-Well B	10/1/19	<2	<2	<2	<2	<2	**2.8 | 2.9**	<2	<2	<2	<2	<2
				10/30/19	<2	<2	<2	<2	<2	**2.7 | 2.9**	<2	<2	<2	<2	<2
	Surface Water	SFRWS	TTF (raw)	10/9/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			Calaveras Reservoir	11/4/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			Pond F2	10/17/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			Pond F3E	2/19/20	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			San Antonio Reservoir	9/24/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			Crystal Springs Reservoir*	*10/16/19*	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**
				12/19/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			Pilarcitos Reservoir*	*10/16/19*	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**
				12/19/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			San Andreas Reservoir*	*10/16/19*	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**	*<2**
				12/19/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Treated	Point of Entry	SFRWS	Alameda East	10/1/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SVWTP	12/10/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			HTWTP	10/1/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
		SFWS	CS#2_BADEN	10/1/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2

Sample Type		**SFPUC System**	**Location**		**Date**	**PFOS**	**PFOA**	**PFDA**	**PFDOA**	**PFHpA**	**PFHxS**	**PFHXA**	**PFNA**	**9CL-PF3ONS**	**PFUnA**	**ADONA**
						Perfluoro octanesulfonic acid	**Perfluoro octanoic acid**	**Perfluoro decanoic acid**	**Perfluoro dodecanoic acid**	**Perfluoro heptanoic acid**	**Perfluoro hexanesulfonic acid**	**Perfluoro hexanoic acid**	**Perfluoro nonanoic acid**	**9-Chloro hexadecafluoro-3-oxanone-1-sulfonic acid**	**Perfluoro undecanoic acid**	**4,8-Dioxa-3H-perfluorononanoic acid**
			SA#2_BADEN		10/1/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SA#2_BADEN		10/1/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SSL_BADEN		10/1/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Treated	Distribution	SFWS	CHS#03	Valencia & Cesar Chavez)	10/8/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			HPS	(Reuel & Hudson)	10/8/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			LS(3)	(1340 Powell)	10/9/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	**2.7** | <2
					12/19/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2 | <2
			MMS#2	(1348 45th Ave)	10/8/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SHS#1	(2155 18th Ave)	10/8/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SS#05	(461 6th Ave)	10/8/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SUMS	(Agua & Teresita)	10/8/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SUTS#6	(2150 California)	10/9/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			UMS#04	(Lombard & Mason/Powell)	10/9/19	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2

Sample Type		**SFPUC System**	**Location**	**Date**	**11CL-PF3OUDS**	**PFBS**	**HFPO-DA**	**NEtFOSAA**	**NMeFOSAA**	**PFTrDA**	**PFTA**
					11-Chloroeicosa fluoro-3 oxaundecane-1-sulfonic acid	**Perfluorobuta nesulfonic acid**	**Hexafluoropropyl ene oxide dimer acid**	**N-ethyl perfluorooctanes ulfonamidoacetic acid**	**N-methyl perfluorooctanes ulfonamidoacetic acid**	**Perfluorotetra decanoic acid**	**Perfluorotetra decanoic acid**
Raw	Groundwater	SFWS	SFGW-LMW	10/2/19	<2	<2	<5	<2	<2	<2	<2
			SFGW-GCW	8/13/19	<2	<2	<5	<2	<2	<2	<2
			SFGW-SSW	10/2/19	<2	<2	<5	<2	<2	<2	<2
			SFGW-WSW	10/2/19	<2	<2	<5	<2	<2	<2	<2
			SFGW-NLW	9/15/20	<2	<2	<5	<2	<2	<2	<2
			SFGW-SWW	9/15/20	<2	<2	<5	<2	<2	<2	<2
			SF Zoo Well	10/2/19	<2	<2	<5	<2	<2	<2	<2
		SFRWS	GSR-BSW	6/24/21	<2	<2	<2**	<2	<2	<2	<2
			GSR-CBW	9/16/20	<2	<2	<5	<2	<2	<2	<2
			GSR-FSW	9/16/20	<2	<2	<5	<2	<2	<2	<2
			GSR-HBW	9/17/20	<2	<2	<5	<2	<2	<2	<2
			GSR-MSW	1/6/22	<2	<2	<2**	<2	<2	<2	<2
			GSR-MYW	9/17/20	<2	<2	<5	<2	<2	<2	<2
			GSR-PDW	9/16/20	<2	<2	<5	<2	<2	<2	<2
		PWF	PWF-Well A	10/30/19	<2	<2	<2**	<2	<2	<2	<2
			PWF-Well B	10/1/19	<2	<2	<5	<2	<2	<2	<2
				10/30/19	<2	<2	<5	<2	<2	<2	<2
	Surface Water	SFRWS	TTF (raw)	10/9/19	<2	<2	<5	<2	<2	<2	<2
			Calaveras Reservoir	11/4/19	<2	<2	<5	<2	<2	<2	<2
			Pond F2	10/17/19	<2	<2	<5	<2	<2	<2	<2
			Pond F3E	2/19/20	<2	<2	<5	<2	<2	<2	<2
			San Antonio Reservoir	9/24/19	<2	<2	<5	<2	<2	<2	<2
			Crystal Springs Reservoir*	*10/16/19*	<2*	<2*	<5*	<2*	<2*	<2*	<2*
				12/19/19	<2	<2	<5	<2	<2	<2	<2
			Pilarcitos Reservoir*	*10/16/19*	<2*	<2*	<5*	<2*	<2*	<2*	<2*
				12/19/19	<2	<2	<5	<2	<2	<2	<2
			San Andreas Reservoir*	*10/16/19*	<2*	<2*	<5*	<2*	<2*	<2*	<2*
				12/19/19	<2	<2	<5	<2	<2	<2	<2

Sample Type		SFPUC System	Location		Date	11CL-PF3OUDS	PFBS	HFPO-DA	NEtFOSAA	NMeFOSAA	PFTrDA	PFTA
						11-Chloroeicosa fluoro-3 oxaundecane-1-sulfonic acid	Perfluorobuta nesulfonic acid	Hexafluoropropyl ene oxide dimer acid	N-ethyl perfluorooctanes ulfonamidoacetic acid	N-methyl perfluorooctanes ulfonamidoacetic acid	Perfluorotetra decanoic acid	Perfluorotetra decanoic acid
Treated	Point of Entry	SFRWS	Alameda East		10/1/19	<2	<2	<5	<2	<2	<2	<2
			SVWTP		12/10/19	<2	<2	<5	<2	<2	<2	<2
			HTWTP		10/1/19	<2	<2	<5	<2	<2	<2	<2
		SFWS	CS#2_BADEN		10/1/19	<2	<2	<5	<2	<2	<2	<2
			SA#2_BADEN		10/1/19	<2	<2	<5	<2	<2	<2	<2
			SA#2_BADEN		10/1/19	<2	<2	<5	<2	<2	<2	<2
			SSL_BADEN		10/1/19	<2	<2	<5	<2	<2	<2	<2
Treated	Distribution	SFWS	CHS#03	Valencia & Cesar Chavez)	10/8/19	<2	<2	<5	<2	<2	<2	<2
			HPS	(Reuel & Hudson)	10/8/19	<2	<2	<5	<2	<2	<2	<2
			LS(3)	(1340 Powell)	10/9/19	<2	<2	<5	<2	<2	<2	<2
					12/19/19	<2	<2	<5	<2	<2	<2	<2
			MMS#2	(1348 45th Ave)	10/8/19	<2	<2	<5	<2	<2	<2	<2
			SHS#1	(2155 18th Ave)	10/8/19	<2	<2	<5	<2	<2	<2	<2
			SS#05	(461 6th Ave)	10/8/19	<2	<2	<5	<2	<2	<2	<2
			SUMS	(Agua & Teresita)	10/8/19	<2	<2	<5	<2	<2	<2	<2
			SUTS#6	(2150 California)	10/9/19	<2	<2	<5	<2	<2	<2	<2
			UMS#04	(Lombard & Mason/Powell)	10/9/19	<2	<2	<5	<2	<2	<2	<2
									These four analytes are unique to USEPA 537.1			

Notes:

** Samples from 10/16/19 for San Andreas, Crystal Springs, and Pilarcitos Reservoirs were analyzed using EPA Method 537.1. However, the corresponding 10/16/19 blanks for QA/QC were incorrectly analyzed using EPA Method 537. Therefore, QA/QC results are incomplete. Precautionary resamples were collected on 12/19/19.*

*** SFPUC's contract laboratory Eurofins confirmed that it could achieve a lower method report limit at 2 ng/L than the prior 5 ng/L since October 2020.*

(1) Sample analysis using EPA Method 537.1. All results are in nanograms per liter (ng/L). Samples collected in 2019 were in accordance with SWRCB's April 2019 PFAS sampling guidance. Samples collected in 2020-2021 were based on the revised SWRCB's sampling guidance dated May 2020. SWRCB recommends collecting a duplicate sample for every field sample, which was followed during all PFAS sample collection. PFAS compounds with two values show the individual sample results that are different.

(2) PFHxS was detected during the 10/1/19 sampling. However, the sample tap at PWF Well B was not sufficiently flushed (approx. 1-min only) due to the water levels in Castlewood Reservoir and the head tank. In addition, Teflon tape was present on the sample tap. A confirmation sample was collected on 10/30/19 and the sample tap was flushed for a minimum of 15 minutes. It appears that flushing duration has negligible impacts on detection above the method reporting limit.

(3) ADONA was detected during the 10/9/19 sampling. However, the corresponding duplicate sample did not detect ADONA. Note that Teflon tape was present on the sample tap at this location. A confirmation sample was collected on 12/19/19 and the sample (along with the duplicate) was non-detect for all PFAS.

Abbreviations

BSW	B Street Well (formerly Serra Bowl)
CBW	Colma Boulevard Well
CHS	College Hill Reservoir System
CS#2	Crystal Springs #2 Pipeline
FSW	F Street Well (formerly Colma BART)
GCW	Golden Gate Park Central Well
HPS	Hunters Point System
HBW	Hickey Boulevard Well
HTWTP	Harry Tracy Water Treatment Plant
LMW	Lake Merced Well
LS	Lombard Reservoir System
MMS	Merced Manor Reservoir System
MSW	Mission Well
MYW	Millbrae Yard Well
NA	not available (pending lab analysis/release)
NLW	North Lake Well
PDW	Poncetta Drive Well (formerly Lake Merced GC)
PFAS	per- and polyfluorinated alkyl substances
PWF	Pleasanton Well Field
SA#2	San Andreas #2 Pipeline
SA#3	San Andreas #3 Pipeline
SBW	Serramonte Boulevard Well
SFGW	San Francisco Groundwater Project
SFRWS	San Francisco Regional Water System
SFWS	San Francisco Water System
SHS	Stanford Heights Reservoir System
SS	Sunset Reservoir System
SSL	Sunset Supply Pipeline
SSW	South Sunset Well
SWW	South Windmill Well
SUMS	Summit Reservoir System
SUTS	Sutro Reservoir System
SVWTP	Sunol Valley Water Treatment Plant
TTF	Tesla Treatment Facility
UMS	University Mound System
WSB	West Sunset Well

PFAS Results - USEPA 533 (last updated 2/17/22)(1)

Sample Type		SFPUC System	Location	Date	PFOS Perfluorooctanesulfonic acid	PFOA Perfluorooctanoic acid	PFDA Perfluorodecanoic acid	PFDOA Perfluorododecanoic acid	PFHpA Perfluoroheptanoic acid	PFHxS Perfluorohexanesulfonic acid	PFHXA Perfluorohexanoic acid	PFNA Perfluorononanoic acid	9CL-PF3ONS 9-Chlorohexadecafluoro-3-oxanone-1-sulfonic acid	PFUnA Perfluoroundecanoic acid	ADONA 4,8-Dioxa-3H-perfluorononanoic acid	11CL-PF3OUDS 11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid	PFBS Perfluorobutanesulfonic acid	HFPO-DA Hexafluoropropylene oxide dimer acid	4:2 FTS 4:2 Fluorotelomer sulfonic acid	6:2 FTS 6:2 Fluorotelomer sulfonic acid	8:2 FTS 1H,1H, 2H, 2H-Perfluorodecane sulfonic acid	NFDHA Nonafluoro-3,6-dioxaheptanoic acid	PFBA Perfluorobutanoic acid	PFEESA Perfluoro (2-ethoxyethane) sulfonic acid	PFHpS Perfluoroheptane sulfonic acid	PFMPA Perfluoro-3-methoxypropanoic acid	PFMBA Perfluoro-4-methoxybutanoic acid	PFPeA Perfluoropentanoic acid	PFPeS Perfluoropentane sulfonic acid
Raw	Ground-water	SFWS	SFGW-LMW	6/8/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SFGW-GCW	6/8/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SFGW-SSW	6/8/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SFGW-WSW	6/8/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SFGW-NLW	6/8/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SFGW-SWW	6/8/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SF Zoo Well	6/8/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
		SFRWS	GSR-BSW	6/3/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			GSR-CBW	6/3/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			GSR-FSW	6/3/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			GSR-HBW	6/2/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			GSR-MSW	1/6/22	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			GSR-MYW	6/2/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			GSR-PDW	6/3/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			GSR-SBW	9/2/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
		PWF	PWF - Well A(2)	--																									
			PWF - Well B(3)	5/11/21	<2	<2	<2	<2	<2	**2.9 | 2.8**	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Surface Water	SFRWS	TTF (raw)	5/11/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			Calaveras Reservoir	5/10/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			Pond F2	5/10/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			Pond F3E	4/15/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			San Antonio Reservoir	5/6/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			Crystal Springs Reservoir	5/13/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			Pilarcitos Reservoir	5/13/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			San Andreas Reservoir	5/12/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Treated	Point of Entry	SFRWS	Alameda East	5/6/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SVWTP	5/6/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			HTWTP	5/12/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
		SFWS	CS#2_BADEN	5/12/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SA#2_BADEN	5/12/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SA#2_BADEN	5/12/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SSL_BADEN	5/12/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
		PWF	Castlewood Reservoir	5/11/21	<2	<2	<2	<2	<2	**3.2 | 3.3**	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Distribution	SFWS	CHS#03 (Valencia & Cesar Chavez)	5/5/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			HPS (Reuel & Hudson)	5/5/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			LS (1340 Powell)	5/4/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			MMS#2 (1348 45th Ave)	5/5/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SHS#1 (2155 18th Ave)	5/5/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SS#05 (461 6th Ave)	5/4/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SUMS (Agua & Teresita)	5/5/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			SUTS#6 (2150 California)	5/4/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
			UMS#04 (Lombard & Mason/Powell)	5/4/21	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
																			These 11 analytes are unique to USEPA 533 (i.e. not analyzed under USEPA 537.1)										

Notes:

(1) Sample analysis using EPA Method 533. All results are in nanograms per liter (ng/L). All samples were collected in accordance with SWRCB's revised May 2020 PFAS sampling guidance. SWRCB recommends collecting a duplicate sample, which was followed during all PFAS sample collection. PFAS compounds with two values show the individual sample results that are different.

(2) PWF Well A was out of service during the May 2021 PFAS monitoring due to pump failure. PFAS sampling will be conducted once the well returns to service.

(3) PFHxS was also detected during the 2019 PFAS (Round 1) monitoring event.

Abbreviations:

BSW	B Street Well (formerly Serra Bowl)
CBW	Colma Boulevard Well
CHS	College Hill Reservoir System
CS#2	Crystal Springs #2 Pipeline
FSW	F Street Well (formerly Colma BART)
GCW	Golden Gate Park Central Well
HPS	Hunters Point System
HBW	Hickey Boulevard Well
HTWTP	Harry Tracy Water Treatment Plant
LMW	Lake Merced Well
LS	Lombard Reservoir System
MMS	Merced Manor Reservoir System
MSW	Mission Well
MYW	Millbrae Yard Well
NA	not available (pending lab analysis/release)
NLW	North Lake Well
PDW	Poncetta Drive Well (formerly Lake Merced Golf Club)
PFAS	per- and polyfluorinated alkyl substances
PWF	Pleasanton Well Field
SA#2	San Andreas #2 Pipeline
SA#3	San Andreas #3 Pipeline
SBW	Serramonte Boulevard Well
SFGW	San Francisco Groundwater Project
SFRWS	San Francisco Regional Water System
SFWS	San Francisco Water System
SHS	Stanford Heights Reservoir System
SS	Sunset Reservoir System
SSL	Sunset Supply Pipeline
SSW	South Sunset Well
SWW	South Windmill Well
SUMS	Summit Reservoir System
SUTS	Sutro Reservoir System
SVWTP	Sunol Valley Water Treatment Plant
TTF	Tesla Treatment Facility
UMS	University Mound System
WSW	West Sunset Well

Water Quality Division, Technical Review 2016 – 2021

Contaminants of Emerging Concern (CEC) in Drinking Water

PFAS – Per- and Polyfluoroalkyl Substances

Per- and polyfluoroalkyl substances (PFAS), also commonly referred to as perfluorinated chemicals or PFCs, are a group of anthropogenic chemicals with past and current uses in industrial processes and consumer products. PFAS are man-made compounds that resist heat, oil, and water, which make them extremely useful for a wide variety of products, including non-stick coating, textiles, and firefighting foam. They are very stable in the environment, and once they make their way into water, they can be found in plants and animals used for human consumption (WRF, 2019).

PFAS are widely used, long lasting chemicals, components of which break down very slowly over time. Because of their widespread use and their persistence in the environment, many PFAS are found in the blood of people and animals all over the world and are present at low levels in a variety of food products and in the environment. PFAS are found in water, air, fish, and soil at locations across the nation and the globe. Scientific studies have shown that exposure to some PFAS in the environment may be linked to harmful health effects in humans and animals. More than 3000 PFAS are on the global market for intentional uses in different consumer, commercial, and industrial products and the chemical identities of many are yet unknown. Beyond unknown chemical identities, there is little to no information on the production and use history for most PFAS on the market; this scarcity of data is rather factitious, that is, information may have been generated in some cases, but has not been made publicly available. This makes it challenging to study and assess the potential human health and environmental risks (USEPA, 2021a; Wang et.al., 2017).

OCCURRENCE AND HEALTH EFFECTS REPORTED IN LITERATURE

PFAS have been detected in all types of waters throughout the world including surface, ground, tap and bottled waters, wastewater influents and effluents, industrial waste influents and effluents, and rivers, lakes, and tributaries with concentrations ranging from below detection limits to µg/L in some cases. The EPA also required monitoring of six PFAS under the Third

Unregulated Contaminant Monitoring Rule (UCMR3) to gain a better understanding of national occurrence in drinking water (WRF, 2019).

Surveys conducted by the Centers for Disease Control and Prevention (CDC) show that most people in the United States have been exposed to some PFAS. Most known exposures are relatively low, but some can be high, particularly when people are exposed to a concentrated source over long periods of time. Some PFAS chemicals can accumulate in the body over time (USEPA, 2021b).

Current research has shown that people can be exposed to PFAS by (USEPA, 2021b):

- Working in occupations such as firefighting or chemicals manufacturing and processing.
- Drinking water contaminated with PFAS.
- Eating certain foods that may contain PFAS, including fish.
- Swallowing contaminated soil or dust.
- Breathing air containing PFAS.
- Using products made with PFAS or that are packaged in materials containing PFAS.

Current scientific research suggests that exposure to high levels of certain PFAS may lead to adverse health outcomes. However, research is still ongoing to determine how different levels of exposure to different PFAS can lead to a variety of health effects (USEPA, 2021b):

- Reproductive effects such as decreased fertility or increased high blood pressure in pregnant women.
- Developmental effects or delays in children, including low birth weight, accelerated puberty, bone variations, or behavioral changes.
- Increased risk of some cancers, including prostate, kidney, and testicular cancers.
- Reduced ability of the body’s immune system to fight infections, including reduced vaccine response.
- Interference with the body’s natural hormones.

- Increased cholesterol levels and/or risk of obesity.

However, health effects associated with exposure to PFAS are difficult to specify for many reasons, such as (USEPA, 2021b):

- There are thousands of PFAS with potentially varying effects and toxicity levels, yet most studies focus on a limited number of better known PFAS compounds.
- People can be exposed to PFAS in different ways and at different stages of their life.
- The types and uses of PFAS change over time, which makes it challenging to track and assess how exposure to these chemicals occurs and how they will affect human health.

Occurrence in Water

PFAS have been found in all types of waters throughout the world including surface, ground, tap and bottled waters, wastewater influents and effluents, industrial waste influents and effluents, and rivers, and lakes in the United States, Germany, Canada, South Korea, China, Brazil, United Kingdom, France, Italy, and Spain (WRF, Dickenson et.al., 2016).

In the United States, a number of PFAS have been detected in the ng/L range or lower in surface waters including lakes, and rivers. PFAS have also been detected in ground waters in the ng/L range or lower (WRF, Dickenson et.al, 2016).

The Environmental Working Group (EWG) has identified and mapped 206 military sites in the U.S. where drinking water or groundwater is contaminated with fluorinated chemicals, known as PFAS, at levels that exceed the USEPA’s health guideline. PFAS contamination on military installations is widespread because for nearly 50 years, the Department of Defense, or DOD, has used firefighting foam – so-called aqueous film-forming foam, or AFFF – that contains PFAS chemicals (EWG, 2019).

From 2013 to 2015, the USEPA, under the UCMR3, required all large water systems (i.e., water systems serving over 10,000 people) nationwide to collect and analyze more than 12,000 drinking water samples for PFOS and PFOA. In addition, some water systems serving less than 10,000 people reported approximately 400 drinking water results for PFOS and PFOA. This occurrence data identified 36 sources with PFOS detections and 32 sources with PFOA detections (SWRCB, 2021).

Table 2-3. Summary of UCMR3 Occurrence (AWWA, 2020)

PFAS	MRL (ng/L)	Number of Systems Sampling	Number of Systems with Results ≥ MRL	Percent of Systems ≥ MRL	Percent of Systems at Least One Sample above 1/2 HRL/HRL*
PFOA	20	4,920	117	2.40%	1.93% / 0.9%
PFOS	40	4,920	95	1.90%	1.07% / 0.3%
PFHpA	10	4,920	86	1.70%	-
PFHxS	30	4,920	55	1.10%	-
PFNA	20	4,920	14	<0.5%	-
PFBS	90	4,920	8	<0.5%	-

*Note: One-half the Health Advisory level for PFOA and PFOS (70 ng/L) is 35 ng/L.
Health Risk Limit (HRL) is a health-based concentration against which the Agency evaluates occurrence data when making decisions about preliminary regulatory determinations (USEPA, 2021h).

The European Environment Agency lists the main effects of PFAS on human health, which include thyroid disease, increased cholesterol levels, effects on reproduction and fertility, immunotoxicity, liver damage, kidney and testicular cancer. Immunotoxicity and endocrine effects have been reported for some PFAS. A recent opinion from the European Food Safety Agency (EFSA) concluded that both PFOS and PFOA are associated with reduced antibody response to vaccination. PFOS also causes a reduced resistance to infection. EFSA concluded that parts of the European population exceed the tolerable weekly intake from food of four PFAS. Reported effects of PFAS on aquatic and terrestrial animals include survival, growth, development and reproduction (European Commission, 2020).

US Regulations

Currently, there are no federal regulations limiting PFAS in water, but the USEPA is considering whether to establish Maximum Contaminant Levels for PFAS in drinking water (WRF, 2019).

A positive regulatory determination by the USEPA for a specified drinking water contaminant must meet three criteria: considerable contaminant toxicity, national contaminant occurrence, and present a meaningful opportunity for health risk reduction. This third criterion is subjective and comes at the sole judgment of the USEPA Administrator. Of the 37 contaminants that have received determinations by the USEPA since 2002, only PFOA and PFOS are currently scheduled for regulation. However, despite the rigidness of the process, there is no standard metric for assessing meaningful opportunities for health risk reduction (Alfredo et.al. 2021).

In the absence of a national regulation, states have initiated their own efforts to implement lower advisories and enforceable standards with New York currently establishing the lowest for PFOS at 10 ng/L. Michigan's 2019 proposed levels recently became enforceable in August 2020 at 8 ng/L for PFOA and 16 ng/L PFOS, pushing the established values for PFOA even lower. California had the lowest threshold concentrations of 5.1 ng/L and 6.5 ng/L for PFOS and PFOA, respectively, set as Notification Levels until recently when Illinois passed health advisory levels for four PFAS to include PFOA at 2 ng/L. Illinois did not include PFOS in these health advisory guidance levels (Alfredo et.al. 2021).

California OEHHA is also requesting information on PFOS and PFOA that could assist in conducting the risk assessments and in calculating the PHGs (California OEHHA, 2019).

Notification Levels (SWRCB, 2021)

- In May 2016, the USEPA issued a lifetime health advisory for PFOS and PFOA for drinking water, advising municipalities that they should notify their customers of the presence of levels over 70 parts per trillion (ng/L) in community water supplies. US EPA recommended that customer notifications include information on the increased risk to health, especially for susceptible populations.
- In July 2018, Division of Drinking Water (DDW) established an interim Notification Level of 14 ppt for PFOA and 13 ppt for PFOS and a single response level of 70 ppt for the combined concentrations of PFOA and PFOS.
- In August 2019, DDW revised the Notification Levels to 6.5 ppt for PFOS and 5.1 ppt for PFOA. These levels are consistent with OEHHA's recommendations. The single health advisory level (for the combined values of PFOS and PFOA) remained at 70 ppt.
- On February 6, 2020, DDW issued updated drinking water response levels of 10 ppt for PFOA and 40 ppt for PFOS based on a running four-quarter average.
- On March 5, 2021, DDW issued a drinking water Notification Level and response level for perfluorobutane sulfonic acid (PFBS)of 0.5 parts per billion (ppb) and 5 ppb, respectively.

PFAS was in the UCMR3 list which included: perfluorooctanesulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorononanoic acid (PFNA), perfluorohexanesulfonic acid (PFHxS), perfluoroheptanoic acid (PFHpA), perfluorobutanesulfonic acid (PFBS) (USEPA, 2020).

EPA has plans to supplement the UCMR3 dataset with additional data to be collected in the UCMR5. UCMR5 is expected to utilize an updated analytical method (EPA Method 537.1) with lower MRLs for the PFAS monitored in UCMR3. The frequency of detection of PFAS initially monitored in UCMR3 is expected to increase as the MRLs decrease. UCMR5 is expected to include sample analysis using a newer analytical method (EPA Method 533), collecting occurrence on an additional 11 individual PFAS incorporating an additional suite of PFAS. The absence of timely health risk assessments prevents EPA from preparing the necessary analyses to support additional regulatory determinations and drinking water standards at this time (AWWA, 2020).

The UCMR 5 was published on December 27, 2021. UCMR 5 requires sample collection for 30 chemical contaminants between 2023 and 2025 using analytical methods developed by EPA and consensus organizations. PFAS in UCMR5 includes 29 Per- and Polyfluoroalkyl Substances (USEPA, 2021d).

Table 2-4. Per- and Polyfluoroalkyl Substances Listed Under UCMR5 (USEPA, 2021d)

11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	9-chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9Cl-PF3ONS)
4,8-dioxa-3H-perfluorononanoic acid (ADONA)	hexafluoropropylene oxide dimer acid (HFPO DA)
nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	perfluorobutanoic acid (PFBA)
perfluorobutanesulfonic acid (PFBS)	1H,1H, 2H, 2H-perfluorodecane sulfonic acid (8:2FTS)
perfluorodecanoic acid (PFDA)	perfluorododecanoic acid (PFDoA)
perfluoro(2-ethoxyethane)sulfonic acid (PFEESA)	perfluoroheptanesulfonic acid (PFHpS)
perfluoroheptanoic acid (PFHpA)	1H,1H, 2H, 2H-perfluorohexane sulfonic acid (4:2FTS)
perfluorohexanesulfonic acid (PFHxS)	perfluorohexanoic acid (PFHxA)
perfluoro-3-methoxypropanoic acid (PFMPA)	perfluoro-4-methoxybutanoic acid (PFMBA)
perfluorononanoic acid (PFNA)	1H,1H, 2H, 2H-perfluorooctane sulfonic acid (6:2FTS)
perfluorooctanesulfonic acid (PFOS)	perfluorooctanoic acid (PFOA)
perfluoropentanoic acid (PFPeA)	perfluoropentanesulfonic acid (PFPeS)

perfluoroundecanoic acid (PFUnA)	N-ethyl perfluorooctanesulfonamidoacetic acid (NEtFOSAA)
N-methyl perfluorooctanesulfonamidoacetic acid (NMeFOSAA)	perfluorotetradecanoic acid (PFTA)
perfluorotridecanoic acid (PFTrDA)	

Sampled during 2019-2021, SFPUC monitoring, all results were non-detect (<2 ng/L, HFPO-DA <5 ng/L).

USEPA's Strategic Roadmap for PFAS

On October 18, 2021, EPA Administrator Michael S. Regan announced the agency's PFAS Strategic Roadmap—laying out a whole-of-agency approach to addressing PFAS. The roadmap sets timelines by which EPA plans to take specific actions and commits to bolder new policies to safeguard public health, protect the environment, and hold polluters accountable (USEPA, 2021c).

The Agency's approach is centered on the following (USEPA, 2021c):

- Consider the Lifecycle of PFAS: EPA will account for the full lifecycle of PFAS, their unique properties, the ubiquity of their uses, and the multiple pathways for exposure.
- Get Upstream of the Problem: EPA will bring deeper focus to preventing PFAS from entering the environment in the first place, a foundational step to reducing the exposure and potential risks of future PFAS contamination.
- Hold Polluters Accountable: EPA will seek to hold polluters and other responsible parties accountable for their actions and for PFAS remediation efforts.
- Ensure Science-Based Decision-Making: EPA will invest in scientific research to fill gaps in understanding of PFAS, to identify which additional PFAS may pose human health and ecological risks at which exposure levels, and to develop methods to test, measure, remove, and destroy them.
- Prioritize Protection of Disadvantaged Communities: When taking action on PFAS, EPA will ensure that disadvantaged communities have equitable access to solutions.

International Regulations

In Canada, PFOS, PFOA, and LC-PFCAs (and their salts and precursors) are prohibited through regulations; however, scientific evidence to date indicates the PFAS used to replace regulated PFOS, PFOA, and LC-PFCAs may also be associated with environmental and/or human health effects (Health Canada, 2021).

Canadian Regulations

The maximum acceptable concentration (MAC) for perfluorooctanoic acid (PFOA) in drinking water is 0.0002 mg/L (0.2 µg/L), based on exposure solely to PFOA (Health Canada, 2018a).

The maximum acceptable concentration (MAC) for perfluorooctane sulfonate (PFOS) in drinking water is 0.0006 mg/L (0.6 µg/L). The MAC is based on exposure solely to PFOS (Health Canada, 2018b).

A Drinking Water Screening Value of 20 ng/L (0.000020 mg/L) is established for PFNA (Health Canada, 2020).

Perfluorononanoic Acid (PFNA) belongs to a group of chemicals referred to as perfluoroalkyl substances. They have been used to make carpets, clothing, fabrics for furniture, paper packaging for food and other materials. They are also used for firefighting at airfields and in a number of industrial processes. Although PFNA is not manufactured in Canada, its past wide variety of uses, as well as its resistance to environmental degradation, has resulted in its detection in the environment, as well as in human blood samples. The major sources of exposure to PFNA are expected to be food and consumer products. However, drinking water can represent a significant source of exposure in the proximity of point sources such as fire-fighting facilities where repeated fire training exercises occur or where large amounts of aqueous film-forming foams are used to extinguish fires fueled by flammable or combustible liquids. Additional point sources may include facilities where perfluoroalkylated substances (PFAS) or PFAS precursors (e.g., fluorotelomer alcohols) are stored and handled.

The Government of Canada will (Health Canada, 2021):

- Continue to invest in research and monitoring on PFAS.
- Collect and examine information on PFAS to inform a class-based approach, and review policy developments in other jurisdictions.

In addition, within the next two years, the Government of Canada will publish a State of PFAS Report, which will summarize relevant information on the class of PFAS. In recent years, a growing number of jurisdictions, including in the United States, Australia, New Zealand, and the European Union, are addressing or are proposing to address PFAS as a class, including restricting specific uses in some jurisdictions. Often these actions relate to foams used to fight fuel fires, or to restricting non-essential uses where alternatives exist. The Stockholm Convention on Persistent Organic Pollutants (POPs) requires its 184 Parties to eliminate or severely restrict PFOS and PFOA and advises against the use of other PFAS in firefighting foams

(Health Canada, 2021). Therefore, these contaminants are now restricted under the EU POPs Regulation (European Commission, 2020).
PFAS water pollution has been identified in countries across Europe, including Austria, Denmark, France, Germany, the Netherlands and Sweden, as well as outside the EU (EEA, 2019).

A case study by the World Health Organization (WHO) documents the story of PFAS contamination of the drinking water of 21 municipalities in the Veneto region of Italy. Industrial activity in the area had polluted both surface waters and ground water, as well as the drinking water of approximately 127,000 citizens. Monitoring conducted by the authorities of the Veneto Region found PFOS in 63-100 % of the locations sampled and PFOA in 100 % of the sites (EEA, 2019, WHO, 2017).

The European Commission has initiated two studies regarding a possible REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) restriction covering all uses of PFAS in fire-fighting foams and textiles (including upholstery, apparels, carpets and leather). These are among the uses with the largest emissions to the environment. REACH is a tool to manage the risk from substances, such as PFAS, that are used in industrial processes but also in products. A restriction can ban the manufacture, placing on the market or use of a chemical substance, or a group of substances. It applies also to imported products and it is flexible, because it can include derogations, unlimited in time or time limited. A group of Member States and Norway have initiated preliminary work on a REACH restriction covering all uses of all PFAS. The restriction dossier could be ready in 2022, for a discussion in Scientific Committees of the European Chemicals Agency (ECHA) in 2022-2023 and a potential entry into force in 2025 (European Commission, 2020).

European and Australian Regulations

Per Directive 98/83/EC, standards for PFAS in drinking water were introduced. The new Directive (took effect on 12 January 2021) includes a limit value of 0.1 µg/L for a sum of 20 individual PFAS listed, as well as a limit value of 0.5 µg/L for total PFAS concentration (European Commission, 2020, ECHA, 2021).

The Australia Department of Health has established a health-based drinking water quality value of 70 nanograms per liter (ng/L), which is equivalent to 0.07 micrograms per liter (µg/L) (the sum of the concentrations of perfluorooctane sulfonate (PFOS) and perfluorohexane sulfonate (PFHxS)). Based on human health considerations, the concentration of perfluorooctanoic acid (PFOA) in drinking water should not exceed 560 ng/L, which is equivalent to 0.56 µg/L (Australian Drinking Water Guidelines, 2021).

Detection Methods

EPA researchers are developing and validating laboratory methods to detect and quantify selected PFAS in air, water, and soil. EPA recently released a revised version of EPA Method 537.1 for additional PFAS (e.g. Hexafluoropropylene oxide dimer acid (HFPO-DA), a GenX chemical) in drinking water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS) (USEPA, 2021c).

SM 537 for the determination of 14 PFAS in drinking water by SPE and LC/MS/MS (USEPA, 2021e).

SM 533 for the determination of PFAS in drinking water by Isotope Dilution Anion Exchange SPE and LC/MS/MS. This method is developed to support measurements of UCMR5 sampling effort and targets short chain PFAS (none greater than C_{12}), including perfluorinated acids, sulfonates, fluorotelomers, and poly/perfluorinated ether carboxylic acids. This method measures a total of 25 PFAS (USEPA, 2021e).

Currently, EPA researchers are working on (USEPA, 2021c):

- Validating methods under EPA’s SW-846 to measure certain PFAS in groundwater, surface water, wastewater, and solids (e.g., soils, sediments, and sewage). EPA recently posted a draft method to measure a group of 24 PFAS compounds in groundwater, surface water, and wastewater samples. Once final, it will be included in the SW846 Compendium.
- Developing and testing sampling and analytical methods for identifying and quantifying PFAS in air and stack emissions.
- Extending the use of non-targeted chemical analysis for air emissions and solids.

Tested and validated methods are important for ensuring that government and private laboratories can accurately and consistently measure PFAS in the environment, which is critical for estimating exposure and risk.

TREATMENT

Treatment Methods

Studies have assessed the occurrence of PFAAs (perfluoroalkyl acids) in raw and finished waters of conventional drinking water treatment trains consisting of coagulation/flocculation, filtration, ozonation, chlorination, and chloramination. These preliminary studies suggested these treatment systems were ineffective towards PFAA removal, but confirmation of these results has not been shown at other full-scale systems or for a wider spectrum of PFAS. To date, some processes, such as anion exchange (AIX), granular activated carbon (GAC), nanofiltration (NF), and reverse osmosis (RO) have been evaluated at the bench scale and showed promise in the removal of some of these chemicals. However, validation of performance of these processes at the full-scale has not been demonstrated (WRF, Dickenson et.al., 2016).

Granular Activated Carbon

The most researched and installed technology for perfluorinated compounds (PFC) removal is granular activated carbon (GAC). GAC has been shown to be effective at removing compounds such as PFOA and PFOS and at favorable loading capacities (McNamara et.al. 2018).

Activated carbon is commonly used to adsorb natural organic compounds, taste and odor compounds, and synthetic organic chemicals in drinking water treatment systems. Adsorption is both the physical and chemical process of accumulating a substance, such as PFAS, at the interface between liquid and solids phases. Activated carbon is an effective adsorbent because it is a highly porous material and provides a large surface area to which contaminants may adsorb. GAC is made from organic materials with high carbon contents such as wood, lignite, and coal. GAC works well on longer-chain PFAS like PFOA and PFOS, but shorter chain PFAS like Perfluorobutanesulfonic acid (PFBS) and Perfluorobutyrate (PFBA) do not adsorb as well (USEPA, 2018f, Zeng et.al., 2020).

A two-year study conducted at a full-scale drinking water treatment plant in the City of Uppsala, Sweden to determine the treatment efficiency for the removal of 15 PFAS. Removal of the five frequently detected PFAS was influenced by the total operation time of GAC filters, GAC type and surface loading rate. The average removal efficiency of PFAS ranged from 92 to 100% for “young” GAC filters and decreased to 7.0 - 100% for “old” GAC filters (up to 357 operation days, 29,300 bed volumes (BV) treated). This study confirmed that conventional treatment techniques are not efficient for PFAS removal in a full-scale WTP. However, GAC filters present a reliable treatment method for the removal of PFAS, which is straight forward to operate and can utilize the existing competitive GAC market to minimize operations costs. The removal efficiency for GAC filters evaluated in this study was higher for long chained PFAS than for short chained PFAS and PFSA were removed better than perfluoroalkyl carboxylic acids (PFCA) (Belkouteb et.al., 2020).

The bench-scale studies revealed that GAC can be effective at removing PFAAs under certain conditions. In 2007, GAC was employed in two public water systems located in Ohio and West Virginia for the treatment of PFOA from their potable water supply. With a dual filter design, careful monitoring for breakthrough, and frequent filter changes, these systems have proven highly effective at removing PFOA. Studies on the effects of potentially limiting factors for GAC performance with these chemicals, such as the presence of Natural Organic Matter (NOM), have not yet been fully explored (WRF, Dickenson et.al., 2016).

Anion Exchange

Anion exchange resins (AER) are made up of highly porous, polymeric material that is acid, base, and water insoluble. The tiny beads that make up the resin are made from hydrocarbons. Ion exchange resins are like tiny powerful magnets that attract and hold the contaminated materials from passing through the water system. Factors that influence AER performance include influent contaminant concentration, treatment design (e.g., flow rate, resin bead size and material), and competing ion concentrations, such as sulfate, nitrate, and bicarbonate. Although used less extensively than GAC, AER has been effective at removing long-chain PFAS. The research shows increased potential for short-chain PFAS removal (removal of PFBA is still not promising), and bench-scale testing is recommended to confirm performance on a given water source. AER has shown to have a high capacity for many PFAS; however, it is typically more expensive than GAC. Of the different types of AER resins, the most promising is an AER in a single use mode followed by incineration of the resin. One benefit of this treatment technology is that there is no need for resin regeneration so there is no contaminant waste stream to handle, treat, or dispose (USEPA, 2018f, CDM Smith, 2019).

Membranes

High-pressure membranes, such as nanofiltration or reverse osmosis, have been extremely effective at removing PFAS. Reverse osmosis membranes are tighter than nanofiltration membranes. This technology depends on membrane permeability. A standard difference between the two is that a nanofiltration membrane will reject hardness to a high degree, but pass sodium chloride; whereas reverse osmosis membrane will reject all salts to a high degree. This also allows nanofiltration to remove particles while retaining minerals that reverse osmosis would likely remove (USEPA, 2018f).

Research shows that these types of membranes are typically more than 90 percent effective at removing a wide range of PFAS, including shorter chain PFAS. With both high pressure membrane types, approximately 80 % of the feed water, the water coming into the membrane, passes through the membrane to the effluent (treated water). Approximately 20 percent of the feedwater is retained as a high-strength concentrated waste. A high-strength waste stream at 20 percent of the feed flow can be difficult to treat or dispose, especially for a contaminant such as PFAS. This technology is best suited as a point of use technology for a homeowner, since the volume of water being treated is much smaller and the waste stream could be disposed of more easily with less cause for concern (USEPA, 2018f).

Chemical Oxidation/Reduction

The PFAA are generally resistant to oxidation. AOPs, which utilize the hydroxyl radical, such as alkaline ozonation, peroxone, Fenton's reagent, and UV/hydrogen peroxide, have been shown ineffective towards PFOA and PFOS. However, other oxidation/reduction technologies, such as photocatalytic oxidation, photochemical oxidation, photochemical reduction, persulfate radical treatment, thermally induced reduction, and sonochemical pyrolysis, have been shown to be effective at degrading some PFAA in water. However, most of these technologies are not employed in current drinking water treatment practices (WRF, Dickenson et.al., 2016).

Outreach to the Community

The use of a community-specific adaptive risk communication strategy can allow municipalities to assess and mitigate PFAS while addressing community concerns (Harclerode et.al., 2021).

WRF has published considerable research on how utilities can improve their customer communication and stakeholder engagement. The recommendations from WRF research are based on the principles of CDC’s Crisis and Emergency Risk Communication (CERC): be first, be right, be credible, express empathy, promote action, and show respect (Henderson et.al., 2020).

Case Study of Sweeney Water Treatment Plant, Cape Fear Public Utility Authority, Wilmington, N.C. (Vandermeyden et.al. 2020)

The details of the study can be found in the article published by AWWA: Managing PFAS: A North Carolina Utility Story

The Cape Fear Public Utility Authority (CFPUA) provides water and wastewater services to more than 200,000 people in New Hanover County in southeast North Carolina. CFPUA’s largest water treatment plant is the 35-mgd Sweeney Water Treatment Plant (WTP), and its source water is the Cape Fear River. Despite the plant's many advanced treatment processes, none are effective at removing per- and polyfluoroalkyl substances (PFAS). Additional technologies, such as deep-bed granular activated carbon (GAC) contactors, ion exchange (IX), or low-pressure reverse osmosis (RO) would be required to manage PFAS levels that have been detected in the Cape Fear River. In 2014, CFPUA was approached by researchers who were studying the presence of newer PFAS, such as GenX, in the Cape Fear River. The results of this study, published in 2016, showed a mean concentration of GenX in raw water of 631 ng/L. The research also detected a number of "novel," previously unidentified PFAS at significantly higher concentrations. Treatment processes in place at the time at Sweeney WTP were not effective at reducing these concentrations in finished drinking water. The potential for risks to human health posed by GenX were largely unknown, and no regulatory guidance existed for GenX.

Following were the key takeaways from the study (Vandermeyden et.al. 2020):

- Comprehensive, year-round sampling of Cape Fear Public Utility Authority's raw water for per- and polyfluoroalkyl substances (PFAS) justified the need for PFAS treatment in conjunction with improved upstream point source control.
- Site-specific pilot testing of different PFAS treatment technologies should be conducted to help identify the most effective treatment solutions based on local conditions.
- Communication strategies should be based on transparency, willingness to engage customers, and consistent messages, along with public advocacy for vigilant, consistently applied regulation.

Halogenated Flame Retardants (Non-PFAS)

Flame retardants are added to products to slow the spread of a fire and provide additional escape time. Over time, concerns have increased about the potential negative effects of many flame retardants on human health and the environment. One of the major classes of flame retardants is halogenated chemicals, which incorporates chlorine or bromine as a building block (DESW, 2015). They help fire fighters on the ground to control and contain a fire and help protect properties. Fire retardants may also be dropped from aircraft during firefighting operations (NSW, 2019).

Fire retardants consist of detergent chemicals made from a combination of wetting agents and foaming chemicals, fertilisers (ammonium and diammonium sulfate and ammonium phosphate) mixed with thickeners (guar gum) and corrosion inhibitors (for aircraft safety). They are mixed with water to form a foam or slurry (NSW, 2019). Most fire retardants have the same active ingredient: phosphorous. Phosphorous is one of the building blocks of plant life, so it can be taken up by plants surviving the fire. The phosphorous that is not taken up by plants on the landscape may become mobile in the first few rainfall events and make its way to the nearest waterbody in runoff. While it is possible that this compound can contribute to eutrophication (SWRCB, 2020).

OCCURRENCE AND HEALTH EFFECTS

Type 1 - Fire retardant materials/coatings

These are chemicals that have been used to make fire retardant products, such as furniture, circuit boards, etc. The historic release of these chemicals is from manufacturing the chemicals (industrial sources) and from the products themselves. This type mainly included brominated and chlorinated flame retardants. There are hundreds of different flame retardants. They are often broken into categories based on chemical structure and properties. Brominated flame retardants and organophosphorus flame retardants are two types of commonly used flame retardants (NIEHS, 2016).

As of January 2020, California has banned the sale and distribution of new upholstered furniture, foam in mattresses, and certain children’s products made for residential use if these products contain more than 0.1% of certain chemicals used for flame retardant purposes, including antimony trioxide, chlorinated tris, TBBPA, and TCEP (Cal. OEEHA, 2020).
Five flame retardants were investigated under UCMR2, and belong to a class of brominated flame retardants knownas polybrominated diphenyl ethers (PBDEs):

- 2,2',4,4'-tetrabromodiphenyl ether (BDE-47)
- 2,2',4,4',5-pentabromodiphenyl ether (BDE-99)
- 2,2',4,4',5,5'-hexabromobiphenyl (HBB)
- 2,2',4,4',5,5'-hexabromodiphenyl ether (BDE-153)
- 2,2',4,4',6-pentabromodiphenyl ether (BDE-100)

A 2010 review (Shaw et al.) summarizes the 5 brominated flame retardants that have been used most extensively,and five types of chlorinated flame retardants in use in the U.S, as follows:

Brominated flame retardants:

- tetra-bromobisphenol A (TBBPA) – used in computer circuit boards and other electronics (NIEHS, 2016)
- hexabromocyclo-dodecane (HBCD) - is an additive primarily used in polystyrene foam building materials (NIEHS, 2016).

Three commercial mixtures of PBDEs: decabromodiphenyl ether (decaBDE), octabromo-diphenyl ether(octaBDE), and pentabromo-diphenyl ether (pentaBDE) [some of these listed on UCMR2]

Organophosphate flame retardants (OPFRs) (NIEHS, 2016):

With the phasing out of Polybrominated diphenyl ethers (PBDE's), some OPFRs have been identified as replacements. National Toxicology Program (NTP) is currently working on a program to compare and contrast the activity of these replacement halogenated and non-halogenated OPFRs with the phased-out PBDEs.

Chlorinated flame retardants:

- tris(1,3-dichloro-2-propyl) phosphate (TDCPP) – also called TDCP or chlorinated Tris
- tris(2-chloroethyl) phosphate (TCEP)
- tris(1-chloro-2-propyl) phosphate (TCPP)
- Dechlorane Plus chlorinated paraffins

<u>Type 2 - Fire extinguishers</u>

Three flame retardants were on the CCL3 and CCL4. These are chemicals used in fire extinguishing fluids/foams and include: Halon 1011 (bromochloromethane – banned in 1969), Perfluorooctane sulfonic acid (PFOS – phased out in 2000), Perfluorooctanoic acid (PFOA – phased out in 2000). UCMR3 included the same three flame retardants plus four other perfluorochemicals (PFBS, PFHxS, PFHpA, PFNA) in addition to PFOS and PFOA that may also be found in aqueous film-forming foams (AFFFs) used for firefighting.
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UCMR3 included the same three flame retardants plus four other perfluorochemicals (PFBS, PFHxS, PFHpA, PFNA) in addition to PFOS and PFOA that may also be found in aqueous film-forming foams (AFFFs) used for firefighting. PFOS was the principle perfluorochemical in AFFFs. Other perfluorochemicals found in AFFF formulations include PFOA, PFBS, and PFHxS (Post, 2012). PFOS and PFOA were phased out in the US in 2000 and current AFFF formulations contain different types of perfluorochemicals; however, these chemicals can-degrade to form PFOA) (UNIDO, 2012; Post, 2012).

Types 1 and 2 have received the most attention from regulators, e.g., they were on UCMR2, CCL3 and CCL4 list. Chlorinated flame retardant - Tris(2-chloroethyl) phosphate (TCEP) is listed on draft CCL5 list.

Type 3 - Aerial-applied fire retardants (forest-fire fighting) *[not CECs]*

Separately, aerial-applied fire retardants for forest-fire fighting are a third type but are not considered CECs and are therefore outside the scope of this review. These are briefly described here for completeness as they may be used in SFPUC watersheds. Type 3 fire retardants consist of detergents (e.g., >85% ammonium phosphates with iron oxides for red color) or are composed primarily of nitrogen and phosphorus (Backer et al., 2004). The US Forest Service oversees the fire retardants used to fight forest fires via spreading by planes and/or helicopters, reviews new fire retardants for safety to aquatic life, and recommends application at least 300 feet from all water bodies (USFS, 2000). Use of Type 3 can result in elevated nutrient levels in affected source waters. Type 3 mightbe more commonly used in SFPUC's watersheds. Types 1 and 2 have received the most attention from regulators, e.g., they were on lists for the UCMR2, CCL3 and CCL4.

The use of non-PFAS inorganic fire retardants to fight wildfires is common. The most commonly used fire retardant is made of nearly 90% water. A nitrogen-based product, similar to fertilizer, is added along with small amounts of additives. This adds a red color, so the fire fighters can see where it is dropped. The fire retardant may cause temporary increases in nitrate/nitrite levels, or turbidity but the amounts will be so small that it is not a health concern and drop off quickly (Health Link British Columbia, 2021).

USGS is conducting studies to determine which nutrients are likely to increase in concentration in areas affected by wildfire in the western U.S. The study will measure the effects of fire retardants on nitrogen (N) and phosphorus (P) in water run-off (USGS, 2020).

With respect to indicators, tris(2-chloroethyl) phosphate (TCEP) or tris(1-chloro-2-propyl) phosphate (TCPP) maybe a good indicators for Type 1 retardants because they are commonly detected in surveys of trace organic chemicals in US drinking waters (Snyder, 2007; Focazio et al., 2008; Benotti et al., 2009; Bruce, 2015). Indicators are not possible for Type 3 retardants as these are naturally occurring salts/nutrients.

The 2006 AwwaRF study on 19 water systems (Snyder et al., 2008) found the chlorinated flame retardants TCEP and TCPP in 67 and 50% of source waters; 53 and 42% of raw intake waters, respectively; and in 28% (both compounds) of finished (treated) drinking waters.

The 2008-2009 National Water Research Institute (NWRI) study on EDCs and PPCPs found TCEP in State Project Water, Colorado River Water, and Santa Ana River water (Guo, 2010), largely associated with wastewater impact.

A new study by EWG and Duke University researchers shows that exposures to two potentially harmful chemicals were higher in California than those found in a similar study in New Jersey. For one chemical, California children had exposures more than twice as high as their Garden State peers. The EWG-Duke study showed that on average, the California children in the study had been exposed to the carcinogenic flame retardant TDCIPP in amounts that were more than double those detected in the New Jersey children. Younger children were the most highly exposed. Mothers in California also had higher exposures to TDCIPP (EWG, 2016).

Mothers and children also had higher levels of a metabolite of the second flame retardant—ip-PDPP, a suspected endocrine disruptor. The metabolite, ip-PPP, forms as the body processes the original chemical (EWG, 2016). The new study is the first to have tested children and their mothers for a newly discovered metabolite of TCIPP, whose chemical structure closely resembles that of carcinogenic TDCIPP. In laboratory experiments TCIPP damages nerve cells, and it has the potential to affect the developing nervous system. Furniture laced with flame retardants is common throughout the United States, but until 2014 California was the only state with regulations that led to their use in virtually all foam cushioning for furniture. This meant that all of the upholstered furniture sold in California before 2014 probably contained flame retardants (EWG, 2016).

Independent researchers are slowly uncovering the toxic properties of many flame retardant chemicals that industry has long maintained are safe. Exposure to halogenated flame retardants is associated with various health effects including endocrine disruption, cancer, and impacts to thyroid and neurologic function (USEPA, 2008, 2014; Post, 2012; Rahman, 2014; Bruce, 2015, EWG, 2016). However, exposure is principally through non-Drinking Water routes (e.g., dust and foods) (Shaw et al., 2010; Post, 2012).

Few studies have evaluated the health significance of the typically very low levels of halogenated flame retardants such as PBDEs, TCEP, and TCPP in drinking water. This is likely because drinking water is not considered a major route of exposure for halogenated flame retardants (e.g., PBDEs: USEPA, 2010; Shaw et al., 2010), compared to other exposure routes like dust, food, etc. A 2009 study evaluated four brominated flame retardants (tetrabromobisphenol-A, tribromoneopentyl alcohol, 2,4,6-tribromophenol,and hexabromocyclododecane) and concluded no risks expected from drinking water (BRE, 2009).

A 2015 study compared observed concentrations of endocrine disrupting compounds, including TCPP, TCEP, TDCPP and PFOS, to known or estimated health threshold concentrations and concluded these chemicals didnot pose a significant risk in drinking water (Bruce, 2015).

Regulations

Types 1 and 2 have received the most attention from regulators, e.g., they were on UCMR2, CCL3 and CCL4 list. Chlorinated flame retardant - Tris(2-chloroethyl) phosphate (TCEP) is listed on draft CCL5 list.

As of January 2020, California has banned the sale and distribution of new upholstered furniture, replacement components of reupholstered furniture, foam in mattresses, and certain children’s products made for residential use if these products contain more than 0.1% of certain chemicals used for flame retardant purposes, including antimony trioxide, chlorinated tris, TBBPA, and TCEP (Cal. OEEHA, 2020).

A number of chemicals that have been used either as flame retardants, or to enhance the flame-retardant properties of other chemicals, are on the Proposition 65 list (Cal. OEHHA, 2020).

Some common flame-retardant chemicals are on the Proposition 65 list because they can cause cancer:

- Antimony trioxide.
- Chlorinated tris [tris(1,3-dichloro-2-propyl)phosphate, TDCPP, and TDCIPP].
- Pentabromodiphenyl ether (PentaBDE) mixture [DE-71 (technical grade)].
- Tetrabromobisphenol A (TBBPA).
- Tris-2-chloroethyl) phosphate (TCEP).

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3. Disinfection Byproducts - Nitrosamines

NDMA is used in research to induce cancer in mice, in the production of 1,1-dimethylhydrazine for rocket fuel, and can be an impurity in pesticides (nematicide), plasticizers for rubber, battery components, solvents, antioxidants, lubricant additives, and polymers/co-polymers (SWRCB, 2017).

NDMA and several other nitrosamines are classified by the USEPA as B2, probable human carcinogens (USEPA, 2014). Considering their health effects and potential future regulations, it is critical to understand the formation and control of nitrosamines in source and drinking waters, and to develop strategies for the removal of its precursors. The people are mainly exposed through foods and beverages such as malt and whiskey, whereas drinking water is a minor source in comparison to dietary sources (DOH, MN, 2018).

MEDIUM PRIORITY FOR SFPUC

Evidence collected to date indicates that control of nitrosamines in SFPUC source and drinking waters is optimized. Nitrosamines are a medium priority because they are occasionally detected at trace levels in SFPUC treated drinking water. CA Notification Levels exist for three nitrosamines, and a future MCL is likely.

This section presents: (1) Screening Evaluation Table, (2) SFPUC Monitoring Review 2016-2021, and (3) Technical Review 2016-2021 of available scientific studies.

Table 3-1. Screening Evaluation Table for Disinfection Byproducts - Nitrosamines

GENERAL INFORMATION ON CEC	
Instructions	This Screening Evaluation may be applied to a CECs group or an individual CEC. The purpose of this section of the Screening Evaluation is to present background information on the CEC or CECs group.
CEC Name	**Disinfection Byproducts (DBPs) NITROSAMINES**
CEC Description Is CEC a group? If individual CEC, which group is CEC part of?	Nitrosamines include: *N*-Nitrosodimethylamine (NDMA), *N*-Nitrosodiethylamine (NDEA), *N*-Nitrosodi-n-propylamine (NDPA), *N*-Nitrosodi-n-butylamine (NDBA), *N*-Nitrosomethylethylamine (NMEA), *N*-Nitrosomorpholine (NMOR), *N*-Nitrosopiperidine (NPIP), and *N*-Nitrosopyrrolidine (NPYR) (Sacher et al., 2008). NDMA is used in research to induce cancer in mice, in the production of 1,1-dimethylhydrazine for rocket fuel, and can be an impurity in pesticides (nematicide), plasticizers for rubber, battery components, solvents, antioxidants, lubricant additives, and polymers/co-polymers (SWRCB, 2017). The presence of NDMA and other nitrosamines in drinking water is primarily associated with the use of chloramine for disinfection of waters derived from wastewater-impacted sources or of waters treated using amine-based cationic polymers and anion exchange resins. Consequently, the best approaches to reduce the concentration of NDMA and other nitrosamines in drinking water are to remove the organic nitrogen precursors in wastewater-impacted sources (e.g., activated carbon), to avoid or minimize the use of amine-based cationic coagulant polymers or anion exchange resins, or to modify the disinfection strategy by incorporating sufficient contact with chlorine, ozone, chlorine dioxide or other primary disinfectants prior to adding ammonia to form chloramine (Health Canada, 2011, WRF 2016a, WRF, 2016b, Wolde-kirkos et.al.2021).
CEC Grouping What is the basis for grouping? *(Grouping factors are: common health effects, treatment, and analytical method, and/or compound co-occurrence)*	Nitrosamines is a group. The AwwaRF study *Strategies for Minimizing Nitrosamine Formation During Disinfection* identifies eight “important nitrosamines” (Sacher et.al., 2008), listed above. USEPA’s 2008 Unregulated Contaminant Monitoring Regulation 2 (UCMR2) included six nitrosamines and USEPA’s Contaminant Candidate List (CCL3) and the CCL4 include five nitrosamines). Draft CCL5 includes six nitrosamines – NDBA, NDEA, NDMA, NDPA, NDPhA (N-Nitrosodiphenylamine), NPYR (USEPA, 2021). Nitrosamines can be grouped for several reasons. Nitrosamines have similar health effects (carcinogens), NDMA may cause liver damage in humans at high concentrations, and overexposure causes headache, fever, nausea, jaundice, vomiting, and dizziness (SWRCB, 2017). Common treatment/reduction approaches are polymer and disinfectant management, and a common analytical method is EPA Method 521 (USEPA, 2010). Several nitrosamines can occur in sewage as a result of industrial discharges and they can also form via analogous pathways during chloramine disinfection.

Examples and Indicators If group, what are notable examples? Are there possible indicator constituents? *(A suitable indicator occurs at quantifiable levels and may co-occur with other CEC, exhibit similar treatment and fate in environment)*	Examples include NDMA, NDEA, NDPA, and other nitrosamines listed above. The occurrence of one nitrosamine could be an indicator for other nitrosamines. NDMA is probably the best indicator for SFPUC, as it is the most commonly detected nitrosamine (Krasner, 2013, 2016) and it is receiving the most regulatory attention. However, NDMA co-occurrence with other nitrosamines was identified as a data gap at a nitrosamine regulatory workshop in September 2010 and needs further study (Malcolm Pirnie, 2010). Although NMOR and NDMA can occur in sewage, NDMA also tends to form during chloramine disinfection, while NMOR typically does not. Only limited co-occurrence of NDMA with other nitrosamines was observed during the UCMR2 study (Krasner, 2016). Data obtained from UCMR monitoring is not enough to determine the variability in nitrosamine concentrations (WRF, 2018). The findings of the study suggest source-to-tap profiling to identify the sources of nitrosamines under different seasonal conditions (WRF, 2018).
Health Advisories Does CEC have a USEPA Health Advisory (e.g., Drinking Water Equivalent Level [DWEL]) or California Notification Level?	There are no USEPA Health Advisories for nitrosamines. NDMA, NDEA, and NDPA have California drinking water Notification Levels of 10 ng/L each and Cal OEHHA has developed PHG of 3 ng/L for NDMA (SWRCB, 2018). OEHHA's PHG for NDMA is 10^{-6} cancer risk level (SWRCB, 2018). SFPUC continues to monitor these nitrosamines, currently on a semi-annual basis. All results in 2018-2021 are below NL.
Regulatory Development Status Is CEC on USEPA Candidate Contaminant List (CCL), Unregulated Contaminant Monitoring Rule (UCMR) list, or California Public Health Goal (PHG) list?	There were five nitrosamines on USEPA's CCL3 and CCL4, including: NDMA, NDEA, NDPA, NDPhA, and NPYR. Six nitrosamines were monitored in 2008 under USEPA's UCMR2, including:NDMA, NDEA, NDPA, NDBA, NMEA, and NPYR. SFPUC continues to monitor these nitrosamines, currently on a semi-annual basis. Draft CCL5 includes six nitrosamines – NDBA, NDEA, NDMA, NDPA, NDPhA, NPYR (USEPA, 2021). NDMA has a California Public Health Goal (PHG) of 3 ng/L. A PHG is a non-enforceable, health-based goal and is the first step in the regulatory process. California Maximum Contaminant Levels (MCLs) are established as close to the PHG as possible after considering technical and economic feasibility. The United States (U.S.) does not currently have regulations, guidelines, or notification levels for N-nitrosomorpholine (NMOR) - a nitrosamine of concern detected in wastewater reuse (Glover et.al., 2019).

CONTEXT OF CEC EVALUATION AT SFPUC	
Instructions	The purpose of this section is to report SFPUC experience with the CEC or CEC Group, including occurrence data for each source water if available.
Purpose Why is evaluation undertaken? What is new about the issue that is considered 'emerging' (e.g., new chemical, new effect)?	Low levels of NDMA and other nitrosamines can be formed during the disinfection process, both by chlorination and chloramination. For nitrosamines to be formed, reactive chlorine, such as chlorine or monochloramine, must be present. In addition, organic nitrogen-containing precursors must be present (Health Canada, 2011). The most likely precursors of nitrosamines in SFPUC's water system are the cationic polymers applied at Harry Tracy WaterTreatment Plant (HTWTP) and Sunol Valley Water Treatment Plant (SVWTP) for turbidity control (Wilczak et al. 2003). Wastewater can be a significant source of NDMA precursors but SFPUC waters are not impacted by wastewater discharges. Due to drought conditions occurring in California for consecutive years, an alternate source of water supply is being considered, which could potentially involve recharging ground water wells with treated wastewater similar to Orange County. Also, a reclaimed water facility is under construction at SFPUC's Oceanside Wastewater Treatment Plant (OSP), which will supply the wastewater receiving tertiary treatment for irrigation purposes. N-nitrosomorpholine (NMOR), another N-nitrosamine of concern frequently detected in wastewater reuse as NDMA has received less attention. Chronic, oral exposure of animals to NMOR has been shown to result in damages and tumors in the liver and kidneys (Glover et.al., 2019). Hence, could be a potential source to impact groundwater and warrants its monitoring. Additionally, bacteria sloughed off the biofilters and their metabolites may be a source of precursors. Certain rubber materials used in distribution systems were found to be a source of NDMA (Krasner et al., 2015). NDMA and other nitrosamines are not currently regulated. However, nitrosamines are likely candidates for future regulations. Therefore, it is important to proactively obtain data on NDMA levels in the SFPUC water system, and, if needed, develop measures to minimize NDMA levels.
Customer Interaction Widespread public concerns? Media coverage?	There is not significant, widespread concern at this point. NDMA detections have been very low, especially when considering other common sources in most diets (meat, fish, milk, etc.) (Health Canada, 2011). Body burden of NDMA from drinking water is very low in comparison to other dietary sources. However, due to a PHG of 3 ng/L and a CA Notification Level of 10 ng/L, NDMA may be discussed in future PHG reports and/or CCRs. Therefore, in the future, there is a potential for customer questions about NDMA.
Expected Outcomes	The investigation should have beneficial impacts to SFPUC and the customers as SFPUC can gather information supporting possible future regulatory compliance and develop cost-effective methods to minimize NDMA formation prior to an NDMA regulatory program.

What are the likely benefits of the investigation to SFPUC and its customers?	
Occurrence Data (US and SFPUC) What occurrence information is available? Have detections, if any, been confirmed by follow-up sampling and/or QA/QC review?	Consistent with the above results, NDMA was detected at low concentrations ranging from ND to 2.9 ng/L in treated HTWTP water and treated Hetch Hetchy water, concentrations which were deemed negligible by the researchers (Reckhow et al., 2016). Nitrosamines are continued to be monitored semi-annually, and the number of locations is scaled down to 10. Table 3-2 in Monitoring Review presents a summary of results collected since 2018 at ten (10) locations, six (6) in SFRWS and four (4) in SFWS. During this time, eight (8) sampling events were conducted for a total of 80 samples collected. Only NDMA was detected, all results below CA Notification Level of 10 ng/L. An increase in frequency of NDMA detection from 7% samples in SFWRS to 47% of samples in SFWS is consistent with expectation of some formation in the distribution system. NDEA, NDBA, NDPA, NMEA, NPYR results were all non-detect. A review of detailed raw data attached electronically indicates that increased chloramine residual in distribution system in 2021 has not coincided with increased nitrosamine formation to date. This needs to be further monitored. Based on this evaluation, SFPUC system is optimized for nitrosamine formation. It is prudent to continue monitoring to observe long-term trends.
Supporting Information List key references	Olson G., May 2018. Tech Memo - Reduction of nitrosamine monitoring from quarterly monitoring to semi-annual monitoring in the San Francisco Regional Water System (SFRWS) and the San Francisco Water System (SFWS). Krasner W.S., Roback S., Qian Y., Li X., Marfil-Vega R., Bukhari Z., 2020. Occurrence of nitrosamines and their precursors in North American drinking waters. American Water Works Association Vol 2 (6). https://doi.org/10.1002/aws2.1208 USEPA, 2017. Technical Fact Sheet –N-Nitroso-dimethylamine (NDMA). https://www.epa.gov/sites/default/files/2017-10/documents/ndma_fact_sheet_update_9-15-17_508.pdf U.S. Food and Drug Administration, 2020. FDA Alerts Patients and Health Care Professionals to Nitrosamine Impurity Findings in Certain Metformin Extended-Release Products. FDA Alerts Patients and Health Care Professionals to Nitrosamine Impurity Findings in Certain Metformin Extended-Release Products | FDA USGS, 2018. Does NDMA Biodegrade at Ground-Water Recharge Facilities? https://toxics.usgs.gov/highlights/ndma_biodegradation.html

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DIAGNOSTIC QUESTIONS TO SUPPORT CEC PRIORITIZATION

Instructions	The purpose of the Diagnostic Questions is to determine whether the CEC or CECs Group are significant to SFPUC drinking water and whether they merit further evaluation and/or action. All answers require explanation except those clearly not applicable. The Diagnostic Questions are divided into Health, Occurrence, and Treatment sections. The more questions are answered with a "Yes", the higher the probability that the CEC is a high priority or that a proactive approach should be taken.

HEALTH EFFECTS FROM SCIENTIFIC STUDIES

Question	**Answer**	**Explanation and Comments**
Is scientific knowledge on CEC health effects well developed?	**Yes**	Its harmful effects are well studied in rodents causing tumors in the liver and other organs. Humans are mainly exposed through foods and beverages such as malt and whiskey, whereas drinking water is a minor source in comparison to dietary sources (DOH, MN, 2018). The risk found during animal studies is extrapolated and associated with human risk levels. There are very few studies published on the nitrosamine exposure causing systemic, reproductive, developmental, neurological, or immunological impacts (USEPA 2016).
Based on current scientific understanding, does the CEC pose potential health risk at the levels typically found in drinking water in the US?	**Possible**	NDMA and several other nitrosamines are classified by the USEPA as probable human carcinogens (USEPA, 2014). Based on non-regulatory guidelines ranging from 3 to 100 ng/L NDMA in drinking water (see below),and that NDMA has been detected in US drinking water in this range, nitrosamines appear to pose a potential risk. Considering their health effects and potential future regulations, it is critical to understand the formation and control of N-nitrosodimethylamine (NDMA) in source waters and drinking water treatment plants (WTPs), and to develop strategies for the removal of its precursors (WRF, 2016a).

Question	Answer	Explanation and Comments
Adverse health impacts observed in other drinking water systems? Are public health studies documenting human health impacts (disease or outbreaks) available?	**No**	To the best of SFPUC knowledge, there have been no adverse health effects due to nitrosamines in other drinking water (DW) systems. In general, it is difficult to link health effects (i.e., cancer) to a specific, responsible agent given the number of low-level carcinogens present in water, foods, air, consumer products, etc. It is estimated that drinking water contributes no more than 0.02% of total NDMA exposure (Hrudey, 2012).
Existing regulations or guidelines outside of US (e.g., WHO, EU)?	**Yes**	For drinking water, WHO has established an NDMA guideline of 100 ng/L (WHO, 2008). Health Canada has established an NDMA guideline of 40 ng/L (Health Canada, 2011). Germany has recommended a drinking water guideline for NMOR of 10 ng/L and Australia has set their Drinking Water Reuse Guideline at 1 ng/L (Glover et.al., 2019).
Existing US health advisories or CA notification levels?	**Yes**	NDMA, NDEA, and NDPA have California Notification Levels of 10 ng/L. USEPA is considering a national regulation for nitrosamines as a group (USEPA, 2010).
Likely US regulation in the next 10 years? **Is CEC on a regulatory development list, such as CCL?** **Is there a pending regulation or California PHG?**	**Possible** **CCl5**	There were 5 nitrosamines on USEPA's CCL3 and CCL4. A PHG of 3 ng/L has been established for NDMA. A regulation (MCL and/or treatment technique), for NDMA and other nitrosamines is likely. There are six nitrosamines on draft CCL5 (USEPA, 2021).
SUMMARY – SIGNIFICANT TO PUBLIC HEALTH IN GENERAL? **(Based on above answers)**	**Possible**	Based on the fact that nitrosamines are probable human carcinogens and are detected in US drinking water at concentrations at or near guideline values (non-regulatory), these CECs are considered significant to public health.

OCCURRENCE

Question	Answer	Explanation and Comments
Is scientific knowledge on CEC sources/formation well developed?	**Yes**	See references, above and technical review. Information is available, especially for NDMA. Information is less developed for other nitrosamines.
CEC presence reported in other water supplies? Are occurrence studies available?	**Yes**	There have been several occurrence studies by Water Research Foundation and others. Results from the UCMR2 published by USEPA in its report has been included in the technical review. The results show the formation, distribution of all six nitrosamines in PWS using different water sources. NDMA was more prevalent in surface water (63%) than groundwater (16%) systems, occurring primarily in the presence of chloramines. California, Texas, Kansas, and North Dakota were the states with higher frequency of occurrence (WRF, 2016a). Systems that use chloramine have significantly higher detection frequency than those that use chlorination (WRF, 2016b).
CEC present in SFPUC watersheds and/or surface waters? Are there complex issues involved in managing CEC ;e.g., point vs. non-point sources?	**No**	SFPUC watersheds are not impacted by wastewater discharges, industrial pollution, or agricultural runoff. Therefore, manmade nitrosamine precursorsare not expected in the watersheds. A new potential source from reclaimed water needs to be monitored in the future.
Is the CEC a potential groundwater contaminant?	**Yes**	In 2000, two drinking water supply wells were taken out of service in Orange County, CA, due to presence of NDMA at concentrations 30-40 ng/L (USGS, 2018). SWRCB sampled 260 wells from 2007 – 2017 and found 60 active and standby public water supply wells had at least one detection for NDMA above California Cancer Potency factor (CA-CPF) of 0.0022 µ/L (increase in cancer risk per unit of exposure calculated by OEHHA - CA). The wells were mainly located in Sacramento (6) and Los Angeles (52) counties (SWRCB, 2017).

Question	Answer	Explanation and Comments
If the CEC is a potential groundwater contaminant, is it highly mobile in the subsurface? Is the CEC low-sorbing and resistant to microbial degradation?	**Yes**	NDMA is susceptible to biotransformation in soils under both aerobic and anaerobic conditions, but the removal rate is dependent on site-specific conditions such as the adaption of the microbial community (Drewes, 2006, USGS 2018) and the concentration of biodegradable organic carbon available (Nalinakumari, 2009). In deep aquifers with low organic carbon, NDMA can be resistant to biodegradation. NDMA is highly mobile in the subsurface and can potentially leach into groundwater (USEPA 2017). A high concentration of NDMA is found in groundwater near rocket testing facilities in California (USEPA, 2017, Health Canada, 2011).
Precursor present in SFPUC source waters? *(Including surface waters and groundwaters)*	**No**	Natural organic matter (NOM) containing nitrogen is a precursor to nitrosamines formed during and after disinfection. Low levels of NOM (derived from plants, animals, and algal blooms) are naturally present in watersheds. However, studies of other drinking waters have indicated that concentrations of organic nitrogen precursors in pristine source waters are generally insufficient to account for observed NDMA formation (Health Canada, 2011). Additionally, wastewater-impacted source waters may contain higher levels of organic nitrogen precursors, referred to as effluent organic matter (EfOM) as opposed to NOM (Health Canada, 2011). Studies have shown that polymer additives used to facilitate particle destabilization during coagulation act as precursors (Wolde-kirkos et.al., 2021). For systems using pristine source waters, the main precursor to nitrosamines appears to be treatment polymers and ion exchange resins, not source water precursors (Wilczak et al. 2003).
Formed or added during current SFPUC treatment? If so, describe whether the formation or addition of CEC can be controlled.	**Yes**	NDMA is formed during disinfection with chlorine or chloramine. The mainprecursors in the SFPUC system appear to be the cationic polymers used forcoagulation and filtration at SVWTP and HTWTP. NDMA is rarely detected in treated Hetch Hetchy water. NDPA and NDBA have been detected in treated Hetch Hetchy water at levels of 2 ng/L and 4.6 ng/L, respectively, but not recently since 2018. There are complex issues involved with reducing NDMA levels as the precursors to NDMA (polymers) are needed for coagulation and filtration performance. Operational changes could involve a modification to chemical dosing levels, a modification to the types of coagulant/flocculation chemicalsused, and/or measures to reduce water age in the distribution system. So far there have been no change in the cationic polymer or its doses.

Formed or added within SFPUC storage or distribution? If so, describe whether the formation or addition of CEC can be controlled.	**Possible**	NDMA and other nitrosamines are disinfection byproducts and are formed during disinfection, including in the distribution system. NDMA levels appear to increase with water age, as the College Hill Pressure Zone has consistently recorded higher concentrations than HTWTP effluent. The monitoring since 2018 confirmed higher incidence of NDMA formation of 47% samples in SFWS as compared with 8% samples in SFRWS.
Detected in SFPUC drinking water?	**Yes**	The quarterly nitrosamine monitoring over the 13-year period from 2005 – 2017 indicates evenly spread detections throughout the year, however, detections have been slightly more frequent in the second and fourth quarters. Hence, in 2018 semi-annual monitoring of nitrosamines particularly in May and November was recommended (Olson, 2018). Based on the data collected between 2016-2018, 28% samples were detected for NDMA with highest concentration of 7.6 ng/L at CHS#13. NDEA was detected in 3% samples with highest concentration of 2.2 ng/L at HTWTP effluent. There was no detection of other four nitrosamines (NDPA, NDBA, NMEA, NPYR) during this period.
SUMMARY – OCCURRENCE IN SOURCE AND DRINKING WATER? *(OR SIGNIFICANT POTENTIAL TO OCCUR)* *(Based on above answers)*	**Yes**	NDMA has been detected in SFPUC finished drinking water. Precursors are likely associated with treatment polymers and potentially also NOM.

TREATMENT		
Question	**Answer**	**Explanation and Comments**
Is scientific knowledge on CEC treatment/removal well developed?	**Yes**	The common approach taken is to remove the precursors present in drinking water sources, including natural and synthetic amines and other nitrogen containing compounds. Precursor removal processes include source management; adsorption using granular activated carbon or powdered activated carbon, polymer optimization, and processes which destroy precursors, such as pre-oxidation, reverse osmosis, nanofiltration (WRF, 2018, USEPA 2016).
Likely to pass through current treatment for Hetch Hetchy Supply? Describe any complex issues involved with the treatment/removal of CEC.	**No**	NDMA, NDPA and NDBA have been occasionally detected in Hetch Hetchy water, but the low frequency of these detections suggests either the lack of precursors in the source water or effectiveness of chlorine to minimize formation during treatment. NDMA was detected at concentration of 6.8 ng/L at Alameda E in Feb 2018, however the levels were below the CA Notification Level.
Likely to pass through current treatment at SVWTP? Describe any complex issues involved with the treatment/removal of CEC.	**Yes**	Formed during treatment. See Occurrence Section, above. The monitoring data from 2004 – 2017, show presence of NDMA with one-time (12 ng/L) level above CA NL in May 2010, probably due to plant start-up conditions. However, NDPA and NDBA were detected at lower concentrations at 2 and 2.6 ng/L respectively. The data after 2016 for nitrosamines have been mostly non detect (NDMA – 2.7 ng/L in Feb 2018 and 2.3 ng/L in May 2018 at SVWTP Eff X12) or at low concentrations. The monitoring results suggests the treatment plant is operated at optimized conditions. Cationic polymer doses are stable and typically about 1.0 mg/L and 1.5 mg/L for San Antonio and Calaveras supplies, respectively.
Likely to pass through current treatment at HTWTP? Describe any complex issues involved with the treatment/removal of CEC.	**Yes**	Formed during treatment. See Occurrence Section, above. The monitoring data from 2004 - 2017 show only one occurrence of NDMA (2.1 ng/L), NDEA (5.0 ng/L), NDPA (4.3 ng/L) and two occurrences of NDBA (highest being at 3.9 ng/L). All occurrences were below CA NL. No occurrences of nitrosamines were observed since 2018 (still one data point for 2021 is not available yet). Polymer doses vary to account for changes in the raw water quality condition, but the average usage is relatively constant year to year.

Question	Answer	Explanation and Comments
Likely to pass through current treatment for groundwater? Describe any complex issues involved with the treatment/removal of CEC.	**No**	Representative groundwater sample at CUP 10A and CUP 11A was chlorinated in the laboratory and tested for 6 nitrosamines following an appropriate contact time. All results were ND (< 2 ng/L) with the exception of a NDMA detection in CUP 11A of 4.3 ng/L; however, this value was invalidated due to a Test Blank NDMA detection of 6.6 ng/L. Earlier SFPUC testing for DBP formation from representative wells indicated no detectable NDMA formation (SFPUC, 2012). Further, please see occurrence section.
SUMMARY – LIKELY TO PASS (NOT REMOVED BY) CURRENT TREATMENT? *(Based on above answers)*	**Yes**	Though approximately 90% of samples are ND, SFPUC monitoring has indicated that nitrosamines are occasionally formed during treatment at SVWTP and HTWTP. Continued slow formation, primarily of NDMA, in the distribution system is evidenced from the monitoring data, consistent with literature.

CEC PRIORITIZATION – CURRENT ASSESSMENT

Instructions	This section prioritizes the CEC based upon the information developed in the above Diagnostic Questions as well as in the background information. For high and medium priorities, develop monitoring and/or mitigation measures as appropriate. For low priorities, maintain current measures, track regulatory developments, health/technical studies and reevaluate priority when needed.
Could CEC occur in SFPUC drinking water at levels of possible health significance? *(Based on above Diagnostic Questions)*	**YES** NDMA has been detected at concentrations between 2 and 8 ng/L. NDMA has a PHG of3 ng/L and a CA Notification Level of 10 ng/L. In May 2017, NDEA was detected in CS2 Baden (2.0 ng/L), UMS#1 (2.1 ng/L), and HTWTP Eff Post (2.2 ng/L). The CA notification levels for NDEA is 10 ng/L.
CEC Prioritization for SFPUC High, Medium, or Low. Provide explanation. *(A high number of "Yes" answers to the Diagnostic Questions indicates a higher priority, and "No" or very few "Yes" answers indicates a lower priority.)*	**MEDIUM PRIORITY FOR SFPUC** Evidence collected to date indicates that control of nitrosamines, for SFPUC water sources and treatment, is optimized. Nitrosamines are a medium priority because they are occasionally detected at trace levels in SFPUC treated drinking water (NDMA occasionally greater than the PHG of 3 ng/L). CA Notification Levels exist for three nitrosamines, and a future MCL is likely. USEPA and/or SWRCB will probably develop an MCL for NDMA (and other nitrosamines) as EPA has classified NDMA as a Class B2 carcinogen and SWRCB has adopted a PHG. Despite the regulatory attention, NDMA in drinking water appears to be a minor source of a typical person's overall NDMA exposure/diet.

Implemented Actions Indicate the progress and results of any action items, above, such as implemented in previous cycles of CEC review. Evaluate whether changes to the action plan are required.	• Continued to minimize detention time in the distribution system through hydraulic improvements (primarily after 2004 chloramine conversion), mixers and seasonal outages of finished waterstorage facilities. • Continued to optimize DADMAC polymer doses at treatment plants. The goal is to minimize polymer doses and still achieve optimized filtration process. • Followed regulatory developments for nitrosamines. • Viewed technical webinars on control of nitrosamines. • In 2015, SFPUC conducted monitoring for 6 nitrosamines (NDMA, NDEA, NDBA, NDPA,NMEA, and NPYR) in 7 new Groundwater Storage and Recovery (GSR) production wells. • From 2016 – 2018, SFPUC monitored 6 nitrosamines (NDEA, NDMA, NDBA, NMEA, NDPA, NPYR) in distribution system and treated plant effluents. The results are discussed above. The six nitrosamines are continued to be monitored semi-annually at 10 locations. • Nitrosamine monitoring in 2013-2015, 2016 -2018 and 2019-2021 indicates treatment optimization is effective.
Recommended Actions Does the situation merit investing additional resources or has the information gathered so far fulfilled due diligence? Actions could include monitoring and other measures (specified by source water, if necessary).	• Maintain optimized treatment: avoid polymer overfeed, provide free chlorine contact time before chloramination, and minimize detention time in the distribution system (Health Canada, 2011; Sacher et al., 2008). Nitrifying portions of disinfection systems shed NDMA precursors. An increase in NDMA formation is anticipated at disinfectant boosting stations that replenish the disinfectant. Hence, minimizing nitrification could help (Zeng et.al., 2016). • Continue voluntary semi-annual monitoring at 10 locations and collect total chlorine, free ammonia, pH, temperature, and conductivity along with nitrosamine samples. Monitor also locations after boosting and nitrification. • Track information, peer-reviewed publications, and any federal and state regulatory developments. • Add NDPhA and NMOR to semi-annual monitoring program because these are listed in CCL5-and of concern in wastewater reuse applications.

This evaluation was prepared based on available information (peer-reviewed literature and occurrence data) with the purpose of prioritizing work and informing the public on unregulated CECs. This evaluation will be updated every 6 years or when significant new research or occurrence data on CECs become available that may warrant changing priority and recommendations.

Water Quality Division, SFPUC Monitoring Review 2016 – 2021

Contaminants of Emerging Concern (CEC) in Drinking Water

Nitrosamines

Initial Monitoring. SFPUC has voluntarily monitored NDMA since 1999 and on a quarterly basis since 2004 (immediately following the conversion from chlorine to chloramine). From 8/2004 to 8/2015, NDMA was detected in 32 of 335 samples (approximately 10% of the samples). Of the detections, NDMA levels ranged from 2.1 ng/L to 8.6 ng/L, excluding one outlier in May 2010 of 12 ng/L in SVWTP effluent free chlorinated water, collected immediately after plant startup. Most of the detections were downstream of HTWTP (i.e., in the College Hill distribution system). This indicates that NDMA levels appear to increase with time/water age.

In addition to this voluntary sampling, under UCMR-2 six nitrosamines (NDMA, NDEA, NDPA, NDBA,NMEA, and NPYR) were monitored at five locations (HTWTP Effluent, Irvington Portal, Mocho Shaft, SA3 Baden, and SSL Baden). None of the six nitrosamines were detected during UCMR-2 sampling.

Special sampling was conducted for *N*-nitrosodiphenylamine, a CCL3 contaminant, in 2003 and 2009. The 2003 data were collected at HTWTP_SED (1 sample, sedimentation basin location that is pre-filtration) and the 2009 data were collected in response to a complaint (3 samples). These data were non-detect (ND).

Ongoing Monitoring. Consistent with the above results, NDMA was detected at low concentrations ranging from ND to 2.9 ng/L in treated HTWTP water and treated Hetch Hetchy water, concentrations which were deemed negligible by the researchers (Reckhow et al., 2016).

In addition to NDMA, since 2011, SFPUC has monitored quarterly for 5 other nitrosamines, including: NDEA, NDPA, NDBA, NMEA and NPYR. There have been 4 detections of NDPA out of 147 samples (less than 3% ofsamples), ranging from 2.0 ng/L to 4.3 ng/L. There have been 19 detections of NDBA out of 146 samples (approximately 13%), ranging from 2.0 ng/L to 7.6 ng/L.

NDMA and other nitrosamines were evaluated in surface water sources and future groundwater (wells CUP 10A (now GSR-SBW) and 11A (now GSR-CRW)) as part of a CECs evaluation in June/July 2012. NDMA was not detected, except in some samples that did not meet data qualification standards or were flagged as very low-level. Other nitrosamines (NDEA, NDPA, NPYR, NDBA, NMEA) were not detected in the treated and untreated groundwater or surface waters. In early 2014, additional upcountry standby surface water sources (Alameda

Creek Pond F2 East A and West B, Cherry Reservoir, Lake Eleanor, Early Intake Reservoir) were sampled for NDMA and other nitrosamines. All samples were non-detect.

In 2015, special sampling of 7 new Groundwater Storage and Recovery (GSR) production wells (GSR-BFW, GSR-FHW, GSR-CBW, GSR-MYW, GSR-TIW and GSR-SMW) included 6 nitrosamines (NDMA, NDEA, NDBA, NDPA, NMEA, and NPYR). All samples were non-detect (ND).

Nitrosamines were in UCMR4 list and the monitoring of the six nitrosamines was conducted by SFPUC from 2016 - 2018. Sampling was done quarterly for one year in distribution system and treatment plants. The results were discussed in 2019 CEC Update Report. Following are the synopsis taken from 2019 CEC Update Report in which a statistical analysis of nitrosamine data collected from 2016 -2018 is described (SFPUC, 2019):

- From the data collected from 2016 -2018, the treatment plants and distribution systems are optimized for nitrosamines.
- NDMA, NDEA, and NDPA measurements were below CA Notification Level of 10 ng/L and most samples (n=642) were non-detect. NDMA was detected in 30 out of 107 samples (28%) – 7.6 ng/L max. at CHS#13. NDEA was detected in 3 out of 107 samples (3%) – 2.2 ng/L max. at HTWTP effluent.
- NDBA, NMEA, NYPR were non detect during 3-year period.

The quarterly nitrosamine monitoring over the 13-year period from 2005 – 2017 indicate evenly spread detections throughout the year, however, detections have been slightly more frequent in the second and fourth quarters. Hence, in 2018 semi-annual monitoring of nitrosamines particularly in May and November was recommended (Olson, 2018).

Current Monitoring: Nitrosamines are continued to be monitored semi-annually, and the number of locations is scaled down to 10. Table 3-2 presents a summary of results collected since 2018 at ten (10) locations, six (6) in SFRWS and four (4) in SFWS. During this time, eight (8) sampling events were conducted for a total of 80 samples collected. Only NDMA was detected, all results below CA Notification Level of 10 ng/L. An increase in frequency of NDMA detection from 7% samples in SFWRS to 47% of samples in SFWS is consistent with expectation of some formation in the distribution system. NDEA, NDBA, NDPA, NMEA, NYPR results were all non-detect. A review of detailed raw data attached electronically indicates that increased chloramine residual in distribution system in 2021 has not coincided with increased nitrosamine formation to date. This needs to be further monitored.

Based on this evaluation, SFPUC system is optimized for nitrosamine formation. It is prudent to continue current monitoring to observe long-term trends.

Table 3-2. Summary of Nitrosamine Semi-Annual Monitoring in SFRWS and SFWS, 2018-2021

Location	Analyte, # Detects (Max, ng/L)						Comments
	NDEA	NDMA	NDBA	NDPA	NMEA	NYPR	8 sampling Events
Alameda E	0 (<2)	1 (6.8)	0 (<2)	0 (<2)	0 (<2)	0 (<2)	Free Chlorine SFWRS
SVWTP EFFX12	0 (<2)	2 (2.7)	0 (<2)	0 (<2)	0 (<2)	0 (<2)	Chloramine SFWRS
IRV Port Meter	0 (<2)	1 (2.6)	0 (<2)	0 (<2)	0 (<2)	0 (<2)	Chloramine SFWRS
IRV Port # 2	0 (<2)	0 (<2)	0 (<2)	0 (<2)	0 (<2)	0 (<2)	Chloramine SFWRS
HTWTP EFF Post	0 (<2)	0 (<2)	0 (<2)	0 (<2)	0 (<2)	0 (<2)	Chloramine SFWRS
CS#2 Baden	0 (<2)	0 (<2)	0 (<2)	0 (<2)	0 (<2)	0 (<2)	Chloramine SFWRS
UMS #01	0 (<2)	5 (3.9)	0 (<2)	0 (<2)	0 (<2)	0 (<2)	Chloramine SFWS
UMS # 09	0 (<2)	4 (3.8)	0 (<2)	0 (<2)	0 (<2)	0 (<2)	Chloramine SFWS
CHS # 08	0 (<2)	5 (5.1)	0 (<2)	0 (<2)	0 (<2)	0 (<2)	Chloramine SFWS
CHS # 13	0 (<2)	3 (3.2)	0 (<2)	0 (<2)	0 (<2)	0 (<2)	Chloramine SFWS

Table 3-3 presents the results for trip blanks associated with nitrosamines monitoring reported in Table 3-2. All the trip blanks were below the detection level of 2 ng/L.

Table 3-3. Trip Blanks Results of Nitrosamine Monitoring Reported in Table 3-2

Date and Location	Analyte						Units
	NDEA	NDMA	NDBA	NDPA	NMEA	NYPR	
2/13/18 and 2/26/18							
TB_City	<2	<2	<2	<2	<2	<2	ng/L
TB_Penninsula	<2	<2	<2	<2	<2	<2	ng/L
TB_East Bay	<2	<2	<2	<2	<2	<2	ng/L
5/7/2018							
TB_City	<2	<2	<2	<2	<2	<2	ng/L
TB_Penninsula	<2	<2	<2	<2	<2	<2	ng/L
TB_East Bay	<2	<2	<2	<2	<2	<2	ng/L
11/13/2018							
TB_City	<2	<2	<2	<2	<2	<2	ng/L
TB_Penninsula	<2	<2	<2	<2	<2	<2	ng/L
TB_East Bay	<2	<2	<2	<2	<2	<2	ng/L
5/19/2019							
TB_City	<2	<2	<2	<2	<2	<2	ng/L
TB_Penninsula	<2	<2	<2	<2	<2	<2	ng/L
TB_East Bay	<2	2.5	<2	<2	<2	<2	ng/L
5/30/2019							
TB_East Bay	<2	<2	<2	<2	<2	<2	ng/L
11/18/2019							
TB_City	<2	<2	<2	<2	<2	<2	ng/L
TB_Penninsula	<2	<2	<2	<2	<2	<2	ng/L
TB_East Bay	<2	<2	<2	<2	<2	<2	ng/L
5/4/2020							
TB_City	<2	<2	<2	<2	<2	<2	ng/L
TB_Penninsula	<2	<2	<2	<2	<2	<2	ng/L
TB_East Bay	<2	<2	<2	<2	<2	<2	ng/L

Date and Location	Analyte						Units
	NDEA	NDMA	NDBA	NDPA	NMEA	NYPR	
11/9/2020							
TB_City	<2	<2	<2	<2	<2	<2	ng/L
TB_Penninsula	<2	<2	<2	<2	<2	<2	ng/L
TB_East Bay	<2	<2	<2	<2	<2	<2	ng/L
11/30/2020							
TB_Penninsula	<2	<2	<2	<2	<2	<2	ng/L
5/3/2021							
TB_City	<2	<2	<2	<2	<2	<2	ng/L
TB_Penninsula	<2	<2	<2	<2	<2	<2	ng/L
TB_East Bay	<2	<2	<2	<2	<2	<2	ng/L
5/5/2021							
TB_East Bay	<2	<2	<2	<2	<2	<2	ng/L

Nitrosamine Detection in Treated Finished Water and Distribution/Storage.

NDPA and NDBA have been occasionally detected at Alameda East, but the low frequency of these detections suggests either the lack of precursors in the Hetch Hetchy source water or effectiveness of chlorine to minimize formation during treatment. NDMA was detected Alameda East at concentration of 6.8 ng/L in Feb 2018, however the levels were below the CA Notification Level. Formation of nitrosamines in treated Hetch Hetchy water can be considered negligible.

The nitrosamine monitoring data from August 2004 to December 2017 at AE, SVWTP Eff, Irv Portal 1 and 2, CS2-Baden, UMS#01, UMS#09, HTWTP Eff Post, CHS#08, and CHS#13, indicate NDMA has been the most detected nitrosamine at 13.6%, followed by NDBA, NDPA, and NDEA at 8%, 1.7%, and 1.3% respectively. NMEA and NPYR were non detect during this period (Olson, 2018).

The data since 2016 for nitrosamines at SVWTP Eff X12 have been mostly non detect or at low concentrations (NDMA – 2.7 ng/L in Feb 2018 and 2.3 ng/L in May 2018). The monitoring results suggest the SVWTP treatment is optimized to minimize nitrosamine formation. Cationic polymer doses are stable and typically about 1.0 mg/L and 1.5 mg/L for San Antonio and Calaveras supplies, respectively.

No occurrences of nitrosamines at HTWTP Eff Post were observed since 2018. Cationic polymer doses range vary to account for changes in the raw water quality condition, but the average usage is relatively constant year to year. HTWTP is also optimized to minimize nitrosamine formation.

Table 3-4. Hetch Hetchy Chlorine Dosing and Contact Time - Average Values Based on Data from Jan 2021 – Jan 2022

CRT Flow (MGD)	TTF to AE (Hours)	TTF to AE (Min)	Chlorine Dose at TTF (mg/L)	Chlorine Res Start of CRT (mg/L)	Chlorine Res Start at AE (mg/L)
206	10.04	602.3	1.55	1.34	1.01

SVWTP chlorine dosing and contact time:

- During plant startup when pre-chlorination is utilized for the first few days until treatment is stable: (1) flash mix Cl2 dose ~1.8 mg/L (2) clearwell Cl2 dose ~1.4 mg/L and (3) CCT effluent Cl2 dose ~1.5 mg/L.
- During plant steady-state operation when pre-chlorination is not typically utilized: (1) flash mix Cl2 dose = 0 mg/L (2) clearwell Cl2 dose ~2.7 mg/L and (3) CCT effluent Cl2 dose ~2.0 mg/L.
- Contact time through the 3.0 MG chlorine contact tank at an average plant flow rate of 40 MGD is about 108 minutes.

Water Quality Division, Technical Review 2016 – 2021

Contaminants of Emerging Concern (CEC)

Nitrosamines

An increasing number of drinking water utilities in the United States (US) have been employing or considering chloramination for disinfection to comply with the stringent regulations for trihalomethanes (THMs) and haloacetic acids (HAAs). Texas, California, and Florida were the top three states having population served with chloraminated water in 2011. These three states also showed the most significant increases in switching to chloramination between 2007 and 2010. However, nitrosamines, a class of unregulated disinfection byproducts (DBPs) classified as probable human carcinogens in water at very low ng/L concentrations, may occur in chloraminated waters. As a result, there has been an increased regulatory attention by the US Environmental Protection Agency (USEPA) that first included nitrosamines in the Contaminant Candidate List 3 (CCL3). N-Nitrosodimethylamine (NDMA) is the most commonly detected and reported nitrosamine in distribution systems that use chloramines as post-oxidants in the US (WRF 2016a).

Nitrosamines on Draft CCL5

NDMA and several other nitrosamines are classified by the United States Environmental Protection Agency (USEPA) as B2, probable human carcinogens (USEPA, 2014). Six nitrosamines are listed under draft CCL5 - *N*-Nitrosodi-n-butylamine (NDBA), *N*-Nitrosodiethylamine (NDEA), *N*-Nitrosodimethylamine (NDMA), *N*-Nitrosodi-n- propylamine (NDPA), NDPhA (N-Nitrosodiphenylamine), *N*-Nitrosopyrrolidine (NDPYR) (USEPA, 2021).

Nitrosamines Studied Previously Include: *N*-Nitrosodimethylamine (NDMA), *N*-Nitrosodiethylamine (NDEA), *N*-Nitrosodi-n- propylamine (NDPA), *N*-Nitrosodi-n-butylamine (NDBA), *N*-Nitrosomethylethylamine (NMEA), *N*- Nitrosomorpholine (NMOR), *N*-Nitrosopiperidine (NPIP), and *N*-Nitrosopyrrolidine (NPYR) (Sacher et al., 2008;SWRCB, 2018).

Considering their health effects and potential future regulations, it is critical to understand the formation and control of N-nitrosodimethylamine (NDMA) in source waters and drinking water treatment plants (WTPs), and to develop strategies for the removal of its precursors. Furthermore, the impacts of various temporal and climatic events (e.g., drought periods, run offs or major rains, algae growth/die off, seasonal changes, and lake turnovers) on the occurrence of NDMA precursors in source waters and its removal across drinking WTPs need to be better understood (WRF, 2016a).

N-nitrosomorpholine (NMOR), another N-nitrosamine of concern has received less attention. Chronic, oral exposure of animals to NMOR has been shown to result in damages and tumors in the liver and kidneys (Glover et.al., 2019).

OCCURRENCE AND HEALTH EFFECTS

Researchers have found the formation of nitrosamines in drinking water mainly due to the use of disinfectants particularly chloramines (WRF, 2016b). It can also form during chlorination in the presence of nitrite, during the ozonation of *N*-dimethylsulfamide (a metabolite of a fungicide), semicarbazide antiyellowing agents, and certain nitrogen-containing pharmaceuticals (Schmidt et al. 2008; Kosaka et al. 2009; Lee et al., 2010). For both chloramination and ozonation, bromide is believed to be a key catalyst (Choi et al., 2002a, 2002b; von Gunten et al. 2010; Shah et al. 2012). The key precursors present in treated and raw waters such as secondary, tertiary, and quaternary amines (polymer DADMAC, anion exchange resins, shampoo constituents) can lead to formation of nitrosamines (WRF, 2016b).

NDBA, NDEA, NMEA and NPYR have all been found in tobacco smoke. Higher concentrations were found in tobacco grown in high-nitrogen soil (USEPA, 2016). NDMA is used in research to induce cancer in mice, in the production of 1,1-dimethylhydrazine for rocket fuel, and has been found in pesticides (nematicide), plasticizers for rubber, battery components, solvents, antioxidants, lubricant additives, and polymers/co-polymers (SWRCB, 2017). In summer of 2018, several medications in Canada and around the world were recalled due to the presence of NDMA impurities in pharmaceutical active ingredients (Health Canada, 2021).

In May 2020, the U.S. Food and Drug Administration announced recall of the extended-release (ER) formulation of metformin, a prescription drug used to control high blood sugar in patients with type 2 diabetes due to the presence of NDMA above the agency's acceptable intake limit (USFDA, 2020).

There has been significant health research on nitrosamines, in both drinking water and food sources (Health Canada, 2011; USEPA, 2014). NDMA is a potent carcinogen based on animal studies by several routes of exposure, including ingestion of drinking water (Health Canada, 2011). NDMA and several other nitrosamines are classified by the United States Environmental Protection Agency (USEPA) as B2, probable human carcinogens (USEPA, 2014).

Nitrosamines have similar health effects (carcinogens), NDMA may cause liver damage in humans at high concentrations, and overexposure causes headache, fever, nausea, jaundice, vomiting, and dizziness (SWRCB, 2018). Its harmful effects are well studied in rodents causing tumors in the organs. The humans are mainly exposed through foods and beverages such as malt and whiskey, whereas drinking water is a minor source in comparison to dietary sources

(MN, DOH, 2018). The risk found during animal studies is extrapolated and associated with human risk levels. There are very few studies published on the nitrosamine exposure indicating systemic, reproductive, developmental, neurological, or immunological impacts (USEPA 2016).

N-Nitrosomorpholine (NMOR) was not included in UCMR2; however, it has been detected at WWTP plants. In a survey conducted to understand the occurrence of nitrosamines, NMOR was detected in 11 of 12 WWTP effluents sampled. Plants with higher levels of industrial inputs compared with domestic inputs contained higher levels of NMOR (Krasner et.al. 2020). When released to soil, NDMA can be highly mobile and will either volatilize or leach into groundwater (USEPA, 2017).

Assays of total N-nitrosamines in recreational and drinking water; however, indicate the nitrosamines may account for only 5-10% of nitrosamines present (Krasner, 2013). NDMA has been detected in groundwater contaminated by industrial facilities (Health Canada, 2011; Krasner, 2013; USEPA, 2014).

UCMR2

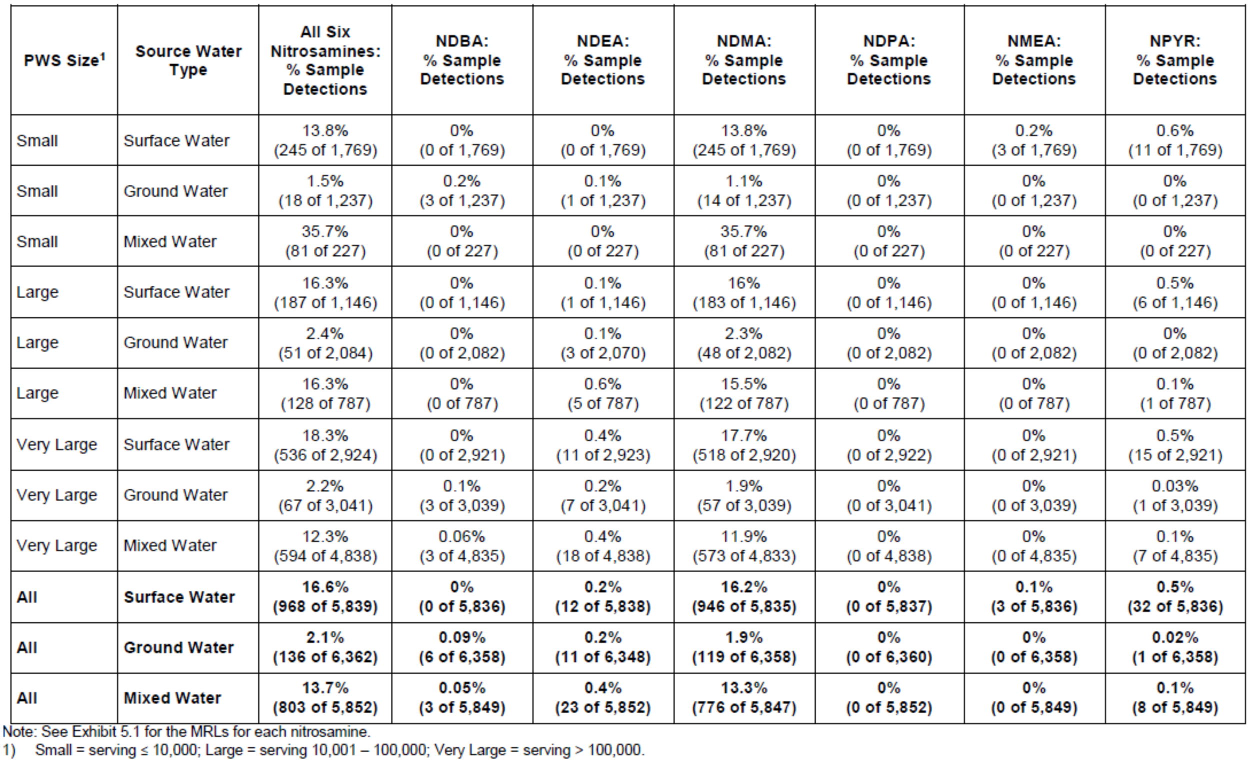
Water Ingestion Accounts for Extremely Low Fraction of Total NDMA Exposure

The statistical analysis performed on the Unregulated Contaminant Monitoring Rule 2 (UCMR2) database demonstrated that even for the highest drinking water formation of NDMA (i.e., chloramination of surface waters), drinking water ingestion accounted (when NDMA was detected) between 0.001 and 0.01 percent of the lifetime daily average dose of NDMA. This extremely low fraction of total NDMA exposure was partly caused by higher NDMA exposure in food, but overwhelmingly because of the extremely high endogenous formation of NDMA in humans (WRF, 2016b).

In the US, the most comprehensive nitrosamine data set in drinking water has been obtained during UCMR2 study, involving 1,198 water utilities. UCMR2 results indicated that NDMA was the dominant nitrosamine species observed in US distribution systems (Russell et al.2012), with concentrations above 2 ng/L of the minimum reporting level (MRL) at 24.6% of the systems monitored. NDMA was more prevalent in surface water (63%) than groundwater (16%) systems, occurring primarily in the presence of chloramines. California, Texas, Kansas, and North Dakota were the states with higher frequency of occurrence. The highest NDMA concentrations (i.e., >50 ng/L) have been observed at water utilities using chloramines (especially as the primary disinfectant and with long contact times), amine-based polymers (polyDADMAC or polyamine), and their source waters influenced by agricultural runoff and wastewater discharges (WRF, 2016a).

The UCMR2 data set published by USEPA is shown in Table 3-5 indicating NDMA being the most detected nitrosamine. Note again that NMOR was not included for analysis within the UCMR2.

Table 3-5. UCMR2 Nitrosamine Detection Rates (USEPA, 2016)



PWS Size[1]	Source Water Type	All Six Nitrosamines: % Sample Detections	NDBA: % Sample Detections	NDEA: % Sample Detections	NDMA: % Sample Detections	NDPA: % Sample Detections	NMEA: % Sample Detections	NPYR: % Sample Detections
Small	Surface Water	13.8% (245 of 1,769)	0% (0 of 1,769)	0% (0 of 1,769)	13.8% (245 of 1,769)	0% (0 of 1,769)	0.2% (3 of 1,769)	0.6% (11 of 1,769)
Small	Ground Water	1.5% (18 of 1,237)	0.2% (3 of 1,237)	0.1% (1 of 1,237)	1.1% (14 of 1,237)	0% (0 of 1,237)	0% (0 of 1,237)	0% (0 of 1,237)
Small	Mixed Water	35.7% (81 of 227)	0% (0 of 227)	0% (0 of 227)	35.7% (81 of 227)	0% (0 of 227)	0% (0 of 227)	0% (0 of 227)
Large	Surface Water	16.3% (187 of 1,146)	0% (0 of 1,146)	0.1% (1 of 1,146)	16% (183 of 1,146)	0% (0 of 1,146)	0% (0 of 1,146)	0.5% (6 of 1,146)
Large	Ground Water	2.4% (51 of 2,084)	0% (0 of 2,082)	0.1% (3 of 2,070)	2.3% (48 of 2,082)	0% (0 of 2,082)	0% (0 of 2,082)	0% (0 of 2,082)
Large	Mixed Water	16.3% (128 of 787)	0% (0 of 787)	0.6% (5 of 787)	15.5% (122 of 787)	0% (0 of 787)	0% (0 of 787)	0.1% (1 of 787)
Very Large	Surface Water	18.3% (536 of 2,924)	0% (0 of 2,921)	0.4% (11 of 2,923)	17.7% (518 of 2,920)	0% (0 of 2,922)	0% (0 of 2,921)	0.5% (15 of 2,921)
Very Large	Ground Water	2.2% (67 of 3,041)	0.1% (3 of 3,039)	0.2% (7 of 3,041)	1.9% (57 of 3,039)	0% (0 of 3,041)	0% (0 of 3,039)	0.03% (1 of 3,039)
Very Large	Mixed Water	12.3% (594 of 4,838)	0.06% (3 of 4,835)	0.4% (18 of 4,838)	11.9% (573 of 4,833)	0% (0 of 4,838)	0% (0 of 4,835)	0.1% (7 of 4,835)
All	**Surface Water**	**16.6% (968 of 5,839)**	**0% (0 of 5,836)**	**0.2% (12 of 5,838)**	**16.2% (946 of 5,835)**	**0% (0 of 5,837)**	**0.1% (3 of 5,836)**	**0.5% (32 of 5,836)**
All	**Ground Water**	**2.1% (136 of 6,362)**	**0.09% (6 of 6,358)**	**0.2% (11 of 6,348)**	**1.9% (119 of 6,358)**	**0% (0 of 6,360)**	**0% (0 of 6,358)**	**0.02% (1 of 6,358)**
All	**Mixed Water**	**13.7% (803 of 5,852)**	**0.05% (3 of 5,849)**	**0.4% (23 of 5,852)**	**13.3% (776 of 5,847)**	**0% (0 of 5,852)**	**0% (0 of 5,849)**	**0.1% (8 of 5,849)**

Note: See Exhibit 5.1 for the MRLs for each nitrosamine.

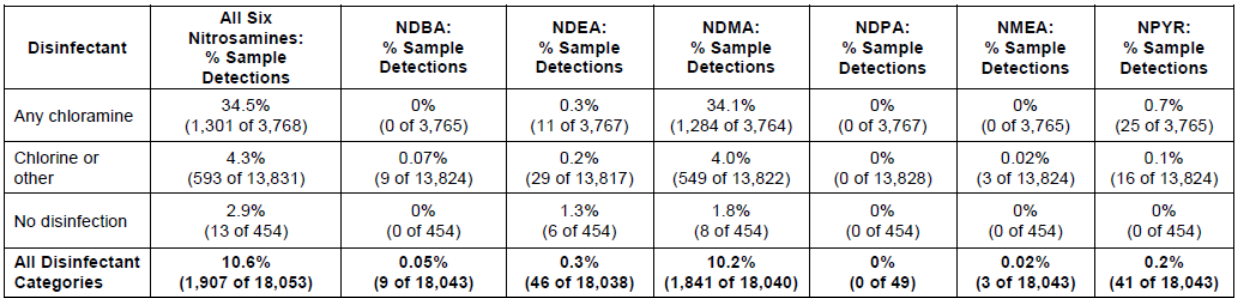
1) Small = serving ≤ 10,000; Large = serving 10,001 – 100,000; Very Large = serving > 100,000.

The UCMR2 monitoring also involved collecting data on the disinfectant used by the respective Public Water System. Following are the results in Table 3-6, presenting the formation of NDMA in samples using chloramine, chlorine, other disinfectants or no disinfection.

NDMA Formation with Chloramine

NDMA was detected in 34% of the samples disinfected with chloramine and was only detected in 3 percent of the samples disinfected with chlorine. Moreover, almost 70% of all chloraminated water systems detected NDMA in at least one sample (minimum reporting level [MRL] = 2 ng/L). The median and 90th percentile concentration of NDMA in chloraminated systems *with detections* was 4.1 and 15 ng/L, respectively. The occurrence data for NDMA typically showed continued formation in the presence of chloramine but not that of chlorine. Note, plant influents were not sampled in UCMR2, so it is unknown to what extent some nitrosamines were present in the raw water and were not formed at the plants, which may have been the case for some of the chlorine plants (WRF, 2016b).

Table 3-6. Nitrosamine Formation Data by Disinfectant (USEPA, 2016)



Disinfectant	All Six Nitrosamines: % Sample Detections	NDBA: % Sample Detections	NDEA: % Sample Detections	NDMA: % Sample Detections	NDPA: % Sample Detections	NMEA: % Sample Detections	NPYR: % Sample Detections
Any chloramine	34.5% (1,301 of 3,768)	0% (0 of 3,765)	0.3% (11 of 3,767)	34.1% (1,284 of 3,764)	0% (0 of 3,767)	0% (0 of 3,765)	0.7% (25 of 3,765)
Chlorine or other	4.3% (593 of 13,831)	0.07% (9 of 13,824)	0.2% (29 of 13,817)	4.0% (549 of 13,822)	0% (0 of 13,828)	0.02% (3 of 13,824)	0.1% (16 of 13,824)
No disinfection	2.9% (13 of 454)	0% (0 of 454)	1.3% (6 of 454)	1.8% (8 of 454)	0% (0 of 454)	0% (0 of 454)	0% (0 of 454)
All Disinfectant Categories	**10.6% (1,907 of 18,053)**	**0.05% (9 of 18,043)**	**0.3% (46 of 18,038)**	**10.2% (1,841 of 18,040)**	**0% (0 of 49)**	**0.02% (3 of 18,043)**	**0.2% (41 of 18,043)**

The survey conducted at full-scale drinking WTPs to assess the formation of N-nitrosamines and its precursors found the plants that use chloramine produced NDMA, whereas plants with chlorine residual in the distribution system typically did not produce NDMA and if formed were at lower concentrations. The study also found the plants that switched from chloramination to free chlorine had less NDMA formation (Krasner et al., 2020).

California Surveys

In a 2002 survey conducted by the California Department of Health Services (CDHS), elevated concentrations of NDMA were detected in locations where wastewater treatment plant effluent was used for aquifer recharge and near facilities that use unsymmetrical dimethylhydrazine (UDMH)-based rocket fuel (USEPA, 2017).

SWRCB sampled 260 wells from 2007 – 2017 and found 60 active and standby public water supply wells (of 260 wells sampled) had at least one detection for NDMA above California Cancer Potency factor (CA-CPF) of 0.0022 µg/L (increase in cancer risk per unit of exposure calculated by OEHHA - CA). The wells were mainly located in Sacramento (6) and Los Angeles (52) counties (SWRCB, 2017)

International Occurrence

Occurrence survey of nitrosamines in European countries indicated that there was no presence of nitrosamines in the drinking water because chloramine is not applied in most countries. The UK water distribution system had none to very negligible amounts of nitrosamines and is speculated due to addition of ammonia after the set chlorine contact time of 30 minutes, which could have possibly destroyed the precursors. Chloramine concentrations in the UK were often low (e.g., 0.5 mg/L). None of the source waters in this study were directly impacted by wastewater. Moreover, the use of certain polymers (e.g., polyDADMAC) was not believed to be widespread in England and Wales (WRF, 2016b).

A survey (2010-2011) in Australian drinking waters indicated the presence of NDMA (with an MRL of 3 ng/L) in 75% of chloraminated drinking waters, but only 33% of chlorinated drinking waters. In addition, the concentration of NDMA was higher in the chloraminated drinking waters (37% had >10 ng/L of NDMA) than in the chlorinated drinking waters (8% had >10 ng/L of NDMA). Also, NDMA occurrence in chloraminated waters was found to vary over time. In the first survey period, NDMA was not detected in 47% of the chloraminated waters and only 26% of the chloraminated waters had >10 ng/L of NDMA; whereas in the second survey period, NDMA was not detected in 17% of the chloraminated waters and 45% of the chloraminated waters had >10 ng/L of NDMA (WRF, 2016b). The major factors contributing to NDMA being detected at >5 ng/L were the chloramination practice and the use of poly-DADMAC as a coagulant aid (Linge et.al. 2017). The link between polymers and nitrosamine formation was first identified by the Ontario Ministry of the Environment in the province of Ontario, Canada, for an alum–polymer blend; the polymer used was a source of *N*-nitrosodimethylamine (NDMA) precursors. (Cornwell et.al., 2017).

The studies conducted in Alberta, Canada, and Japan indicated that NDMA is the most commonly detected nitrosamine at the highest concentration, where occurrence was more prevalent in chloraminated or, in some cases, ozonated systems, and that formation continued in chloraminated distribution systems (Krasner et al. 2020).

US and International Regulations

The World Health Organization issued a guideline value of 100 ng/L (0.1 µg/L) for NDMA in drinking water, based on the organization's estimated 10^{-5} cancer risk level (WHO, 2008). In 2011, Health Canada adopted a maximum acceptable concentration of 40 ng/L for NDMA in drinking water, based on the agency's estimated 10^{-5} cancer risk level (Health Canada, 2011). The Australian Drinking Water Guidelines (Australia NHMRC, 2013) list a health-based guideline value of 100 ng/L for NDMA. There have been no recent changes in the above guidelines.

California Drinking Water Notification Levels

There are no USEPA Health Advisories for nitrosamines. However, NDMA, NDEA, and NDPA have California drinking water Notification Levels of 10 ng/L each and OEHHA has developed PHG of 3 ng/L for NDMA (SWRCB, 2018). OEHHA's PHG for NDMA is at 10^{-6} cancer risk level (SWRCB, 2018).

Following are recent State guidelines established for surface and groundwater for NDMA.

Table 3-7. State guidelines for Surface and Groundwater for NDMA (USEPA, 2017)

State Guideline (µg/L)	Alabama 0.0013	Alaska 0.017	California 0.003	Colorado 0.00069	Delaware 0.001
Source	ADEM 2008	AL DEC 2008	Cal/EPA 2006	CDPHE 2013	DE DNR 1999
State Guideline (µg/L)	Florida 0.0007	Indiana 0.0049	Massachusetts 0.01	Mississippi 0.00131	New Jersey 0.0007
Source	FDEP 2005	IDEM 2015	MADEP 2004	MS DEQ 2002	NJDEP 2015
State Guideline (µg/L)	North Carolina 0.0007	Pennsylvania 0.0014	Texas 0.018	Washington 0.000858	W Virginia 0.0013
Source	NCDENR 2015	PADEP 2011	TCEQ 2016	WA DEP 2015	WV DEP 2009

If EPA decides to regulate nitrosamines, impacted water systems will need to explore strategies to reduce concentrations in their finished water and in the distribution system. More than one out of every 10 chloraminated water systems could be impacted by an NDMA maximum contaminant level (MCL) equivalent to the current California Notification Level (NL) of 10 ng/L (WRF, 2018).

The US does not currently have regulations, guidelines, or notification levels for NMOR. Germany has recommended a drinking water guideline of 10 ng/L and Australia has set their Drinking Water Reuse Guideline at 1 ng/L (Glover et.al., 2019).

Analytical Methods

Methods capable of detecting nitrosamines in drinking water include one EPA-developed method and two Standard Methods (SM) (USEPA 2016):

- EPA Method 521 uses solid phase extraction (SPE) and capillary column gas chromatography (GC) with large-volume injection and chemical ionization tandem mass spectroscopy (MS)
- SM 6450B Method is a solid-phase extraction method that uses a granular carbonaceous adsorbent resin.
- SM 6450C is a micro-liquid-liquid extraction method.

While contaminant-specific reporting levels are not available for SM 6450B and SM 6450C, comparison of MDLs suggests that they may be comparable to, or slightly higher than, reporting levels for EPA Method 521. All three methods include six nitrosamines – NDBA, NDEA, NDMA, NDPA, NMEA, NYPR (USEPA 2016).

TREATMENT METHODS

The common approach taken is to remove the precursors present in drinking water sources, including natural and synthetic amines and other nitrogen-containing compounds. Precursor removal processes include source management; adsorption using granular activated carbon (GAC) or powdered activated carbon (PAC), polymer optimization, and processes which destroy precursors, such as pre-oxidation, reverse osmosis, nanofiltration, distribution system and control management (WRF, 2018, USEPA, 2016). Substituting the most used polymer DADMAC at drinking water treatment plants was evaluated using natural polymers derived from corn, potato, tapioca, shellfish (chitosan), extracts of moringa seeds, cactus, Papilionaceae, *Vicia*, and seaweed (sodium alginate). Nine water treatment plants tested using these natural polymers and none of these polymers formed reportable levels of nitrosamines (USEPA, 2016, Cornwell et.al., 2017a).

Effects of Oxidants

The oxidants (e.g., chlorine, chloramine, chlorine dioxide, and ozone) commonly employed in water treatment are involved in NDMA formation and control in different ways; they may (1) participate directly in NDMA formation, (2) break some complex precursors to release NDMA, which enhances NDMA formation, and (3) break or deactivate precursors to suppress NDMA formation (WRF, 2016a).

Optimization of Chlorine and Ammonia Addition

Since dichloramine is considered as the important oxidant for NDMA formation from some precursors, hence adding chlorine prior to ammonia is preferable to prevent the formation of local high chlorine to ammonia ratio zones, promoting dichloramine formation, in water when chlorine is added with ammonia. Optimizing the chlorine and ammonia addition sequence is important for controlling nitrosamine formation (WRF, 2016a).

As a part of WRF project, a study was conducted at a midwestern US water treatment facility to evaluate replacement of alum plus polyDADMAC with a tapioca- or corn-based polymer with no added alum or other metal salt coagulant. Settled water turbidity in bench-scale testing with natural polymers was similar to or lower than with alum plus polyDADMAC. Residuals with natural polymer without alum were easier to thicken and dewater than residuals produced from alum plus polyDADMAC. Potential benefits of replacing alum plus polyDADMAC with natural polymers could include less metal content in residuals, residuals reduction, improved thickening and dewatering characteristics of residuals, and increased biodegradability of residuals (biodegradable cornstarch or tapioca starch replacing nonbiodegradable alum plus polyDADMAC), rendering the residuals suitable for disposal, discharge, or reuse applications not currently possible using alum plus polyDADMAC (Cornwell et.al.,2017b).

Unknown Precursors in Polymers

NDMA formation during chloramination of polyDADMAC solutions may result from reactions with either the polymer or low molecular weight contaminants, such as DMA, allyldimethylamine (ADMA), and diallyldimethyl ammonium chloride (DADMAC) monomer, but no conclusive results have been observed. NDMA formation from commercial polyDADMACs has been found to vary depending on manufacturer and batch (Hanigan et al. 2015). However, it is not known whether differences in measured NDMA formation relate to the presence of impurities in the polymer solution, or differences in the polymer itself (WRF, 2019a).

A study conducted on polyDADMAC impurities indicated presence of tertiary amine impurities within the polymer structure, which is believed to be the precursor that lead to the formation of NDMA. The treatment of polyDADMAC with methyl iodide to convert tertiary amine groups to less chloramine-reactive quaternary ammonium groups significantly reduced the formation of NDMA (Zeng et.al., 2016).

Other Treatment Processes

The majority of research to date has focused on NDMA and NDMA precursor removal, since NDMA is the most frequently detected nitrosamine in drinking water. Conventional treatment processes (e.g., lime softening and/or coagulation, followed by clarification and granular media filtration) that are effective at reducing the formation of regulated DBPs (i.e., TTHM and HAA5) are less effective for removal of NDMA precursors. Riverbank filtration and UV photolysis have been demonstrated to remove NDMA from contaminated sources. The most common method to treat NDMA in drinking water systems is photolysis by ultraviolet radiation in the wavelength range of 225 to 250 nanometers (nm). UV photolysis has been applied to degrade NDMA in contaminated water at groundwater treatment plants in the U.S. and Canada ranging in capacity from < 1 to more than 10 million gallons per day. Studies indicate reformation of NDMA after UV treatment; but the observed increase in NDMA concentration from reformation is small compared to the amount of NDMA removed during UV photolysis. Nanofiltration at bench-scale has shown to remove between 9 – 75% of NDMA depending on the membrane type (USEPA 2017, WRF, 2018).

A study conducted by Uzun et.al. (2017), showed that polymer type and dose, PAC application, and oxidation practices affected the NDMA FP removals at full-scale WTPs. An average NDMA FP removal efficiency of alum clarification was 12–30%, and different seasons and various temporal climatic conditions did not significantly affect the removal efficiencies of NDMA FP. PAC addition significantly increased the removal of NDMA FP. The use of oxidants (i.e., Cl2 and ClO2, and especially their simultaneous application), enhanced the removal of NDMA FP and lowered the NDMA concentration in the distribution systems to less than 10 ng/L under different operational conditions. However, simultaneous application of ClO2 and Cl2 led to the formation of elevated levels of ClO3-. The average NDMA FP reduction by RO and MF filtration was 81 and 7%, respectively (Uzun et.al., 2017).

An Environmental Security Technology Certification Program demonstration project evaluated the technical effectiveness and cost of using a fluidized bed bioreactor (FBR) for treating NDMA in groundwater at a test facility. The FBR was found to be an effective means to treat NDMA, decreasing concentrations from 1 µg/L to 4.2 ng/L. The cost of the full-scale FBR was determined to be significantly less than the comparable ultraviolet system over a 30-year remedial timeframe (USEPA, 2017).

Biological Filtration

Employing biofiltration ahead of chloramine or ozone disinfection could be a beneficial treatment strategy in reducing NDMA precursors. Biofiltration is a known strategy for reducing chloramine derived NDMA formation. Possible removal mechanisms during biofiltration are biotransformation, adsorption to the media, and adsorption to biofilm. Full-scale biological activated carbon (BAC) filters have been shown to reduce chloramine derived NDMA formation potential by more than 80% (Marti et.al., 2017).

Biological filtration (biofiltration) is the operational practice of managing, maintaining, and promoting biological activity on granular media in a high-rate, gravity-fed filter to enhance the removal of organic and inorganic constituents before introducing treated water into the distribution system. Many utilities are either operating or considering converting to biofiltration to meet a range of water quality goals including removal of organic matter, taste and odor compounds, manganese (Mn), ammonia (NH3), and DBP precursors. Research has shown both increases and decreases in N-nitrosodimethylamine (NDMA) precursors across biological filters (biofilters) (WRF, 2019b).

The WRF research team has developed three hypotheses regarding the source of NDMA precursors during biofiltration and the potential effects of biofiltration on these precursors (WRF, 2019b).

- Microorganisms on biofilters may provide a source of NDMA precursors through production of biomolecules or through cells that are sloughed off the filters. In addition, previous results suggest that nitrifying conditions in biofilters may increase NDMA precursor formation.
- Microorganisms on biofilters may transform organic compounds in the influent, such as polymers or contaminants from wastewater discharges, into NDMA precursors. It is also possible, but less common, that microorganisms in biofilters can degrade precursors.
- Microorganisms on biofilters may transform inorganic precursors in the influent or formed in the biofilter (e.g., hydroxylamine) into more potent NDMA precursors.

A study conducted on polyDADMAC impurities indicated presence of tertiary amine impurities within the polymer structure, which is believed to be the precursor that lead to the formation of NDMA. The treatment of polyDADMAC with methyl iodide to convert tertiary amine groups to less chloramine-reactive quaternary ammonium groups significantly reduced the formation of NDMA (Zeng et.al., 2016).

Filter Backwash

Filter backwash is an essential maintenance technique applied to clean and restore biofilter treatment capacity by removing both retained particles and excess biomass. Granular-media-based filtration systems are required to optimize backwash procedures to reduce negative impacts of degraded effluent water quality associated with filter ripening. Currently turbidity serves as the only regulated parameter used to evaluate the effectiveness of a backwash, even though the release of biofilm-related materials, reported to be NDMA precursors, could also occur during filter ripening. With an increasing number of utilities switching to chloramination for secondary disinfection (Li, 2011), it is critical to examine the impact of filter backwash on N-DBP formation potential during filter ripening (Feng, 2020). Wilczak et.al. (2003) demonstrated increased NDMA formation during recycling of filter backwash supernatant.

Recommendations to Utilities (WRF, 2016a and 2016b):

- It is important to characterize and understand NDMA Formation Potential (FP) patterns in the watersheds for identifying the sources of NDMA precursors and developing source control and/or use strategies. The presence of upstream reservoirs, wastewater treatment plant discharges, mixing conditions and other such factors can influence the NDMA FP levels at the intake(s) of a utility.
- Modifications in treatment and disinfection practices may be needed to control nitrosamine formation.
- Utilities that use chloramine need to determine the occurrence of nitrosamines in their finished water.
- Event monitoring to assess possible peak formation of nitrosamines. Events can include times in which high polymer doses are used; when river flow is low, where the wastewater impact in the source water may be higher; or during spring runoff, when there may be more precursors or ammonia in the raw water.
- If significant levels of nitrosamines are detected (e.g., California has a notification level of 10 ng/L for NDMA), then the utility should do a study to determine the source(s) of the precursors and the efficacy of current treatment processes to remove/destroy precursors.
- If polyDADMAC and/or polyamine are used, Formation Potential (FP) tests of the water before and after polymer use should be conducted to determine if the polymer adds substantial levels of precursors to the water.
- Utilities should frequently perform optimization testing of the polymer by conducting jar tests, especially when a new batch of polymer is introduced but also when raw water quality changes rapidly (Wolde-kirkos et.al.2021).
- An improved understanding of water systems with systematic and continuous investigation (from source to tap) may allow water utilities to identify different options to more effectively control NDMA formation while complying with regulated DBPs in chloraminated finished waters (Uzun et.al., 2017).

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4. Unregulated Disinfection Byproducts

Disinfection Byproducts (DBPs) are produced as a byproduct of disinfecting drinking water. DBPs are formed by the reaction of disinfectants (such as chlorine, chloramine, or ozone) with naturally occurring organic matter, bromide, iodide, and anthropogenic pollutants (Richardson and Postigo, 2012). DBPs continue to be a subject of research studies. As with many CECs, occurrence studies are more frequent than health studies, and therefore interpretation of occurrence in terms of health is difficult.

MEDIUM PRIORITY FOR SFPUC

Although unregulated DBPs have been detected in SFPUC drinking water, concentrations are relatively low or are below guidelines where available (e.g., chlorate and formaldehyde). Additionally, DBP precursors are low in SFPUC source waters.

This section presents: (1) Screening Evaluation Table, (2) SFPUC Monitoring Review 2016-2021, and (3) Technical Review 2016-2021 of available scientific studies.

Table 4-1. Screening Evaluation Table for Unregulated Disinfection Byproducts

GENERAL INFORMATION ON CEC	
Instructions	This Screening Evaluation may be applied to a CEC group or an individual CEC. The purpose of this section of the Evaluation is to develop background information on the CEC or CEC group.
CEC Name	**Unregulated Disinfection Byproducts**
CEC Description Is CEC a group? If individual CEC, which group is CEC part of?	DBPs are produced as a byproduct of disinfecting drinking water. DBPs are formed by the reaction of disinfectants (such as chlorine, chloramine, or ozone) with naturally occurring organic matter, bromide, iodide, and anthropogenic pollutants. (Richardson and Postigo, 2012) Haloacetonitriles (HAN) and haloacetamides (HAM) are preferentially derived from algal precursors. Nitrosamines are a separate group of disinfection byproducts and are not included in this CEC grouping. List of DBPs is shown in Table 4-2.
CEC Grouping What is the basis for grouping? *(Grouping factors are: common health effects, treatment, and analytical method, and/or compound co-occurrence)*	The basis for the grouping is common source (byproduct of disinfection), precursors, analytical methods, and compound co-occurrence.
Examples and Indicators If group, what are notable examples? Are there possible indicator constituents? *(A suitable indicator occurs at quantifiable levels and may co-occur with other CEC, exhibit similar treatment and fate in environment)*	The subset that has been quantified constitutes only ~30% of the total organic halogen (TOX) in chlorinated waters on a median basis, with THM4 and HAA each accounting for ~10% of TOX. (Li and Mitch, 2018) The evidence supporting the practice of using a single DBP species as an indicator for the others is not strong. (Marcoux et al., 2017) For example, THM are not a reliable surrogate for HAN, which can be measured with the same method as THM. (Furst et al. 2021) Bromide concentration may not be a good predictor of potential iodo-THM formation. (Tuguela et al. 2018) Iodo- THM formation does not correlate well with THM formation. Total iodine was found to be the best indicator for the presence of iodine precursors that favor the formation of iodo-THM. (Tuguela et al. 2018) Measuring TOX provides an estimate of the total amount of organic compounds containing covalently-bound chlorine, bromine, and iodine—including both known and unknown DBPs formed during treatment—in a water sample. (WRF, Westerhoff et al. 2022) Ion chromatography has been adopted to separate and measure individual halides, which allows the calculation of total organic chlorine (TOCl), total organic bromine (TOBr), and TOI. (Dong et al. 2019)

	Finally, total organic nitrogen (TON) might also be a way of capturing the more toxic N-DBPs. However, these surrogate approaches would invariably incorporate many low-toxic or non-toxic compounds into the measurement and will likely include DBPs that may not pose significant health risks. (Richardson and Plewa, 2020)
Health Advisories Does CEC have a USEPA Health Advisory (e.g., Drinking Water Equivalent Level [DWEL]) or California Notification Level?	Health Advisories and DWELs exist for many DBPs. For example: Formaldehyde DWEL 7 mg/L, CA NL 0.1 mg/L MX DWEL 2.0 mg/L, CA NL 0.35 mg/L Chlorate CA NL 0.8 mg/L
Regulatory Development Status Is CEC on USEPA CCL, UCMR, or California (PHG) list?	HAA9 and HAABr6 were on UCMR4. Four unregulated HAA, two haloacetonitriles (DBAN, DCAN), three halonitromethanes (BDCNM, TCNM, DBCNM), formaldehyde, iodinated THM, chlorate, are on Draft CCL5
CONTEXT OF CEC EVALUATION AT SFPUC	
Instructions	The purpose of this section is to report SFPUC experience with the CEC or CEC Group, including occurrence data for each source water if available.
Purpose Why is evaluation undertaken? What is new about the issue that is considered 'emerging' (e.g., new chemical, new effect)?	DBPs continue to be a subject of research studies. As with many CEC, occurrence studies are more frequent than health studies, and therefore interpretation of occurrence in terms of health is difficult.
Customer Interaction Widespread public concerns? Media coverage?	Occasionally, some customers become concerned about unregulated trace DBP. The importance of disinfection far outweighs any concerns for unregulated DBP.

Expected Outcomes What are the likely benefits of the investigation to SFPUC and its customers?	The state of the science for unregulated DBPs is evolving. With a strong knowledge base and participation in state or national monitoring surveys, SFPUC can continue to be responsive to emerging evidence.
Occurrence Data (US and SFPUC) What occurrence information is available? Have detections, if any, been confirmed by follow-up sampling and/or QA/QC review?	Based on UCMR4 data, the calculated population-weighted averages are 24.9 µg/L for HAA9, 19.1 µg/L for HAA5, and 7.0 µg/L for HAA6Br for the systems included in UCMR monitoring. The population-weighted average of THM4 in the United States community water supplies are 26 µg/L. (Evans et al. 2020) The concentration levels reported for I-DBP in drinking water are either in ng/L or low µg/L. In general, I-DBP can be found in drinking water treated with chlorine, chloramine, and ozone in the presence of iodide, but predominantly by chloramination. Water from coastal areas subject to salt-water intrusion can increase the formation of I-DBP. (Mian, 2021)
Supporting Information List key references	Li Xing-Fang and William A. Mitch (2018). Drinking Water Disinfection Byproducts (DBPs) and Human Health Effects: Multidisciplinary Challenges and Opportunities. Environ. Sci. Technol. 2018, 52, 1681−1689. DOI: 10.1021/acs.est.7b05440. Mian Haroon R., Guangji Hu , Kasun Hewage, Manuel J. Rodriguez, Rehan Sadiq (2018). Prioritization of unregulated disinfection byproducts in drinking water distribution systems for human health risk mitigation: A critical review. Water Research 147 (2018) 112-131. WRF, Reckhow, D.A., et al. (2016) Water Research Foundation, Fate of Non-Regulated Disinfection By-Products in Distribution Systems, [WRF Project #4242], 2016. WRF, Westerhoff Paul, Naushita Sharma, Chao Zeng, Tanju Karanfil, Daekyun Kim, Amlan Ghosh, Chad Seidel, Carleigh Samson, Andy Eaton (2022). Occurrence Survey of Bromide and Iodide in Water Supplies. Water Research Foundation, ISBN: 978-1-60573-568-9, WRF Project # 4711.

DIAGNOSTIC QUESTIONS TO SUPPORT CEC PRIORITIZATION		
Instructions	The purpose of the Diagnostic Questions is to determine whether the CEC or CECs Group are significant to SFPUC drinking water and whether they merit further evaluation and/or action. All answers require explanation except those clearly not applicable. The Diagnostic Questions are divided into Health, Occurrence, and Treatment sections. The more questions are answered with a “Yes”, the higher the probability that the CEC is a high priority or that a proactive approach should be taken.	
HEALTH EFFECTS FROM SCIENTIFIC STUDIES		
Question	**Answer**	**Explanation and Comments**
Is scientific knowledge on CEC health effects well developed?	**Yes** **No for New**	HAA have overall greater cancer potency than THM. HAA5 are associated with a smaller number of attributable cancer cases compared to the HAA6Br group, suggesting that in addition to HAA5, levels of other HAA should be lowered in drinking water in order to protect public health. (Evans et al. 2020) Genotoxicity assays have shown compounds with mono or dihalogenated carbon atoms to be more toxic than their trihalo analogues. While systems using free chlorine tend to produce large amounts of trihalo compounds, chloramine systems favor dihalogenated species (WRF, Reckhow, et al., 2016). Bromine-containing DBPs are believed to be of a higher health concern than the chlorine-containing analogues based on toxicology research. Moreover, certain nitrogenous DBPs (e.g., HANs) are considered more cytotoxic and genotoxic than the regulated THMs and HAAs (Krasner et al. 2016) Haloacetonitriles, may be greater contributors to the DBP-associated toxicity of disinfected waters than the THM4, HAA5, and nitrosamines of current regulatory interest. (Li and Mitch, 2018) Future studies should include real toxicity measurements to assess whole water mixtures, especially since quantified DBPs only account for a portion of the overall TOX. (Cuthbertson et al. 2020)

Question	Answer	Explanation and Comments
Based on current scientific understanding, does the CEC pose potential health risk at the levels typically found in drinking water in the US?	**Possible**	Risk management for regulated and unregulated DBPs represents a health risk trade-off between a non-existent or small cancer risk from DBPs versus overwhelming direct evidence that a failure to disinfect drinking water will make some consumers ill from microbial disease (Hrudey, 2012). Hrudey and Charrois (2012) state that on the basis of the available toxicological information for chlorination DBPs, there is little indication of harm to human health at the low concentrations found in drinking water, even allowing for additive or synergistic effects from the presence of multiple chlorination DBP. On the other hand, epidemiological studies taken together have suggested an association between chlorination DBP and urinary bladder cancer (Hrudey, 2012; WRF, Hurdley et al. 2015). On this basis, unregulated DBP may occur in U.S. drinking waters at greater than a de minimis risk.
Adverse health impacts observed in other drinking water systems? **Are public health studies documenting human health impacts (disease or outbreaks) available?**	**Possible**	In general, it is difficult to link specific health effects to any individual DBP or group of DBPs, however chlorination DBP have been identified as a credible source of risk for urinary bladder, colon or rectum cancer (Hrudey, 2012, WRF, Hrudey et al. 2015) as well as adverse reproductive outcomes (Hrudey, 2012). Epidemiological data on unregulated DBPs are scarce and reported health effects have not been specifically associated with unregulated DBP (Hebert et al., 2010). To the best of SFPUC knowledge, there have been no adverse health effects due to unregulated DBPs in other drinking water systems.
Existing regulations or guidelines outside of US (e.g., WHO, EU)?	**Yes**	HAN, HAL, NHAL, please see Table 4-12.
Existing US health advisories or CA notification levels?	**Yes**	Health Advisories and DWELs exist for many DBPs. For example: Formaldehyde DWEL 7 mg/L, CA NL 0.1 mg/L MX DWEL 2.0 mg/L, CA NL 0.35 mg/L Chlorate CA NL 0.8 mg/L

Question	Answer	Explanation and Comments
Likely US regulation in the next 10 years? **Is CEC on a regulatory development list, such as CCL?** **Is there a pending regulation or California PHG?**	**Possible**	HAA9 and HAABr6 were on UCMR4. Four unregulated HAA, two haloacetonitriles (DBAN, DCAN), three halonitromethanes (BDCNM, TCNM, DBCNM), formaldehyde, iodinated THM, chlorate, are on Draft CCL5
SUMMARY – SIGNIFICANT TO PUBLIC HEALTH IN GENERAL? (Based on above answers)	**Possible**	DBPs continue to be a subject of research studies. As with many CEC, occurrence studies are more frequent than health studies, and therefore interpretation of occurrence in terms of health is difficult.

OCCURRENCE

Question	Answer	Explanation and Comments
Is scientific knowledge on CEC sources/formation well developed?	**Yes**	DBPs are produced as a byproduct of disinfecting drinking water. They are formed by the reaction of disinfectants (such as chlorine, chloramine, or ozone) with naturally occurring organic matter, bromide, iodide, and anthropogenic pollutants (Richardson and Postigo, 2012; Krasner, 2012). Source waters impacted by wastewater and/or algae may have higher levels of N-DBPs (unregulated) due to the increased organic nitrogen precursors (Bond et al., 2011). Anthropogenic sources of bromide in source waters include effluent from coal-fired power plants, hydraulic fracturing, wastewater from oil production, and textile production. (Samson et al. 2017) Chlorate may be introduced as a contaminant of hypochlorite solutions used for disinfection (Gorzalski, 2015). Factors affecting DBP formation include bromide [and iodide] content, the type and quantity of the NOM, water pH and temperature, the type and dose of disinfectants used, and the point in the treatment process at which the disinfectant is added. Chloramine produces lower levels of THM and trihalogenated HAA (TXAA) but may not adequately minimize the formation of dihalogenated HAA (DXAA). Disinfection of waters high in bromide can form more brominated compounds (Krasner et al. 2016) Iodo-THM (as well as iodo-HAA) have been found in disinfected water from water sources with no detectable iodide (MDL = 0.13 µg/L); possibly other organic or inorganic iodine sources may have been involved. Naturally occurring ammonium in the source water can significantly increase the potential for the formation of iodo-THM. (Tuguela et al. 2018) Chloramination promotes greater formation of I-DBP than chlorination. (Huang et al. 2018) Haloacetonitriles (HAN), halonitromethanes (HNM) and haloacetamides (HAcAm) are among the most frequently detected N-DBP in drinking water but are not included in the drinking water guidelines of any country. They can be formed by disinfection with both chlorine and chloramine. (WRF, Farré et al. 2016)

Question	Answer	Explanation and Comments
CEC presence reported in other water supplies? Are occurrence studies available?	Yes	Unregulated DBPs have been detected in many U.S. drinking waters. In a study covering the drinking water distribution systems of 23 cities in the United States, highly toxic IAA and I-THM were detected with concentrations ranging from sub µg/L to several µg/L levels. (Huang et al. 2018) At 8 locations, including WTS using chlorine or chloramine, total iodo-THM concentrations were in the same range or higher than regulated THM4 concentrations (Tuguela et al. 2018). This is highly unusual (Dr. Mitch, personal communication). TOBr levels in distribution systems ranged from 2 to 116 µg/L. The TOI levels were always below the detection limit of 20 µg/L. (WRF, Westerhoff et al. 2022) I-DBPs can also form in pipes in the distribution system. Corrosion leads to formation of scales on inner surfaces as well as release of metal ions into the water. PbO2 and MnO2 can provide an oxidant reservoir for I-DBP formation in distribution systems. (Dong et al. 2019) An increased concentration of HAN was observed in distribution systems due to decreasing pH and increasing temperature conditions. According to the data collected for this literature review, the level of HAN in drinking water ranged between 0.6-24 µg/L. Dichloroacetonitrile (DCAN) is the most prominent species among HAN, detected in drinking waters. (Mian, 2021) HK concentrations vary throughout the distribution systems due to base-catalyzed hydrolysis reactions and are not stable in high pH (>7) environments. The concentration of HK ranged from 1.23-8.6 µg/L. (Mian, 2021) High levels of CNCL were reported as a result of using chloramination compared to chlorination. The average level of CNCL in distribution systems was around 4 µg/L. (Mian, 2021) Chloramination generally produces a greater percentage of unknown AOX compared to chlorination, but this trend was not observed at the two WTPs that use in situ-formed chloramines for distribution, likely due to the initial contact time with free chlorine. (WRF, Farré et al. 2016)

Question	Answer	Explanation and Comments
CEC present in SFPUC watersheds and/or surface waters? Are there complex issues involved in managing CEC ;e.g., point vs. non-point sources?	**No**	DBPs are not found in SFPUC watersheds, or source waters (surface waters and groundwater) prior to disinfection.
Is the CEC a potential groundwater contaminant?	**No**	As with surface water, regulated and unregulated DBPs would be expected upon groundwater disinfection (UMass, 2012). Concentrations of regulated DBPs formed in chlorinated/ chloraminated groundwaters were lower than in surface water. Unregulated DBPs in treated groundwater also tend to be lower than in surface water. Because of the lower levels of DBP precursors, DBPs are likely not to be an issue for groundwater wells.
If the CEC is a potential groundwater contaminant, is it highly mobile in the subsurface? *Is* the CEC low-sorbing and resistant to microbial degradation?	**N/A**	

Question	Answer	Explanation and Comments
Precursor present in SFPUC source waters? *(Including surface waters and groundwaters)*	Yes	The primary organic precursors for DBPs are humic substances in NOM. These are derived from natural biopolymers, including humic and fulvic acids, but their extensive degradation fosters a diversity of structures that prevents clear characterization. (Li and Mitch, 2018) Precursors such as bromide and iodide are present in low levels in SFPUC source waters. Bromide-related and iodide-related DBP levels have been low or non-detectable in SFPUC drinking water. Occurrence survey in 2018-2019 reported median bromide concentration of 80 µg/L. Weekly or monthly variations in bromide concentrations regularly occur within any given source water. Iodide was detected in 46% of surface waters and 64% of groundwater at or above the detection limit of 1 µg/L. Iodate ion was widely detected in surface water and groundwater. The 75th percentile concentrations of iodide and iodate were 5 and 3 µg/L, but maximum concentrations reached 252 and 145 µg/L, respectively. Water systems with groundwater sources tend to have higher bromide incorporation factor (BIF) values than systems with surface water sources. (WRF, Westerhoff et al. 2022) The average raw water TON concentration in this study was 0.34 mg/L-N, compared to 0.20 mg/L-N in a study of 28 U.S. WTPs and 0.29 mg/L-N reported by another U.S. study that targeted algae- and wastewater impacted sources. The average DON concentration for 28 water treatment plants was reported to be 0.19 mg/L in raw waters and 0.15 mg/L in finished waters and ranged from <0.05 to 0.45 mg/L. (WRF, Farré et al. 2016)
Formed or added during current SFPUC treatment? If so, describe whether the formation or addition of CEC can be controlled.	Yes	DBPs form as a result of disinfection. Chemical disinfectants used by SFPUC (in different parts of the local and regional systems) include chlorine, chloramine, and ozone. Controlling DBP formation during treatment is complex because different DBPs are formed depending on the type of disinfectant and strategy. For example, use of chloramine rather than chlorine may reduce the levels of certain regulated DBPs but can increase the levels of certain unregulated DBPs (e.g., nitrogen-containing DBPs and haloacetaldehydes) (Richardson and Postigo, 2012; Krasner, 2012). Ozonation prior to chlorination may increase the formation of chloropicrin and halonitromethanes (Krasner, 2012). Hypochlorite, especially when stored at high temperatures, can introduce disinfection byproducts such as chlorate, perchlorate, and bromate into the drinking water. (Breytus et al. 2017)

Question	Answer	Explanation and Comments
Formed or added within SFPUC storage or distribution? If so, describe whether the formation or addition of CEC can be controlled.	Yes	DBP can increase in the distribution system due to additional contact time between precursors and the disinfectant. DBP precursors can be shed by nitrifying biofilms in chloraminated distribution systems. SFPUC prevents this by minimizing detention time in the distribution system.
Detected in SFPUC drinking water?	Yes	Chlorate, HAA9, and iodo-DBPs have been detected in SFPUC finished drinking water. In addition, other unregulated DBPs have been detected as part of the WRF #4242 Study by UMass and Yale (Reckhow, et al., 2016).
SUMMARY – OCCURRENCE IN SOURCE AND DRINKING WATER? *(OR SIGNIFICANT POTENTIAL TO OCCUR)* *(Based on above answers)*	Yes	Unregulated DBPs have been detected in SFPUC finished drinking water and distribution system. However, concentrations of regulated and unregulated DBPs are minimized by optimizing treatment and disinfection. Detention time in the distribution system is minimized. Additionally, the precursors bromide and iodide are low in SFPUC source waters. In 2006, SFPUC participated in an USEPA survey of iodo-THMs and the concentrations have been some of the lowest in the survey. Similarly, a 2012 survey of unregulated DBPs in the distribution system indicated relatively low or similar concentrations compared to other utilities for most DBPs evaluated (Reckhow, et al., 2016). There is no single set of conditions (e.g., chlorine vs chloramine, dose, pH, water age, etc.) that can be used in water distribution that results in minimization of all DBPs (Reckhow, et al., 2016). Regulated and unregulated DBPs are readily formed during disinfection. In the case of SFPUC, levels of select unregulated DBP that have been sampled have been low. The only exception is chlorate. Chlorate levels at SVWTP have been above 700 ug/L with a CA Notification Level of 800 ug/L. Precursors for unregulated DBPs can be contributed by algae and wastewater discharges. Additionally, the impact of fire within the watershed on precursors for unregulated DBPs is unclear.

TREATMENT

Question	Answer	Explanation and Comments
Is scientific knowledge on CEC treatment/removal well developed?	**Yes**	The best way of controlling all DBP is to reduce the amount and reactivity of the TOC prior to addition of chemical disinfectants or oxidants (Reckhow, et al., 2016). DBP species behave differently during treatment and distribution. Efforts to reduce regulated and non-regulated DBPs must focus primarily on WTP operations and distribution system. (Marcoux et al., 2017) DBP formation and calculated toxicity is highly dependent on source water precursor material and disinfectant type, making comparisons between plants difficult. A large portion of total organic halogen remains unknown in chloraminated waters. (Cuthbertson et al. 2020) Currently, there are no commercial technologies employed by drinking water utilities to remove bromide from drinking water. (WRF, Westerhoff et al. 2022) The HNM concentrations increase due to pre-ozonation before chlorine or chloramine disinfection. The concentrations of HNM were between 0.16-1.50 µg/L. (Mian, 2021) HAM are generally produced by chloramination and ozonation without biofiltration. The concentration of HAM ranged 1.50-7 µg/L. Dihalogenated species of HAL are prone to be formed with the presence of chloramine and ozone. Trihalogenated HAL occur more frequently when using chlorine instead of chloramine. (Mian, 2021)
Likely to pass through current treatment for Hetch Hetchy Supply? Describe any complex issues involved with the treatment/removal of CEC.	**Yes**	DBPs form as a result of disinfection. Tesla Water Treatment Facility provides primary disinfection using UV treatment and chlorine.

Question	Answer	Explanation and Comments
Likely to pass through current treatment at SVWTP? Describe any complex issues involved with the treatment/removal of CEC.	Yes	DBPs form as a result of disinfection. Sunol Valley Water Treatment Plant (SVWTP) uses chlorine and chloramine for disinfection. Some precursor material is being removed prior to disinfection during coagulation and filtration but it is not 100% effective.
Likely to pass through current treatment at HTWTP? Describe any complex issues involved with the treatment/removal of CEC.	Yes	DBPs form as a result of disinfection. Harry Tracy Water Treatment Plant (HTWTP) uses ozone, chlorine, and chloramine for disinfection. Some precursor material is being removed during coagulation and filtration but it is not 100% effective. Brominated DBPs increased after biofiltration (on anthracite/sand filters), with a much higher increase at longer EBCTs. This could be explained by the increase in bromide to carbon ratio during biofiltration. (WRF, Farré et al. 2016) BAC provides mixed performance in the overall reduction in regulated and unregulated DBP formation potential. BAC filters, the performance in DBP reduction is not nearly as significant as with GAC that is operated in adsorptive mode with replacement intervals on the order of <1 year. (WRF, Stanford et al. 2019)
Likely to pass through current treatment for groundwater? Describe any complex issues involved with the treatment/removal of CEC.	Yes	DBPs form as a result of disinfection. Groundwater will be disinfected using chlorine prior to blending with chloraminated surface waters and chloraminated at the well head for regional wells.
SUMMARY – LIKELY TO PASS (NOT REMOVED BY) CURRENT TREATMENT? *(Based on above answers)*	Yes	DBPs form as a result of disinfection.

CEC PRIORITIZATION – CURRENT ASSESSMENT	
Instructions	This section prioritizes the CEC based upon the information developed in the above Diagnostic Questions as well as in the background information. For high and medium priorities, develop monitoring and/or mitigation measures as appropriate. For low priorities, maintain current measures, track regulatory developments, health/technical studies and reevaluate priority when needed.
Could CEC occur in SFPUC drinking water at levels of possible health significance? *(Based on above Diagnostic Questions)*	**YES** Unregulated DBPs are formed at trace levels during disinfection and occur in SFPUC drinking water. The occurrence and fate of these CECs are a focus of ongoing research; much less is known about the health significance in drinking water. In 2012, SFPUC completed participation in a WRF Project #4242, which identified levels of unregulated DBPs that were generally lower than or similar to other utilities (Reckhow, et al., 2016).
CEC Prioritization for SFPUC <u>High</u>, <u>Medium</u>, or <u>Low</u>. Provide explanation. *(A high number of "Yes" answers to the Diagnostic Questions indicates a higher priority, and "No" or very few "Yes" answers indicates a lower priority.)*	**MEDIUM** Although unregulated DBP have been detected in SFPUC drinking water, concentrations are low relative to other drinking waters (e.g., iodo-DBP) or are below guidelines where available (e.g., chlorate and formaldehyde). Additionally, DBP precursors are low in SFPUC source waters. It is not likely that these CEC, other than chlorate, will be regulated in the near future. Chlorate and formaldehyde have CA NL. Chlorate and formaldehyde are detected in SFPUC treated drinking waters at levels below CA NL; however, chlorate in SVWTP effluent has been detected near the NL. Reduction of chlorate levels is recommended.
Implemented Actions Indicate the progress and results of any action items, above, such as implemented in previous cycles of CEC review. Evaluate whether changes to the action plan are required.	• Adjustment of operations at Tesla Treatment Facility for better control of regulated DBP during elevated TOC seasons. Conducted mixing evaluation at Alameda Siphons. • Discontinued prechlorination at SVWTP (only as needed now). Constructed Chlorine Contact Tank. • Conducted peroxide bench tests for Hetch Hetchy water supply. • Conducted UCMR4 mandatory monitoring for 9 HAA and 2 indicator parameters in 2018-2020. • Minimized detention time in the distribution system through hydraulic improvements (primarily after 2004 chloramine conversion), mixers and seasonal outages of finished water storage facilities. • Continued to implement the Chemical Quality Control Program. • Followed studies and regulatory developments for unregulated DBP.

Recommended Actions Does the situation merit investing additional resources or has the information gathered so far fulfilled due diligence? Actions could include monitoring and other measures (specified by source water, if necessary).	• Maintain source water protection and optimized multibarrier water treatment and distribution system operation. • Track information, peer-reviewed publications, and any federal and state regulatory developments. • Implement preozonation at SVWTP. • Monitor bromide on a regular schedule (weekly) in source waters. • Monitor TOX to provide an estimate of the total amount of organic compounds containing covalently-bound chlorine, bromine, and iodine—including both known and unknown DBPs. • Evaluate the effects of wildfires on loadings of precursors for unregulated DBPs into the SFPUC system. • Monitor the effects of algal blooms in SFPUC reservoirs on loadings of unregulated DBP precursors. • Monitor the effects of nitrification within storage facilities on loadings of unregulated DBP precursors. • Evaluate impacts of any plans for potable reuse on loadings of precursors for unregulated DBPs.

This evaluation was prepared based on available information (peer-reviewed literature and occurrence data) with the purpose of prioritizing work and informing the public on unregulated CEC. This evaluation will be updated every 6 years or when significant new research or occurrence data on CEC become available that may warrant changing priority and recommendations.

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Contaminants of Emerging Concern (CEC) in Drinking Water

Unregulated Disinfection Byproducts

The list of DBP reviewed here is presented in Table 4-2[1]. Brominated HAA have been the focus of UCMR4. Several of brominated HAA are on Draft CCL5, as are two HAN, Halonitromethanes, formaldehyde, iodinated THM, and chlorate.

Bromide and Iodide in SFPUC Water Supplies. Longer period of record (2000 – 2021) has been reviewed for bromide and iodide because of limited information about these elements that contribute to DBP formation. Table 4-3 presents the summary of data for bromide and iodide (bromine where available).

Almost Two Orders of Magnitude More Bromide and Iodide Could be Expected in South Bay Aqueduct Water and various Groundwaters than in SFPUC Upcountry Water Supplies but More Data is Needed

The upcountry water supplies have very low levels of bromide, expected to be < 10 ug/L, from available information. High detection limits for bromide historically used do not allow for quantification but available bromine data at Tesla Portal and Alameda East suggest that indeed typical level for upcountry water supplies is < 10 ug/L bromide.

East Bay and West Bay surface waters have higher levels of bromide, typically less than 20 ug/L as indicated by the bromide and bromine data for SVWTP RAW and HTWTP Raw.

Major contributor of bromide in East Bay is Alameda Creek (up to 120 ug/L bromide), and Pleasanton Wellfield (up to 600 ug/L). For comparison with SFPUC upcountry supplies, available extensive data for South Bay Aqueduct indicate up to 540 ug/L bromide (median 170 ug/L, 90th percentile 410 ug/L, and 99th percentile 530 ug/L), which is almost two orders of magnitude higher level than in Hetch Hetchy and other upcountry supplies (Stantec, SBA Simulation Water Quality Evaluation, TM1, Table 5a, 2021).

GSR wells and City wells could contain up to 1000 ug/L bromide.

Iodide dataset is extremely limited, as shown in Table 4-3, but there is an indication of possibly two orders of magnitude difference as well.

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[1] Tables and figures are presented at the end of the Monitoring Review section (Pages 4-21 to 4-63).

More Variable TOC, DOC and UV 254 in Hetch Hetchy Water Supply in Last Several Years

Recent drought and rain cycles beginning around 2016 have contributed to more variable natural organic material (NOM) concentrations in the main SFPUC water supply, as shown in Figures 4-1 and 4-2. DOC tracked with TOC as well as unfiltered and filtered UV absorbance at 254 nm. This in turn translated into more variable regulated DBP concentrations tracking closely with NOM, as shown in Figure 4-3 (THM4) and Figure 4-4 (HAA5) at Alameda East, which is the point for disinfection compliance for the Hetch Hetchy water supply. This has a potential of impacting the DBP regulatory compliance and has created a lot of operational challenges to manage DBP during increased NOM periods, typically following significant rainfall events in the watershed. Wildfires in the watershed may change quantity and character of NOM.

TON, TOX, TOBr, TOI have not been monitored to date by SFPUC.

Speciation of HAA5 and HAA9 in SFPUC Drinking Water. Table 4-4 presents speciation of HAA5 in effluents of three main water treatment facilities at SFPUC in the most recent 2021 through beginning of 2022 time frame. HAA5 at Alameda East (Hetch Hetchy) was dominated by chlorinated DCAA and TCAA, as expected in free chlorinated effluent. Values at or above 15 ug/L for each species were highlighted. As discussed, due to the most recent period of rains at the end of 2021 and elevated NOM coincided with the greater values of DCAA and TCAA as shown by the highlights. Conversely, MCAA and other brominated HAA5 were not detected at Alameda East, as expected for the water source with very low bromide levels.

SVWTP has undergone recently several improvements to its treatment train, primarily discontinuing prechlorination and implementing a small Chlorine Contact Tank after filtration. The sampling location at SVWTP is from chloraminated effluent of the Treated Water Reservoir. These improvements resulted in low concentrations of DCAA and TCAA, typically below 10 ug/L each. MCAA and brominated HAA5 were not detected. Future ozonation should further reduce the formation of HAA5 at SVWTP.

Finally, HTWTP is equipped with preozonation and has similarly small Chlorine Contact Basin. The sampling location at HTWTP is from chloraminated effluent of the Treated Water Reservoir. These improvements resulted in very low concentrations of DCAA and TCAA, typically below 5 ug/L each. MCAA and brominated HAA5 were not detected.

The results of HAA9 UCMR4 sampling in 2018 within SFWS monitoring locations is shown in Table 4-5. Similarly, dominating species of DCAA and TCAA have been detected, whereas MBAA, DBAA and TBAA were not detected. Traces of chlorinated MCAA, and brominated BCAA, BDCAA and BCAA were observed near the detection limit. It is noteworthy that HAA5 in the SFWS were varying that year by as much as 100% at some locations (e.g., FOREST_K_HPS_1).

Speciation of THM4 in SFPUC Drinking Water. Table 4-6 presents speciation of THM4 in effluents of three main water treatment facilities at SFPUC in the most recent 2021 through beginning of 2022 time frame. THM4 at Alameda East (Hetch Hetchy) was dominated by chloroform, as expected in free chlorinated effluent. Values at or above 30 ug/L for chloroform were highlighted. As discussed, due to the most recent period of rains at the end of 2021 and elevated NOM coincided with the greater values of chloroform as shown by the highlights. Conversely, other brominated THM4 were either not detected or at trace levels at Alameda East, as expected for the water source with very low bromide levels.

Chloroform was also dominant THM4 at SVWTP Effluent but at lower levels than for disinfected Hetch Hetchy supply. Bromodichloromethane was consistently detected at SVWTP at levels below 10 ug/L, likely due to contributions of bromide from sources in the local watershed. Dibromochloromethane was detected at trace levels just above DLR, and bromoform was not detected.

Similarly, chloroform was dominant THM4 at HTWTP Effluent but at much lower levels than for disinfected Hetch Hetchy supply, typically below 10 ug/L. Bromodichloromethane was consistently detected at HTWTP at low levels below 5 ug/L. Dibromochloromethane was detected at trace levels just above DLR, and bromoform was not detected.

Chlorate. Chlorate in SVWTP Effluent was acceptable in 2021 and it was consistently well below the California Notification Level of 800 ug/L at HTWTP Effluent, as shown in Table 4-7.

Other Unregulated DBP. Haloacetonitriles (HAN), formaldehyde, acetaldehyde and chloropicrin have been monitored in the past and results are shown in Tables 4-8 to 4-11. HAN were monitored once in 2001 in drinking water. Slightly higher levels of HAN were observed in SVWTP Effluent, possibly due to more organic nitrogen in East Bay reservoirs and algae blooms. HAN are prioritized in several surveys in the literature. It would be valuable to repeat this monitoring form 2001 by extending it to all 5 HAN and all four seasons (2001 sampling was conducted in February and June).

Formaldehyde (Table 4-9) was monitored in2012 in surface source water and drinking water. It was not detected in source waters and detected at 10 ug/L in drinking waters. More recently, it was monitored in groundwaters in Pleasanton, on the Peninsula and in the City and it was consistently not detected (< 5 ug/L).

Acetaldehyde (Table 4-10) was monitored in 2000-2001 in drinking waters and there are two results for groundwater in 2012. Consistently, acetaldehyde was detected just above DLR in SVWTP and HTWTP and in SFWS at levels at or below 5 ug/L. Concentrations in treated Hetch Hetchy water were < 1 ug/l or 1 ug/L, and in groundwater < 1 ug/L.

Chloropicrin (Table 4-11) was monitored in 2001 in drinking water with results either not detected (< 0.5 ug/L) or just above.

Recommendations

Conduct bromide and iodide monitoring, as well as TON, in SFPUC water sources and other water sources under development and consideration to determine concentrations and variability of these constituents and their potential impact on regulated and unregulated DBP classes.

Conduct monitoring of HAA9 in SFWS to evaluate the effect of groundwater, increased NOM in Hetch Hetchy water supply, increased detention time and temperature, and increased chloramine residual to control nitrification.

Conduct preliminary monitoring of TOX in the distribution system to evaluate levels of all halogenated DBP and compare with available national data.

Increase monitoring of chlorate at SVWTP_TRW_EFF to monthly and manage the hypochlorite supply to stay within 80% of the Notification Level of 640 ug/L or less, preferably 400 ug/L.

Conduct repeat monitoring of 5 HAN in 4 seasons following same locations as in 2001. This would provide information about potential effects of changing organic nitrogen in water supplies, treatment changes and chloramination. Include monitoring of HAL and HAM at the same time. They can be obtained within the same method as THMs.

Treatment train modifications (e.g., incorporating O3 at SVWTP) should be evaluated.

Table 4-2. Regulated and Unregulated Disinfection Byproducts (other than nitrosamines)

DBP	US EPA			California			Comments
	MCL	MCLG	DWEL	MCL	NL	PHG	
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
Total THMs (TTHMs)							
Chloroform	0.080	0.07	0.35	0.080		0.0004	
Bromodichloromethane		0	0.1			0.00006	
Dibromochloromethane		0.06	0.7			0.0001	
Bromoform		0	1.0			0.0005	
Haloacetic Acids							
Dichloroacetic acid (DCAA)	0.060	0	0.1	0.060		Draft	UCMR4
Monochloroacetic acid (MCAA)		0.07	0.35			Draft	UCMR4
Trichloroacetic acid (TCAA)		0.02	1.0			Draft	UCMR4
Monobromoacetic acid (MBAA)						Draft	UCMR4
Dibromoacetic acid (DBAA)						Draft	UCMR4
Bromochloroacetic acid (BCAA)							UCMR4, Draft CCL5
Bromodichloroacetic acid (BDCAA)							UCMR4, Draft CCL5
Chlorodibromoacetic acid (CDBAA)							UCMR4
Tribromoacetic acid (TBAA)							UCMR4, Draft CCL5
Dibromochloroacetic acid (DBCAA)*							UCMR4, Draft CCL5
Haloacetonitriles							
Dichloroacetonitrile (DCAN)							Draft CCL5
Dibromoacetonitrile (DBAN)*							Draft CCL5
Bromochloroacetonitrile (BCAN)							

DBP	**US EPA**			**California**			**Comments**
	MCL	**MCLG**	**DWEL**	**MCL**	**NL**	**PHG**	
	mg/L	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	
Trichloroacetonitrile (TCAN)							
Bromoacetonitrile (MBAN)*							
Halofuranones							
MX*			2.0		0.35		
Halomethanes							
Dichloromethane (Methylene Chloride)							
Tetrachloromethane (Carbon Tetrachloride)							
Halonitromethanes							
Bromodichloronitromethane (BDCNM)*							Draft CCL5
Chloropicrin (trichloronitromethane, TCNM)							Draft CCL5
Dibromochloronitromethane (DBCNM)*							Draft CCL5
Dichloronitromethane (DCNM)*							
Bromochloronitromethane (BCNM)*							
Haloketones							
Trichloropropanone (TCP)*							
Dichloropropanone (DCP)*							
Haloacetamides							
Dibromoacetamide (DBAcAm)*							
Dichloroacetamide (DCAcAm)*							

DBP	US EPA			California			Comments
	MCL	MCLG	DWEL	MCL	NL	PHG	
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
Trichloromoacetamide (TCAcAm)*							
Haloacetaldehydes							
Chloroacetaldehyde (CAL)*							
Bromoacetaldehyde (BAL)*							
Iodoacetaldehyde (IAL)*							
Dichloroacetaldehyde (DCAL)*							
Dibromoacetaldehyde (DBAL)*							
Bromochloroacetaldehyde (BCAL)*							
Trichloroacetaldehyde (TCAL)*							
Tribromoacetaldehyde (TBAL)*							
Bromodichloroacetaldehyde (BDCAL)*							
Dibromochloroacetaldehyde (DBCAL)*							
Non-Halogenated Aldehydes							
Formaldehyde			7.0		0.1		CCL3, CCL4, Draft CCL5
Acetaldehyde							CCL3, CCL4
Iodo-Acids							
Iodoacetic acid (IAA)*							
Bromoiodoacetic acid*							
(Z)-3-Bromo-3-iodopropenoic acid*							
(E)-3-Bromo-3-iodopropenoic acid*							
(E)-2-Iodo-3-methylbutenedioic acid*							

DBP	**US EPA**			**California**			**Comments**
	MCL	**MCLG**	**DWEL**	**MCL**	**NL**	**PHG**	
	mg/L	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	
(Z)-2-Iodo-3-methylbutenedioic acid*							
Iodinated Trihalomethanes							
Bromochloroiodomethane (BCIM)*							Draft CCL5
Bromodiiodomethane (BDIM)*							Draft CCL5
Chlorodiiodomethane (CDIM)*							Draft CCL5
Dibromoiodomethane (DBIM)*							Draft CCL5
Dichloroiodomethane (DCIM)*							Draft CCL5
Iodoform (triiodomethane, TIM)*							Draft CCL5
Others							
Bromate	0.010	0	0.14	0.010		0.0001	
Chlorite	1.0	0.8	1.0	1.0		0.05	
Chlorate					0.8		UCMR3, CCL3, CCL4, Draft CCL5
Hydrazine*							CCL3, CCL4
Chloromethane (methyl chloride)							UCMR3, CCL3, CCL4
Haloamides*							
Halobenzoquinones*							
Trichlorophenol*			0.01				

*Not sampled by SFPUC.

Table 4-3. Summary of Bromide, Bromine and Iodide Concentrations, SFPUC, 2000 - 2021

Source	n #	Median ug/L	90% tile ug/L	Max ug/L	Comments
Upcountry Water					
Hetch Hetchy Reservoir	19	< 20	< 50	< 50	Bromide
Cherry Reservoir	9	< 20	< 50	< 50	Bromide
Lake Eleanor	9	< 50	< 50	< 50	Bromide
Moccasin Reservoir	15	< 50	< 50	< 50	Bromide
Tesla Portal Raw	35	3	7	9	Bromine, Metals Lab
Alameda East	27	< 20	< 50	< 50	Bromide
Alameda East	35	4	8	10	Bromine, Metals Lab
East Bay Water					
South Bay Aqueduct	4	425	570	600	Bromide
Alameda Creek	50	100	120	NA	Bromide
Plesanton Wellfield	49	435	524	607	Bromide
Calaveras Reservoir	19	< 50	20	20	Bromide
San Antonio Reservoir	18	30	53	60	Bromide
SVWTP RAW	55	< 50	NA	60	Bromide
SVWTP RAW	24	12	18	23	Bromine, Metals Lab
West Bay Water					
San Andreas Reservoir	19	< 50	NA	36	Bromide
HTWTP RAW	40	NA	NA	35	Bromide
HTWTP RAW	32	12	18	23	Bromine, Metals Lab

Source	n #	Median ug/L	90% tile ug/L	Max ug/L	Comments
GSR Wells	56	290	385	NA	Bromide
City Wells					
SF Groundwater	26	181	220	NA	Bromide
WSB Groundwater	245	260	522	910	Bromide
Hetch Hetchy Reservoir	1			<1	Iodide
Alameda East	1			< 1	Iodide
Calaveras Reservoir	1			< 1	Iodide
San Antonio Reservoir	1			< 1	Iodide
SVWTP EFF	1			< 1	Iodide
San Andreas Reservoir	1			< 1	Iodide
HTWTP EFF	1			< 1	Iodide
GSR Wells	20	1.6	7.7	27	Iodide

Table 4-4. HAA5 Speciation, Alameda East, SVWTP Effluent, HTWTP Effluent, SFPUC, 2021 - 2022

SamplePointName_ (Source)	Sample_Date	Laboratory	Analyte	RQualifier_ (rn3)	Value	Units
ALAMEDA_EAST	4-Jan-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	18-Jan-21	SUB-Subcontract	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	1-Feb-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	1-Mar-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	15-Mar-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	29-Mar-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	12-Apr-21	SUB-Subcontract	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	26-Apr-21	SUB-Subcontract	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	10-May-21	SUB-Subcontract	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	24-May-21	SUB-Subcontract	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	7-Jun-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	21-Jun-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	5-Jul-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	19-Jul-21	SUB-Subcontract	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	2-Aug-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	16-Aug-21	SUB-Subcontract	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	30-Aug-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	13-Sep-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	27-Sep-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	11-Oct-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	25-Oct-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	8-Nov-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	22-Nov-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	6-Dec-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	20-Dec-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	3-Jan-22	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	14-Mar-22	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L

SamplePointName_ (Source)	Sample_Date	Laboratory	Analyte	RQualifier_ (rn3)	Value	Units
ALAMEDA_EAST	4-Jan-21	MB-Organics	Dichloroacetic Acid, HAA		10	µg/L
ALAMEDA_EAST	18-Jan-21	SUB-Subcontract	Dichloroacetic Acid, HAA		9	µg/L
ALAMEDA_EAST	1-Feb-21	MB-Organics	Dichloroacetic Acid, HAA		9	µg/L
ALAMEDA_EAST	1-Mar-21	MB-Organics	Dichloroacetic Acid, HAA		10	µg/L
ALAMEDA_EAST	15-Mar-21	MB-Organics	Dichloroacetic Acid, HAA		9	µg/L
ALAMEDA_EAST	29-Mar-21	MB-Organics	Dichloroacetic Acid, HAA		11	µg/L
ALAMEDA_EAST	12-Apr-21	SUB-Subcontract	Dichloroacetic Acid, HAA		9	µg/L
ALAMEDA_EAST	26-Apr-21	SUB-Subcontract	Dichloroacetic Acid, HAA		9	µg/L
ALAMEDA_EAST	10-May-21	SUB-Subcontract	Dichloroacetic Acid, HAA		12	µg/L
ALAMEDA_EAST	24-May-21	SUB-Subcontract	Dichloroacetic Acid, HAA		11	µg/L
ALAMEDA_EAST	7-Jun-21	MB-Organics	Dichloroacetic Acid, HAA		11	µg/L
ALAMEDA_EAST	21-Jun-21	MB-Organics	Dichloroacetic Acid, HAA		11	µg/L
ALAMEDA_EAST	5-Jul-21	MB-Organics	Dichloroacetic Acid, HAA		12	µg/L
ALAMEDA_EAST	19-Jul-21	SUB-Subcontract	Dichloroacetic Acid, HAA		13	µg/L
ALAMEDA_EAST	2-Aug-21	MB-Organics	Dichloroacetic Acid, HAA		13	µg/L
ALAMEDA_EAST	16-Aug-21	SUB-Subcontract	Dichloroacetic Acid, HAA		12	µg/L
ALAMEDA_EAST	30-Aug-21	MB-Organics	Dichloroacetic Acid, HAA		12	µg/L
ALAMEDA_EAST	13-Sep-21	MB-Organics	Dichloroacetic Acid, HAA		14	µg/L
ALAMEDA_EAST	27-Sep-21	MB-Organics	Dichloroacetic Acid, HAA		13	µg/L
ALAMEDA_EAST	11-Oct-21	MB-Organics	Dichloroacetic Acid, HAA		14	µg/L
ALAMEDA_EAST	25-Oct-21	MB-Organics	Dichloroacetic Acid, HAA		17	µg/L
ALAMEDA_EAST	8-Nov-21	MB-Organics	Dichloroacetic Acid, HAA		15	µg/L
ALAMEDA_EAST	22-Nov-21	MB-Organics	Dichloroacetic Acid, HAA		25	µg/L
ALAMEDA_EAST	6-Dec-21	MB-Organics	Dichloroacetic Acid, HAA		14	µg/L
ALAMEDA_EAST	20-Dec-21	MB-Organics	Dichloroacetic Acid, HAA		16	µg/L
ALAMEDA_EAST	3-Jan-22	MB-Organics	Dichloroacetic Acid, HAA		19	µg/L
ALAMEDA_EAST	14-Mar-22	MB-Organics	Dichloroacetic Acid, HAA		15	µg/L

SamplePointName_ (Source)	Sample_Date	Laboratory	Analyte	RQualifier_ (rn3)	Value	Units
ALAMEDA_EAST	4-Jan-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	18-Jan-21	SUB-Subcontract	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	1-Feb-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	1-Mar-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	15-Mar-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	29-Mar-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	12-Apr-21	SUB-Subcontract	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	26-Apr-21	SUB-Subcontract	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	10-May-21	SUB-Subcontract	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	24-May-21	SUB-Subcontract	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	7-Jun-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	21-Jun-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	5-Jul-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	19-Jul-21	SUB-Subcontract	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	2-Aug-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	16-Aug-21	SUB-Subcontract	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	30-Aug-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	13-Sep-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	27-Sep-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	11-Oct-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	25-Oct-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	8-Nov-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	22-Nov-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	6-Dec-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	20-Dec-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	3-Jan-22	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	14-Mar-22	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
ALAMEDA_EAST	4-Jan-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	18-Jan-21	SUB-Subcontract	Monochloroacetic Acid, HAA	<	2	µg/L

SamplePointName_ (Source)	Sample_Date	Laboratory	Analyte	RQualifier_ (rn3)	Value	Units
ALAMEDA_EAST	1-Feb-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	1-Mar-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	15-Mar-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	29-Mar-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	12-Apr-21	SUB-Subcontract	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	26-Apr-21	SUB-Subcontract	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	10-May-21	SUB-Subcontract	Monochloroacetic Acid, HAA		2	µg/L
ALAMEDA_EAST	24-May-21	SUB-Subcontract	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	7-Jun-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	21-Jun-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	5-Jul-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	19-Jul-21	SUB-Subcontract	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	2-Aug-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	16-Aug-21	SUB-Subcontract	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	30-Aug-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	13-Sep-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	27-Sep-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	11-Oct-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	25-Oct-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	8-Nov-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	22-Nov-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	6-Dec-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	20-Dec-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	3-Jan-22	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	14-Mar-22	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
ALAMEDA_EAST	4-Jan-21	MB-Organics	Trichloroacetic Acid, HAA		8	µg/L
ALAMEDA_EAST	18-Jan-21	SUB-Subcontract	Trichloroacetic Acid, HAA		7	µg/L
ALAMEDA_EAST	1-Feb-21	MB-Organics	Trichloroacetic Acid, HAA		7	µg/L
ALAMEDA_EAST	1-Mar-21	MB-Organics	Trichloroacetic Acid, HAA		8	µg/L

SamplePointName_ (Source)	Sample_Date	Laboratory	Analyte	RQualifier_ (rn3)	Value	Units
ALAMEDA_EAST	15-Mar-21	MB-Organics	Trichloroacetic Acid, HAA		7	µg/L
ALAMEDA_EAST	29-Mar-21	MB-Organics	Trichloroacetic Acid, HAA		10	µg/L
ALAMEDA_EAST	12-Apr-21	SUB-Subcontract	Trichloroacetic Acid, HAA		9	µg/L
ALAMEDA_EAST	26-Apr-21	SUB-Subcontract	Trichloroacetic Acid, HAA		8	µg/L
ALAMEDA_EAST	10-May-21	SUB-Subcontract	Trichloroacetic Acid, HAA		10	µg/L
ALAMEDA_EAST	24-May-21	SUB-Subcontract	Trichloroacetic Acid, HAA		8	µg/L
ALAMEDA_EAST	7-Jun-21	MB-Organics	Trichloroacetic Acid, HAA		10	µg/L
ALAMEDA_EAST	21-Jun-21	MB-Organics	Trichloroacetic Acid, HAA		13	µg/L
ALAMEDA_EAST	5-Jul-21	MB-Organics	Trichloroacetic Acid, HAA		13	µg/L
ALAMEDA_EAST	19-Jul-21	SUB-Subcontract	Trichloroacetic Acid, HAA		16	µg/L
ALAMEDA_EAST	2-Aug-21	MB-Organics	Trichloroacetic Acid, HAA		13	µg/L
ALAMEDA_EAST	16-Aug-21	SUB-Subcontract	Trichloroacetic Acid, HAA		15	µg/L
ALAMEDA_EAST	30-Aug-21	MB-Organics	Trichloroacetic Acid, HAA		13	µg/L
ALAMEDA_EAST	13-Sep-21	MB-Organics	Trichloroacetic Acid, HAA		8	µg/L
ALAMEDA_EAST	27-Sep-21	MB-Organics	Trichloroacetic Acid, HAA		10	µg/L
ALAMEDA_EAST	11-Oct-21	MB-Organics	Trichloroacetic Acid, HAA		13	µg/L
ALAMEDA_EAST	25-Oct-21	MB-Organics	Trichloroacetic Acid, HAA		17	µg/L
ALAMEDA_EAST	8-Nov-21	MB-Organics	Trichloroacetic Acid, HAA		14	µg/L
ALAMEDA_EAST	22-Nov-21	MB-Organics	Trichloroacetic Acid, HAA		20	µg/L
ALAMEDA_EAST	6-Dec-21	MB-Organics	Trichloroacetic Acid, HAA		12	µg/L
ALAMEDA_EAST	20-Dec-21	MB-Organics	Trichloroacetic Acid, HAA		18	µg/L
ALAMEDA_EAST	3-Jan-22	MB-Organics	Trichloroacetic Acid, HAA		24	µg/L
ALAMEDA_EAST	14-Mar-22	MB-Organics	Trichloroacetic Acid, HAA		16	µg/L
SVWTP_TWR_EFF	2-Feb-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	15-Feb-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	5-May-21	SUB-Subcontract	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	11-Jun-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L

SamplePointName_ (Source)	Sample_Date	Laboratory	Analyte	RQualifier_ (rn3)	Value	Units
SVWTP_TWR_EFF	21-Jul-21	SUB-Subcontract	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	2-Aug-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	16-Aug-21	SUB-Subcontract	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	30-Aug-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	13-Sep-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	20-Oct-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	25-Oct-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	28-Dec-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	3-Jan-22	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	17-Jan-22	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	31-Jan-22	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	14-Feb-22	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	28-Feb-22	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	2-Feb-21	MB-Organics	Dichloroacetic Acid, HAA		19	µg/L
SVWTP_TWR_EFF	15-Feb-21	MB-Organics	Dichloroacetic Acid, HAA		3	µg/L
SVWTP_TWR_EFF	5-May-21	SUB-Subcontract	Dichloroacetic Acid, HAA		6	µg/L
SVWTP_TWR_EFF	11-Jun-21	MB-Organics	Dichloroacetic Acid, HAA		8	µg/L
SVWTP_TWR_EFF	21-Jul-21	SUB-Subcontract	Dichloroacetic Acid, HAA		5	µg/L
SVWTP_TWR_EFF	2-Aug-21	MB-Organics	Dichloroacetic Acid, HAA		3	µg/L
SVWTP_TWR_EFF	16-Aug-21	SUB-Subcontract	Dichloroacetic Acid, HAA		3	µg/L
SVWTP_TWR_EFF	30-Aug-21	MB-Organics	Dichloroacetic Acid, HAA		3	µg/L
SVWTP_TWR_EFF	13-Sep-21	MB-Organics	Dichloroacetic Acid, HAA		2	µg/L
SVWTP_TWR_EFF	20-Oct-21	MB-Organics	Dichloroacetic Acid, HAA		10	µg/L
SVWTP_TWR_EFF	25-Oct-21	MB-Organics	Dichloroacetic Acid, HAA		8	µg/L
SVWTP_TWR_EFF	28-Dec-21	MB-Organics	Dichloroacetic Acid, HAA		12	µg/L
SVWTP_TWR_EFF	3-Jan-22	MB-Organics	Dichloroacetic Acid, HAA		10	µg/L
SVWTP_TWR_EFF	17-Jan-22	MB-Organics	Dichloroacetic Acid, HAA		9	µg/L
SVWTP_TWR_EFF	31-Jan-22	MB-Organics	Dichloroacetic Acid, HAA		8	µg/L

SamplePointName_ (Source)	Sample_Date	Laboratory	Analyte	RQualifier_ (rn3)	Value	Units
SVWTP_TWR_EFF	14-Feb-22	MB-Organics	Dichloroacetic Acid, HAA		4	µg/L
SVWTP_TWR_EFF	28-Feb-22	MB-Organics	Dichloroacetic Acid, HAA		3	µg/L
SVWTP_TWR_EFF	2-Feb-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	15-Feb-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	5-May-21	SUB-Subcontract	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	11-Jun-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	21-Jul-21	SUB-Subcontract	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	2-Aug-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	16-Aug-21	SUB-Subcontract	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	30-Aug-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	13-Sep-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	20-Oct-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	25-Oct-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	28-Dec-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	3-Jan-22	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	17-Jan-22	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	31-Jan-22	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	14-Feb-22	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	28-Feb-22	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	2-Feb-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	15-Feb-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	5-May-21	SUB-Subcontract	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	11-Jun-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	21-Jul-21	SUB-Subcontract	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	2-Aug-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	16-Aug-21	SUB-Subcontract	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	30-Aug-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	13-Sep-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L

SamplePointName_ (Source)	Sample_Date	Laboratory	Analyte	RQualifier_ (rn3)	Value	Units
SVWTP_TWR_EFF	20-Oct-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	25-Oct-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	28-Dec-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	3-Jan-22	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	17-Jan-22	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	31-Jan-22	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	14-Feb-22	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	28-Feb-22	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
SVWTP_TWR_EFF	2-Feb-21	MB-Organics	Trichloroacetic Acid, HAA		12	µg/L
SVWTP_TWR_EFF	15-Feb-21	MB-Organics	Trichloroacetic Acid, HAA		2	µg/L
SVWTP_TWR_EFF	5-May-21	SUB-Subcontract	Trichloroacetic Acid, HAA		4	µg/L
SVWTP_TWR_EFF	11-Jun-21	MB-Organics	Trichloroacetic Acid, HAA		7	µg/L
SVWTP_TWR_EFF	21-Jul-21	SUB-Subcontract	Trichloroacetic Acid, HAA		3	µg/L
SVWTP_TWR_EFF	2-Aug-21	MB-Organics	Trichloroacetic Acid, HAA		1	µg/L
SVWTP_TWR_EFF	16-Aug-21	SUB-Subcontract	Trichloroacetic Acid, HAA		2	µg/L
SVWTP_TWR_EFF	30-Aug-21	MB-Organics	Trichloroacetic Acid, HAA		2	µg/L
SVWTP_TWR_EFF	13-Sep-21	MB-Organics	Trichloroacetic Acid, HAA	<	1	µg/L
SVWTP_TWR_EFF	20-Oct-21	MB-Organics	Trichloroacetic Acid, HAA		10	µg/L
SVWTP_TWR_EFF	25-Oct-21	MB-Organics	Trichloroacetic Acid, HAA		7	µg/L
SVWTP_TWR_EFF	28-Dec-21	MB-Organics	Trichloroacetic Acid, HAA		10	µg/L
SVWTP_TWR_EFF	3-Jan-22	MB-Organics	Trichloroacetic Acid, HAA		9	µg/L
SVWTP_TWR_EFF	17-Jan-22	MB-Organics	Trichloroacetic Acid, HAA		10	µg/L
SVWTP_TWR_EFF	31-Jan-22	MB-Organics	Trichloroacetic Acid, HAA		9	µg/L
SVWTP_TWR_EFF	14-Feb-22	MB-Organics	Trichloroacetic Acid, HAA		2	µg/L
SVWTP_TWR_EFF	28-Feb-22	MB-Organics	Trichloroacetic Acid, HAA		2	µg/L
HTWTP_EFF_POST	4-Jan-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	18-Jan-21	SUB-Subcontract	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	1-Feb-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L

SamplePointName_ (Source)	Sample_Date	Laboratory	Analyte	RQualifier_ (rn3)	Value	Units
HTWTP_EFF_POST	15-Feb-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	1-Mar-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	15-Mar-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	29-Mar-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	12-Apr-21	SUB-Subcontract	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	26-Apr-21	SUB-Subcontract	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	24-May-21	SUB-Subcontract	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	7-Jun-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	21-Jun-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	5-Jul-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	19-Jul-21	SUB-Subcontract	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	21-Sep-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	27-Sep-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	11-Oct-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	8-Nov-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	22-Nov-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	6-Dec-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	20-Dec-21	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	3-Jan-22	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	17-Jan-22	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	31-Jan-22	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	14-Feb-22	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	28-Feb-22	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	14-Mar-22	MB-Organics	Dibromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	4-Jan-21	MB-Organics	Dichloroacetic Acid, HAA		2	µg/L
HTWTP_EFF_POST	18-Jan-21	SUB-Subcontract	Dichloroacetic Acid, HAA		2	µg/L
HTWTP_EFF_POST	1-Feb-21	MB-Organics	Dichloroacetic Acid, HAA		2	µg/L
HTWTP_EFF_POST	15-Feb-21	MB-Organics	Dichloroacetic Acid, HAA		2	µg/L
HTWTP_EFF_POST	1-Mar-21	MB-Organics	Dichloroacetic Acid, HAA		2	µg/L

SamplePointName_ (Source)	Sample_Date	Laboratory	Analyte	RQualifier_ (rn3)	Value	Units
HTWTP_EFF_POST	15-Mar-21	MB-Organics	Dichloroacetic Acid, HAA		2	µg/L
HTWTP_EFF_POST	29-Mar-21	MB-Organics	Dichloroacetic Acid, HAA		3	µg/L
HTWTP_EFF_POST	12-Apr-21	SUB-Subcontract	Dichloroacetic Acid, HAA		2	µg/L
HTWTP_EFF_POST	26-Apr-21	SUB-Subcontract	Dichloroacetic Acid, HAA		2	µg/L
HTWTP_EFF_POST	24-May-21	SUB-Subcontract	Dichloroacetic Acid, HAA		2	µg/L
HTWTP_EFF_POST	7-Jun-21	MB-Organics	Dichloroacetic Acid, HAA		2	µg/L
HTWTP_EFF_POST	21-Jun-21	MB-Organics	Dichloroacetic Acid, HAA		2	µg/L
HTWTP_EFF_POST	5-Jul-21	MB-Organics	Dichloroacetic Acid, HAA		3	µg/L
HTWTP_EFF_POST	19-Jul-21	SUB-Subcontract	Dichloroacetic Acid, HAA		3	µg/L
HTWTP_EFF_POST	21-Sep-21	MB-Organics	Dichloroacetic Acid, HAA		9	µg/L
HTWTP_EFF_POST	27-Sep-21	MB-Organics	Dichloroacetic Acid, HAA		3	µg/L
HTWTP_EFF_POST	11-Oct-21	MB-Organics	Dichloroacetic Acid, HAA		3	µg/L
HTWTP_EFF_POST	8-Nov-21	MB-Organics	Dichloroacetic Acid, HAA		3	µg/L
HTWTP_EFF_POST	22-Nov-21	MB-Organics	Dichloroacetic Acid, HAA		2	µg/L
HTWTP_EFF_POST	6-Dec-21	MB-Organics	Dichloroacetic Acid, HAA		2	µg/L
HTWTP_EFF_POST	20-Dec-21	MB-Organics	Dichloroacetic Acid, HAA		2	µg/L
HTWTP_EFF_POST	3-Jan-22	MB-Organics	Dichloroacetic Acid, HAA		3	µg/L
HTWTP_EFF_POST	17-Jan-22	MB-Organics	Dichloroacetic Acid, HAA		2	µg/L
HTWTP_EFF_POST	31-Jan-22	MB-Organics	Dichloroacetic Acid, HAA		3	µg/L
HTWTP_EFF_POST	14-Feb-22	MB-Organics	Dichloroacetic Acid, HAA		8	µg/L
HTWTP_EFF_POST	28-Feb-22	MB-Organics	Dichloroacetic Acid, HAA		3	µg/L
HTWTP_EFF_POST	14-Mar-22	MB-Organics	Dichloroacetic Acid, HAA		4	µg/L
HTWTP_EFF_POST	4-Jan-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	18-Jan-21	SUB-Subcontract	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	1-Feb-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	15-Feb-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	1-Mar-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	15-Mar-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	29-Mar-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L

SamplePointName_ (Source)	Sample_Date	Laboratory	Analyte	RQualifier_ (rn3)	Value	Units
HTWTP_EFF_POST	12-Apr-21	SUB-Subcontract	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	26-Apr-21	SUB-Subcontract	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	24-May-21	SUB-Subcontract	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	7-Jun-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	21-Jun-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	5-Jul-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	19-Jul-21	SUB-Subcontract	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	21-Sep-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	27-Sep-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	11-Oct-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	8-Nov-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	22-Nov-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	6-Dec-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	20-Dec-21	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	3-Jan-22	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	17-Jan-22	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	31-Jan-22	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	14-Feb-22	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	28-Feb-22	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	14-Mar-22	MB-Organics	Monobromoacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	4-Jan-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	18-Jan-21	SUB-Subcontract	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	1-Feb-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	15-Feb-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	1-Mar-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	15-Mar-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	29-Mar-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	12-Apr-21	SUB-Subcontract	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	26-Apr-21	SUB-Subcontract	Monochloroacetic Acid, HAA	<	2	µg/L

SamplePointName_ (Source)	Sample_Date	Laboratory	Analyte	RQualifier_ (rn3)	Value	Units
HTWTP_EFF_POST	24-May-21	SUB-Subcontract	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	7-Jun-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	21-Jun-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	5-Jul-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	19-Jul-21	SUB-Subcontract	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	21-Sep-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	27-Sep-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	11-Oct-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	8-Nov-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	22-Nov-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	6-Dec-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	20-Dec-21	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	3-Jan-22	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	17-Jan-22	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	31-Jan-22	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	14-Feb-22	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	28-Feb-22	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	14-Mar-22	MB-Organics	Monochloroacetic Acid, HAA	<	2	µg/L
HTWTP_EFF_POST	4-Jan-21	MB-Organics	Trichloroacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	18-Jan-21	SUB-Subcontract	Trichloroacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	1-Feb-21	MB-Organics	Trichloroacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	15-Feb-21	MB-Organics	Trichloroacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	1-Mar-21	MB-Organics	Trichloroacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	15-Mar-21	MB-Organics	Trichloroacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	29-Mar-21	MB-Organics	Trichloroacetic Acid, HAA		1	µg/L
HTWTP_EFF_POST	12-Apr-21	SUB-Subcontract	Trichloroacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	26-Apr-21	SUB-Subcontract	Trichloroacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	24-May-21	SUB-Subcontract	Trichloroacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	7-Jun-21	MB-Organics	Trichloroacetic Acid, HAA		1	µg/L

SamplePointName_ (Source)	Sample_Date	Laboratory	Analyte	RQualifier_ (rn3)	Value	Units
HTWTP_EFF_POST	21-Jun-21	MB-Organics	Trichloroacetic Acid, HAA		1	µg/L
HTWTP_EFF_POST	5-Jul-21	MB-Organics	Trichloroacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	19-Jul-21	SUB-Subcontract	Trichloroacetic Acid, HAA		1	µg/L
HTWTP_EFF_POST	21-Sep-21	MB-Organics	Trichloroacetic Acid, HAA		6	µg/L
HTWTP_EFF_POST	27-Sep-21	MB-Organics	Trichloroacetic Acid, HAA		1	µg/L
HTWTP_EFF_POST	11-Oct-21	MB-Organics	Trichloroacetic Acid, HAA		1	µg/L
HTWTP_EFF_POST	8-Nov-21	MB-Organics	Trichloroacetic Acid, HAA		1	µg/L
HTWTP_EFF_POST	22-Nov-21	MB-Organics	Trichloroacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	6-Dec-21	MB-Organics	Trichloroacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	20-Dec-21	MB-Organics	Trichloroacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	3-Jan-22	MB-Organics	Trichloroacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	17-Jan-22	MB-Organics	Trichloroacetic Acid, HAA	<	1	µg/L
HTWTP_EFF_POST	31-Jan-22	MB-Organics	Trichloroacetic Acid, HAA		1	µg/L
HTWTP_EFF_POST	14-Feb-22	MB-Organics	Trichloroacetic Acid, HAA		4	µg/L
HTWTP_EFF_POST	28-Feb-22	MB-Organics	Trichloroacetic Acid, HAA		1	µg/L
HTWTP_EFF_POST	14-Mar-22	MB-Organics	Trichloroacetic Acid, HAA		2	µg/L

Table 4-5. HAA Speciation, San Francisco Distribution System, UCMR4 Data, SFPUC, 2018
Rasprojectno_(Project_ID): UCMR4
TCR System: SF_City
Testno_(Analysis): SUB_HAA6Br

SamplePointName (Source)	Sample Date	RQualifier (rn3)	Value	Units
Analyte (Synonym): Bromochloroacetic Acid, HAA (HAA_BCAA)				
UMS#01	5-Mar-18		1.7	µg/L
UMS#02	5-Mar-18		0.9	µg/L
HPS	4-Jun-18		0.7	µg/L
UMS#03	4-Jun-18		0.7	µg/L
SS#07	4-Jun-18		0.7	µg/L
HPS	4-Sep-18		0.4	µg/L
UMS#01	4-Sep-18		0.9	µg/L
UMS#02	4-Sep-18		0.4	µg/L
Analyte (Synonym): Bromodichloroacetic Acid, HAA (HAA_BDCAA)				
FOREST_K_HPS_1	5-Mar-18		0.7	µg/L
UMS#09	4-Jun-18	<	0.5	µg/L
FOREST_K_HPS_1	4-Jun-18		0.6	µg/L
UMS#02	4-Sep-18	<	0.5	µg/L
UMS#09	4-Sep-18	<	0.5	µg/L
SUTS#03	4-Sep-18		0.9	µg/L
Analyte (Synonym): Chlorodibromoacetic Acid, HAA (HAA_CDBAA)				
HPS	5-Mar-18		0.3	µg/L
UMS#01	5-Mar-18		0.7	µg/L
FOREST_K_HPS_1	5-Mar-18	<	0.3	µg/L
LA_GRANDE_TK	4-Jun-18	<	0.3	µg/L
HPS	4-Sep-18	<	0.3	µg/L
UMS#01	4-Sep-18		0.3	µg/L
PHS	4-Sep-18	<	0.3	µg/L
Analyte (Synonym): Tribromoacetic Acid, HAA (HAA_TBAA)				
MT_DAVIDSON_TK	5-Mar-18	<	2.0	µg/L
UMS#01	4-Jun-18	<	2.0	µg/L
UMS#09	4-Jun-18	<	2.0	µg/L
FOREST_K_HPS_1	4-Jun-18	<	2.0	µg/L
FOREST_K_HPS_1	4-Sep-18	<	2.0	µg/L
Analyte (Synonym): Dibromoacetic Acid, HAA (HAA_DBAA)				
UMS#02	5-Mar-18	<	0.3	µg/L
LA_GRANDE_TK	5-Mar-18	<	0.3	µg/L
MT_DAVIDSON_TK	5-Mar-18	<	0.3	µg/L
FOREST_K_HPS_1	4-Jun-18	<	0.3	µg/L
UMS#01	4-Sep-18	<	0.3	µg/L

SamplePointName (Source)	Sample Date	RQualifier (rn3)	Value	Units
UMS#02	4-Sep-18	<	0.3	µg/L
UMS#03	4-Sep-18	<	0.3	µg/L
MT_DAVIDSON_TK	4-Sep-18	<	0.3	µg/L
Analyte (Synonym): Dichloroacetic Acid, HAA (HAA_DCAA)				
UMS#02	5-Mar-18		16.5	µg/L
LA_GRANDE_TK	5-Mar-18		16.5	µg/L
MT_DAVIDSON_TK	5-Mar-18		15.6	µg/L
UMS#03	4-Jun-18		30.0	µg/L
SHS#02	4-Jun-18		27.0	µg/L
Analyte (Synonym): Monobromoacetic Acid, HAA (HAA_MBAA)				
HPS	4-Jun-18	<	0.3	µg/L
UMS#02	4-Jun-18	<	0.3	µg/L
UMS#09	4-Jun-18	<	0.3	µg/L
UMS#02	4-Sep-18	<	0.3	µg/L
Analyte (Synonym): Bromochloroacetic Acid, HAA (HAA_BCAA)				
UMS#03	5-Mar-18		2.0	µg/L
UMS#09	5-Mar-18	<	2.0	µg/L
FOREST_K_HPS_1	5-Mar-18		2.3	µg/L
MT_DAVIDSON_TK	5-Mar-18	<	2.0	µg/L
UMS#09	4-Sep-18		2.2	µg/L
SS#07	4-Sep-18	<	2.0	µg/L
Analyte (Synonym): Trichloroacetic Acid, HAA (HAA_TCAA)				
PHS	5-Mar-18		10.4	µg/L
SHS#02	5-Mar-18		11.3	µg/L
PHS	4-Jun-18		16.0	µg/L
SHS#02	4-Sep-18		15.0	µg/L
Analyte (Synonym): HAA5 (HAA Total)				
FOREST_K_HPS_1	5-Mar-18		32.9	µg/L
HPS	4-Jun-18		57.0	µg/L
SUTS#03	4-Jun-18		42.0	µg/L
FOREST_K_HPS_1	4-Jun-18		65.0	µg/L
UMS#02	4-Sep-18		46.0	µg/L
UMS#09	4-Sep-18		42.0	µg/L
PHS	4-Sep-18		51.0	µg/L
MT_DAVIDSON_TK	4-Sep-18		41.0	µg/L

Table 4-6. THM4 Speciation, Alameda East, SVWTP Effluent, HTWTP Effluent, SFPUC, 2021–2022 (Laboratory: MB-Organics)

SamplePointName (Source)	Sample Date	RQualifier (rn3)	Value	Units
Analyte: Bromodichloromethane, THM				
ALAMEDA_EAST	4-Jan-21		1.1	µg/L
ALAMEDA_EAST	18-Jan-21		1.3	µg/L
ALAMEDA_EAST	1-Feb-21		1.4	µg/L
ALAMEDA_EAST	1-Mar-21		1.5	µg/L
ALAMEDA_EAST	15-Mar-21		1.0	µg/L
ALAMEDA_EAST	29-Mar-21		0.9	µg/L
ALAMEDA_EAST	12-Apr-21		0.7	µg/L
ALAMEDA_EAST	26-Apr-21		0.9	µg/L
ALAMEDA_EAST	10-May-21		1.0	µg/L
ALAMEDA_EAST	24-May-21		0.9	µg/L
ALAMEDA_EAST	7-Jun-21		0.9	µg/L
ALAMEDA_EAST	21-Jun-21		1.0	µg/L
ALAMEDA_EAST	5-Jul-21		1.0	µg/L
ALAMEDA_EAST	19-Jul-21		1.3	µg/L
ALAMEDA_EAST	2-Aug-21		1.2	µg/L
ALAMEDA_EAST	16-Aug-21		1.1	µg/L
ALAMEDA_EAST	30-Aug-21		1.2	µg/L
ALAMEDA_EAST	13-Sep-21		1.0	µg/L
ALAMEDA_EAST	27-Sep-21		0.9	µg/L
ALAMEDA_EAST	11-Oct-21		1.0	µg/L
ALAMEDA_EAST	25-Oct-21		1.0	µg/L
ALAMEDA_EAST	8-Nov-21		1.4	µg/L
ALAMEDA_EAST	22-Nov-21		1.5	µg/L
ALAMEDA_EAST	6-Dec-21		1.3	µg/L
ALAMEDA_EAST	20-Dec-21		2.2	µg/L
ALAMEDA_EAST	3-Jan-22		2.3	µg/L
ALAMEDA_EAST	14-Mar-22		1.3	µg/L
Analyte: Bromoform, THM				
ALAMEDA_EAST	4-Jan-21	<	0.5	µg/L
ALAMEDA_EAST	18-Jan-21	<	0.5	µg/L
ALAMEDA_EAST	1-Feb-21	<	0.5	µg/L
ALAMEDA_EAST	1-Mar-21	<	0.5	µg/L
ALAMEDA_EAST	15-Mar-21	<	0.5	µg/L
ALAMEDA_EAST	29-Mar-21	<	0.5	µg/L
ALAMEDA_EAST	12-Apr-21	<	0.5	µg/L
ALAMEDA_EAST	26-Apr-21	<	0.5	µg/L
ALAMEDA_EAST	10-May-21	<	0.5	µg/L
ALAMEDA_EAST	24-May-21	<	0.5	µg/L

SamplePointName (Source)	Sample Date	RQualifier (rn3)	Value	Units
ALAMEDA_EAST	7-Jun-21	<	0.5	µg/L
ALAMEDA_EAST	21-Jun-21	<	0.5	µg/L
ALAMEDA_EAST	5-Jul-21	<	0.5	µg/L
ALAMEDA_EAST	19-Jul-21	<	0.5	µg/L
ALAMEDA_EAST	2-Aug-21	<	0.5	µg/L
ALAMEDA_EAST	16-Aug-21	<	0.5	µg/L
ALAMEDA_EAST	30-Aug-21	<	0.5	µg/L
ALAMEDA_EAST	13-Sep-21	<	0.5	µg/L
ALAMEDA_EAST	27-Sep-21	<	0.5	µg/L
ALAMEDA_EAST	11-Oct-21	<	0.5	µg/L
ALAMEDA_EAST	25-Oct-21	<	0.5	µg/L
ALAMEDA_EAST	8-Nov-21	<	0.5	µg/L
ALAMEDA_EAST	22-Nov-21	<	0.5	µg/L
ALAMEDA_EAST	6-Dec-21	<	0.5	µg/L
ALAMEDA_EAST	20-Dec-21	<	0.5	µg/L
ALAMEDA_EAST	3-Jan-22	<	0.5	µg/L
ALAMEDA_EAST	14-Mar-22	<	1.0	µg/L
Analyte: Chloroform, THM				
ALAMEDA_EAST	4-Jan-21		27.5	µg/L
ALAMEDA_EAST	18-Jan-21		27.9	µg/L
ALAMEDA_EAST	1-Feb-21		26.9	µg/L
ALAMEDA_EAST	1-Mar-21		32.4	µg/L
ALAMEDA_EAST	15-Mar-21		27.9	µg/L
ALAMEDA_EAST	29-Mar-21		23.8	µg/L
ALAMEDA_EAST	12-Apr-21		22.8	µg/L
ALAMEDA_EAST	26-Apr-21		25.8	µg/L
ALAMEDA_EAST	10-May-21		26.5	µg/L
ALAMEDA_EAST	24-May-21		28.2	µg/L
ALAMEDA_EAST	7-Jun-21		29.9	µg/L
ALAMEDA_EAST	21-Jun-21		30.1	µg/L
ALAMEDA_EAST	5-Jul-21		33.5	µg/L
ALAMEDA_EAST	19-Jul-21		35.0	µg/L
ALAMEDA_EAST	2-Aug-21		37.0	µg/L
ALAMEDA_EAST	16-Aug-21		36.8	µg/L
ALAMEDA_EAST	30-Aug-21		37.7	µg/L
ALAMEDA_EAST	13-Sep-21		35.2	µg/L
ALAMEDA_EAST	27-Sep-21		30.9	µg/L
ALAMEDA_EAST	11-Oct-21		33.0	µg/L
ALAMEDA_EAST	25-Oct-21		32.2	µg/L
ALAMEDA_EAST	8-Nov-21		39.1	µg/L
ALAMEDA_EAST	22-Nov-21		44.6	µg/L
ALAMEDA_EAST	6-Dec-21		38.9	µg/L

SamplePointName (Source)	Sample Date	RQualifier (rn3)	Value	Units
ALAMEDA_EAST	20-Dec-21		47.8	µg/L
ALAMEDA_EAST	3-Jan-22		53.8	µg/L
ALAMEDA_EAST	14-Mar-22		44.0	µg/L
Analyte: Dibromochloromethane, THM				
ALAMEDA_EAST	4-Jan-21	<	0.5	µg/L
ALAMEDA_EAST	18-Jan-21	<	0.5	µg/L
ALAMEDA_EAST	1-Feb-21	<	0.5	µg/L
ALAMEDA_EAST	1-Mar-21	<	0.5	µg/L
ALAMEDA_EAST	15-Mar-21	<	0.5	µg/L
ALAMEDA_EAST	29-Mar-21	<	0.5	µg/L
ALAMEDA_EAST	12-Apr-21	<	0.5	µg/L
ALAMEDA_EAST	26-Apr-21	<	0.5	µg/L
ALAMEDA_EAST	10-May-21	<	0.5	µg/L
ALAMEDA_EAST	24-May-21	<	0.5	µg/L
ALAMEDA_EAST	7-Jun-21	<	0.5	µg/L
ALAMEDA_EAST	21-Jun-21	<	0.5	µg/L
ALAMEDA_EAST	5-Jul-21	<	0.5	µg/L
ALAMEDA_EAST	19-Jul-21	<	0.5	µg/L
ALAMEDA_EAST	2-Aug-21	<	0.5	µg/L
ALAMEDA_EAST	16-Aug-21	<	0.5	µg/L
ALAMEDA_EAST	30-Aug-21	<	0.5	µg/L
ALAMEDA_EAST	13-Sep-21	<	0.5	µg/L
ALAMEDA_EAST	27-Sep-21	<	0.5	µg/L
ALAMEDA_EAST	11-Oct-21	<	0.5	µg/L
ALAMEDA_EAST	25-Oct-21	<	0.5	µg/L
ALAMEDA_EAST	8-Nov-21	<	0.5	µg/L
ALAMEDA_EAST	22-Nov-21	<	0.5	µg/L
ALAMEDA_EAST	6-Dec-21	<	0.5	µg/L
ALAMEDA_EAST	20-Dec-21	<	0.5	µg/L
ALAMEDA_EAST	3-Jan-22	<	0.5	µg/L
ALAMEDA_EAST	14-Mar-22	<	1.0	µg/L
Analyte: Bromodichloromethane, THM				
SVWTP_TWR_EFF	2-Feb-21		8.1	µg/L
SVWTP_TWR_EFF	15-Feb-21		4.2	µg/L
SVWTP_TWR_EFF	5-May-21		4.7	µg/L
SVWTP_TWR_EFF	11-Jun-21		5.8	µg/L
SVWTP_TWR_EFF	21-Jul-21		4.7	µg/L
SVWTP_TWR_EFF	2-Aug-21		3.5	µg/L
SVWTP_TWR_EFF	16-Aug-21		3.8	µg/L
SVWTP_TWR_EFF	30-Aug-21		4.4	µg/L
SVWTP_TWR_EFF	13-Sep-21		1.1	µg/L
SVWTP_TWR_EFF	20-Oct-21		6.6	µg/L

SamplePointName (Source)	Sample Date	RQualifier (rn3)	Value	Units
SVWTP_TWR_EFF	25-Oct-21		6.9	µg/L
SVWTP_TWR_EFF	28-Dec-21		6.5	µg/L
SVWTP_TWR_EFF	3-Jan-22		6.5	µg/L
SVWTP_TWR_EFF	17-Jan-22		6.5	µg/L
SVWTP_TWR_EFF	31-Jan-22		6.2	µg/L
SVWTP_TWR_EFF	14-Feb-22		3.6	µg/L
SVWTP_TWR_EFF	28-Feb-22		3.4	µg/L
Analyte: Bromoform, THM				
SVWTP_TWR_EFF	2-Feb-21	<	0.5	µg/L
SVWTP_TWR_EFF	15-Feb-21	<	0.5	µg/L
SVWTP_TWR_EFF	5-May-21	<	0.5	µg/L
SVWTP_TWR_EFF	11-Jun-21	<	0.5	µg/L
SVWTP_TWR_EFF	21-Jul-21	<	0.5	µg/L
SVWTP_TWR_EFF	2-Aug-21	<	0.5	µg/L
SVWTP_TWR_EFF	16-Aug-21	<	0.5	µg/L
SVWTP_TWR_EFF	30-Aug-21	<	0.5	µg/L
SVWTP_TWR_EFF	13-Sep-21	<	0.5	µg/L
SVWTP_TWR_EFF	20-Oct-21	<	0.5	µg/L
SVWTP_TWR_EFF	25-Oct-21	<	0.5	µg/L
SVWTP_TWR_EFF	28-Dec-21	<	0.5	µg/L
SVWTP_TWR_EFF	3-Jan-22	<	0.5	µg/L
SVWTP_TWR_EFF	17-Jan-22	<	0.5	µg/L
SVWTP_TWR_EFF	31-Jan-22	<	1.0	µg/L
SVWTP_TWR_EFF	14-Feb-22	<	1.0	µg/L
SVWTP_TWR_EFF	28-Feb-22	<	1.0	µg/L
Analyte: Chloroform, THM				
SVWTP_TWR_EFF	2-Feb-21		34.7	µg/L
SVWTP_TWR_EFF	15-Feb-21		8.4	µg/L
SVWTP_TWR_EFF	5-May-21		11.6	µg/L
SVWTP_TWR_EFF	11-Jun-21		21.5	µg/L
SVWTP_TWR_EFF	21-Jul-21		14.9	µg/L
SVWTP_TWR_EFF	2-Aug-21		9.5	µg/L
SVWTP_TWR_EFF	16-Aug-21		10.4	µg/L
SVWTP_TWR_EFF	30-Aug-21		11.8	µg/L
SVWTP_TWR_EFF	13-Sep-21		5.5	µg/L
SVWTP_TWR_EFF	20-Oct-21		23.4	µg/L
SVWTP_TWR_EFF	25-Oct-21		25.1	µg/L
SVWTP_TWR_EFF	28-Dec-21		26.5	µg/L
SVWTP_TWR_EFF	3-Jan-22		27.6	µg/L
SVWTP_TWR_EFF	17-Jan-22		27.4	µg/L
SVWTP_TWR_EFF	31-Jan-22		27.9	µg/L
SVWTP_TWR_EFF	14-Feb-22		9.2	µg/L

SamplePointName (Source)	Sample Date	RQualifier (rn3)	Value	Units
SVWTP_TWR_EFF	28-Feb-22		8.9	µg/L
Analyte: Dibromochloromethane, THM				
SVWTP_TWR_EFF	2-Feb-21		1.2	µg/L
SVWTP_TWR_EFF	15-Feb-21		1.3	µg/L
SVWTP_TWR_EFF	5-May-21		1.6	µg/L
SVWTP_TWR_EFF	11-Jun-21		1.3	µg/L
SVWTP_TWR_EFF	21-Jul-21		1.4	µg/L
SVWTP_TWR_EFF	2-Aug-21		1.3	µg/L
SVWTP_TWR_EFF	16-Aug-21		1.4	µg/L
SVWTP_TWR_EFF	30-Aug-21		1.6	µg/L
SVWTP_TWR_EFF	13-Sep-21	<	0.5	µg/L
SVWTP_TWR_EFF	20-Oct-21		1.3	µg/L
SVWTP_TWR_EFF	25-Oct-21		1.3	µg/L
SVWTP_TWR_EFF	28-Dec-21		1.0	µg/L
SVWTP_TWR_EFF	3-Jan-22		0.9	µg/L
SVWTP_TWR_EFF	17-Jan-22		0.9	µg/L
SVWTP_TWR_EFF	31-Jan-22	<	1.0	µg/L
SVWTP_TWR_EFF	14-Feb-22	<	1.0	µg/L
SVWTP_TWR_EFF	28-Feb-22	<	1.0	µg/L
Analyte: Bromodichloromethane, THM				
HTWTP_EFF_POST	4-Jan-21		2.3	µg/L
HTWTP_EFF_POST	18-Jan-21		2.3	µg/L
HTWTP_EFF_POST	1-Feb-21		2.9	µg/L
HTWTP_EFF_POST	15-Feb-21		2.1	µg/L
HTWTP_EFF_POST	1-Mar-21		2.3	µg/L
HTWTP_EFF_POST	15-Mar-21		2.8	µg/L
HTWTP_EFF_POST	29-Mar-21		2.3	µg/L
HTWTP_EFF_POST	12-Apr-21		2.3	µg/L
HTWTP_EFF_POST	26-Apr-21		2.1	µg/L
HTWTP_EFF_POST	10-May-21		2.5	µg/L
HTWTP_EFF_POST	24-May-21		2.5	µg/L
HTWTP_EFF_POST	7-Jun-21		2.5	µg/L
HTWTP_EFF_POST	21-Jun-21		2.6	µg/L
HTWTP_EFF_POST	5-Jul-21		2.7	µg/L
HTWTP_EFF_POST	19-Jul-21		2.9	µg/L
HTWTP_EFF_POST	21-Sep-21		3.9	µg/L
HTWTP_EFF_POST	27-Sep-21		2.7	µg/L
HTWTP_EFF_POST	11-Oct-21		2.4	µg/L
HTWTP_EFF_POST	8-Nov-21		2.8	µg/L
HTWTP_EFF_POST	22-Nov-21		2.3	µg/L
HTWTP_EFF_POST	6-Dec-21		2.3	µg/L
HTWTP_EFF_POST	20-Dec-21		2.7	µg/L

SamplePointName (Source)	Sample Date	RQualifier (rn3)	Value	Units
HTWTP_EFF_POST	3-Jan-22		3.2	µg/L
HTWTP_EFF_POST	17-Jan-22		3.7	µg/L
HTWTP_EFF_POST	31-Jan-22		4.2	µg/L
HTWTP_EFF_POST	14-Feb-22		3.4	µg/L
HTWTP_EFF_POST	28-Feb-22		3.7	µg/L
HTWTP_EFF_POST	14-Mar-22		4.6	µg/L
Analyte: Bromoform, THM				
HTWTP_EFF_POST	4-Jan-21	<	0.5	µg/L
HTWTP_EFF_POST	18-Jan-21	<	0.5	µg/L
HTWTP_EFF_POST	1-Feb-21	<	0.5	µg/L
HTWTP_EFF_POST	15-Feb-21	<	0.5	µg/L
HTWTP_EFF_POST	1-Mar-21	<	0.5	µg/L
HTWTP_EFF_POST	15-Mar-21	<	0.5	µg/L
HTWTP_EFF_POST	29-Mar-21	<	0.5	µg/L
HTWTP_EFF_POST	12-Apr-21	<	0.5	µg/L
HTWTP_EFF_POST	26-Apr-21	<	0.5	µg/L
HTWTP_EFF_POST	10-May-21	<	0.5	µg/L
HTWTP_EFF_POST	24-May-21	<	0.5	µg/L
HTWTP_EFF_POST	7-Jun-21	<	0.5	µg/L
HTWTP_EFF_POST	21-Jun-21	<	0.5	µg/L
HTWTP_EFF_POST	5-Jul-21	<	0.5	µg/L
HTWTP_EFF_POST	19-Jul-21	<	0.5	µg/L
HTWTP_EFF_POST	21-Sep-21	<	0.5	µg/L
HTWTP_EFF_POST	27-Sep-21	<	0.5	µg/L
HTWTP_EFF_POST	11-Oct-21	<	0.5	µg/L
HTWTP_EFF_POST	8-Nov-21	<	0.5	µg/L
HTWTP_EFF_POST	22-Nov-21	<	0.5	µg/L
HTWTP_EFF_POST	6-Dec-21	<	0.5	µg/L
HTWTP_EFF_POST	20-Dec-21	<	0.5	µg/L
HTWTP_EFF_POST	3-Jan-22	<	0.5	µg/L
HTWTP_EFF_POST	17-Jan-22	<	0.5	µg/L
HTWTP_EFF_POST	31-Jan-22	<	1.0	µg/L
HTWTP_EFF_POST	14-Feb-22	<	1.0	µg/L
HTWTP_EFF_POST	28-Feb-22	<	1.0	µg/L
HTWTP_EFF_POST	14-Mar-22	<	1.0	µg/L
Analyte: Chloroform, THM				
HTWTP_EFF_POST	4-Jan-21		3.2	µg/L
HTWTP_EFF_POST	18-Jan-21		2.9	µg/L
HTWTP_EFF_POST	1-Feb-21		4.6	µg/L
HTWTP_EFF_POST	15-Feb-21		2.7	µg/L
HTWTP_EFF_POST	1-Mar-21		2.9	µg/L
HTWTP_EFF_POST	15-Mar-21		4.0	µg/L

SamplePointName (Source)	Sample Date	RQualifier (rn3)	Value	Units
HTWTP_EFF_POST	29-Mar-21		3.9	µg/L
HTWTP_EFF_POST	12-Apr-21		3.9	µg/L
HTWTP_EFF_POST	26-Apr-21		3.8	µg/L
HTWTP_EFF_POST	10-May-21		4.6	µg/L
HTWTP_EFF_POST	24-May-21		4.3	µg/L
HTWTP_EFF_POST	7-Jun-21		4.6	µg/L
HTWTP_EFF_POST	21-Jun-21		4.9	µg/L
HTWTP_EFF_POST	5-Jul-21		4.8	µg/L
HTWTP_EFF_POST	19-Jul-21		5.8	µg/L
HTWTP_EFF_POST	21-Sep-21		18.6	µg/L
HTWTP_EFF_POST	27-Sep-21		5.3	µg/L
HTWTP_EFF_POST	11-Oct-21		4.4	µg/L
HTWTP_EFF_POST	8-Nov-21		4.7	µg/L
HTWTP_EFF_POST	22-Nov-21		3.5	µg/L
HTWTP_EFF_POST	6-Dec-21		3.2	µg/L
HTWTP_EFF_POST	20-Dec-21		3.9	µg/L
HTWTP_EFF_POST	3-Jan-22		4.7	µg/L
HTWTP_EFF_POST	17-Jan-22		4.6	µg/L
HTWTP_EFF_POST	31-Jan-22		5.2	µg/L
HTWTP_EFF_POST	14-Feb-22		4.7	µg/L
HTWTP_EFF_POST	28-Feb-22		5.5	µg/L
HTWTP_EFF_POST	14-Mar-22		9.9	µg/L
Analyte: Dibromochloromethane, THM				
HTWTP_EFF_POST	4-Jan-21		1.3	µg/L
HTWTP_EFF_POST	18-Jan-21		1.2	µg/L
HTWTP_EFF_POST	1-Feb-21		1.4	µg/L
HTWTP_EFF_POST	15-Feb-21		1.2	µg/L
HTWTP_EFF_POST	1-Mar-21		1.2	µg/L
HTWTP_EFF_POST	15-Mar-21		1.3	µg/L
HTWTP_EFF_POST	29-Mar-21		1.1	µg/L
HTWTP_EFF_POST	12-Apr-21		1.2	µg/L
HTWTP_EFF_POST	26-Apr-21		1.0	µg/L
HTWTP_EFF_POST	10-May-21		1.1	µg/L
HTWTP_EFF_POST	24-May-21		1.3	µg/L
HTWTP_EFF_POST	7-Jun-21		1.1	µg/L
HTWTP_EFF_POST	21-Jun-21		1.1	µg/L
HTWTP_EFF_POST	5-Jul-21		1.1	µg/L
HTWTP_EFF_POST	19-Jul-21		1.2	µg/L
HTWTP_EFF_POST	21-Sep-21		1.2	µg/L
HTWTP_EFF_POST	27-Sep-21		1.1	µg/L
HTWTP_EFF_POST	11-Oct-21		1.0	µg/L
HTWTP_EFF_POST	8-Nov-21		1.2	µg/L

SamplePointName (Source)	Sample Date	RQualifier (rn3)	Value	Units
HTWTP_EFF_POST	22-Nov-21		1.1	µg/L
HTWTP_EFF_POST	6-Dec-21		1.1	µg/L
HTWTP_EFF_POST	20-Dec-21		1.2	µg/L
HTWTP_EFF_POST	3-Jan-22		1.6	
HTWTP_EFF_POST	17-Jan-22		1.7	
HTWTP_EFF_POST	31-Jan-22		1.9	
HTWTP_EFF_POST	14-Feb-22		1.5	
HTWTP_EFF_POST	28-Feb-22		1.6	
HTWTP_EFF_POST	14-Mar-22		1.7	

Table 4-7. Chlorate. SFPUC, 2016 - 2021

Rasprojectno_(Project_ID)	ClSampNo	Sample_Date	Analyte	Final µg/L
SURFACE WATER EAST BAY				
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	15-Jun-16	Chlorate, ClO3-	56
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	18-Jun-18	Chlorate, ClO3-	<10
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	17-Jun-19	Chlorate, ClO3-	<10
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	1-Jul-20	Chlorate, ClO3-	<10
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	3-Mar-21	Chlorate, ClO3-	<10
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	19-Jun-17	Chlorate, ClO3-	34
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	18-Jun-18	Chlorate, ClO3-	24
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2-May-19	Chlorate, ClO3-	42
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	1-Jul-20	Chlorate, ClO3-	26
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	3-Mar-21	Chlorate, ClO3-	30
T22_ANNUAL_RUNS	CAL_SURF	15-Jun-16	Chlorate, ClO3-	<10
T22_ANNUAL_RUNS	CAL_SURF	19-Jun-17	Chlorate, ClO3-	<10
T22_ANNUAL_RUNS	CAL_SURF	18-Jun-18	Chlorate, ClO3-	<10
T22_ANNUAL_RUNS	CAL_SURF	17-Jun-19	Chlorate, ClO3-	<10
T22_ANNUAL_RUNS	CAL_SURF	20-Jul-20	Chlorate, ClO3-	<10
T22_ANNUAL_RUNS	CAL_SURF	28-Jun-21	Chlorate, ClO3-	<10
T22_ANNUAL_RUNS	SANT_SURF	15-Jun-16	Chlorate, ClO3-	14
T22_ANNUAL_RUNS	SANT_SURF	19-Jun-17	Chlorate, ClO3-	<10
T22_ANNUAL_RUNS	SANT_SURF	18-Jun-18	Chlorate, ClO3-	<10
T22_ANNUAL_RUNS	SANT_SURF	17-Jun-19	Chlorate, ClO3-	<10
T22_ANNUAL_RUNS	SANT_SURF	24-Jun-20	Chlorate, ClO3-	11
T22_ANNUAL_RUNS	SANT_SURF	14-Jun-21	Chlorate, ClO3-	<10
SURFACE WATER WEST BAY				
T22_ANNUAL_RUNS	LCS_SURF	14-Jun-16	Chlorate, ClO3-	57
T22_ANNUAL_RUNS	LCS_SURF	19-Jun-17	Chlorate, ClO3-	35
T22_ANNUAL_RUNS	LCS_SURF	18-Jun-18	Chlorate, ClO3-	48
T22_ANNUAL_RUNS	LCS_SURF	17-Jun-19	Chlorate, ClO3-	28
T22_ANNUAL_RUNS	LCS_SURF	28-Jul-20	Chlorate, ClO3-	46
T22_ANNUAL_RUNS	LCS_SURF	14-Jun-21	Chlorate, ClO3-	54
T22_ANNUAL_RUNS	SA_SURF	14-Jun-16	Chlorate, ClO3-	36
T22_ANNUAL_RUNS	SA_SURF	19-Jun-17	Chlorate, ClO3-	29
T22_ANNUAL_RUNS	SA_SURF	18-Jun-18	Chlorate, ClO3-	27
T22_ANNUAL_RUNS	SA_SURF	17-Jun-19	Chlorate, ClO3-	16
T22_ANNUAL_RUNS	SA_SURF	15-Jun-20	Chlorate, ClO3-	19
T22_ANNUAL_RUNS	SA_SURF	16-Jun-21	Chlorate, ClO3-	26
T22_ANNUAL_RUNS	CASTLEWOOD_RES	14-Jun-16	Chlorate, ClO3-	86
T22_ANNUAL_RUNS	CASTLEWOOD_RES	19-Jun-17	Chlorate, ClO3-	65
T22_ANNUAL_RUNS	CASTLEWOOD_RES	18-Jun-18	Chlorate, ClO3-	110
T22_ANNUAL_RUNS	CASTLEWOOD_RES	17-Jun-19	Chlorate, ClO3-	57
T22_ANNUAL_RUNS	CASTLEWOOD_RES	16-Jun-20	Chlorate, ClO3-	70

Rasprojectno_(Project_ID)	ClSampNo	Sample_Date	Analyte	Final µg/L
T22_ANNUAL_RUNS	CASTLEWOOD_RES	22-Jun-21	Chlorate, ClO3-	45
GROUNDWATER SF CITY				
T22_ANNUAL_RUNS	LK_MERCED_S	19-Jun-17	Chlorate, ClO3-	<10
T22_ANNUAL_RUNS	LK_MERCED_S	14-Jul-20	Chlorate, ClO3-	10
SFGW_1ST-YR	SFGW-LMW	11-Jan-18	Chlorate, ClO3-	39
SFGW_1ST-YR	SFGW-GCW	6-Mar-18	Chlorate, ClO3-	<20
SFGW_1ST-YR	SFGW-SSW	6-Mar-18	Chlorate, ClO3-	25
SFGW_1ST-YR	SFGW-WSW	8-Mar-18	Chlorate, ClO3-	32
GROUNDWATER PENINSULA				
GSR_PARTNER	GSR-SMW	17-Feb-16	Chlorate, ClO3-	<10
GSR_PRE-COMP	GSR-HBW	24-Jun-19	Chlorate, ClO3-	<10
GSR_PRE-COMP	GSR-PDWLGWLGW	24-Jun-19	Chlorate, ClO3-	<10
GSR_PRE-COMP	GSR-SBW	24-Jun-19	Chlorate, ClO3-	<10
GSR_PRE-COMP	GSR-MSW	25-Jun-19	Chlorate, ClO3-	59
GSR_PRE-COMP	GSR-MYW	25-Jun-19	Chlorate, ClO3-	<10
GSR_PRE-COMP	GSR-SDW	25-Jun-19	Chlorate, ClO3-	<10
GSR_PRE-COMP	GSR-BSW	26-Jun-19	Chlorate, ClO3-	19
GSR_PRE-COMP	GSR-CBW	26-Jun-19	Chlorate, ClO3-	<10
GSR_PRE-COMP	GSR-FSW	26-Jun-19	Chlorate, ClO3-	11
TI				
T22_ANNUAL_RUNS	TI_BBPS	16-Jun-20	Chlorate, ClO3-	14
GROUNDWATER EAST BAY				
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	16-Jun-20	Chlorate, ClO3-	19
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	16-Jun-20	Chlorate, ClO3-	16
DRINKING WATER				
T22_ANNUAL_RUNS	EI_TK	14-Jun-16	Chlorate, ClO3-	**890**
T22_ANNUAL_RUNS	EI_TK	19-Jun-17	Chlorate, ClO3-	790
T22_ANNUAL_RUNS	EI_TK	19-Jun-18	Chlorate, ClO3-	780
T22_ANNUAL_RUNS	EI_TK	19-Jun-19	Chlorate, ClO3-	550
T22_ANNUAL_RUNS	EI_TK	23-Jun-20	Chlorate, ClO3-	380
T22_ANNUAL_RUNS	EI_TK	14-Jul-21	Chlorate, ClO3-	760
T22_ANNUAL_RUNS	MOC_TK	15-Jun-16	Chlorate, ClO3-	470
T22_ANNUAL_RUNS	MOC_TK	20-Jun-17	Chlorate, ClO3-	320
T22_ANNUAL_RUNS	MOC_TK	18-Sep-18	Chlorate, ClO3-	420
T22_ANNUAL_RUNS	MOC_TK	18-Jun-19	Chlorate, ClO3-	250
T22_ANNUAL_RUNS	MOC_TK	15-Jun-20	Chlorate, ClO3-	300
T22_ANNUAL_RUNS	MOC_TK	14-Jul-21	Chlorate, ClO3-	500
T22_ANNUAL_RUNS	OSH_TK	15-Jun-16	Chlorate, ClO3-	750
T22_ANNUAL_RUNS	OSH_TK	19-Jun-17	Chlorate, ClO3-	620
T22_ANNUAL_RUNS	OSH_TK	10-Jul-18	Chlorate, ClO3-	710
T22_ANNUAL_RUNS	OSH_TK	18-Jun-19	Chlorate, ClO3-	640

Rasprojectno_(Project_ID)	ClSampNo	Sample_Date	Analyte	Final µg/L
T22_ANNUAL_RUNS	OSH_TK	16-Jun-20	Chlorate, ClO3-	660
T22_ANNUAL_RUNS	OSH_TK	14-Jul-21	Chlorate, ClO3-	<10
T22_ANNUAL_RUNS	ALAMEDA_EAST	14-Jun-16	Chlorate, ClO3-	47
T22_ANNUAL_RUNS	ALAMEDA_EAST	19-Jun-17	Chlorate, ClO3-	51
T22_ANNUAL_RUNS	ALAMEDA_EAST	18-Jun-18	Chlorate, ClO3-	42
T22_ANNUAL_RUNS	ALAMEDA_EAST	17-Jun-19	Chlorate, ClO3-	40
T22_ANNUAL_RUNS	ALAMEDA_EAST	15-Jun-20	Chlorate, ClO3-	67
T22_ANNUAL_RUNS	ALAMEDA_EAST	22-Jun-21	Chlorate, ClO3-	28
TS_RUNS	SVWTP_TWR_EFF	14-May-18	Chlorate, ClO3-	84
TS_RUNS	SVWTP_TWR_EFF	12-Nov-18	Chlorate, ClO3-	190
TS_RUNS	SVWTP_TWR_EFF	5-Jun-19	Chlorate, ClO3-	210
TS_RUNS	SVWTP_TWR_EFF	10-Apr-20	Chlorate, ClO3-	270
TS_RUNS	SVWTP_TWR_EFF	18-May-20	Chlorate, ClO3-	520
TS_RUNS	SVWTP_TWR_EFF	28-Aug-20	Chlorate, ClO3-	**1200**
TS_RUNS	SVWTP_TWR_EFF	10-Nov-20	Chlorate, ClO3-	270
TS_RUNS	SVWTP_TWR_EFF	8-Feb-21	Chlorate, ClO3-	380
TS_RUNS	SVWTP_TWR_EFF	5-May-21	Chlorate, ClO3-	250
T22_ANNUAL_RUNS	SVWTP_TWR_EFF	14-Jun-21	Chlorate, ClO3-	420
TS_RUNS	SVWTP_TWR_EFF	2-Aug-21	Chlorate, ClO3-	390
TS_RUNS	SVWTP_TWR_EFF	9-Aug-21	Chlorate, ClO3-	290
T22_ANNUAL_RUNS	SVWTP_EFF	14-Jun-16	Chlorate, ClO3-	200
T22_ANNUAL_RUNS	SVWTP_EFF	19-Jun-17	Chlorate, ClO3-	79
T22_ANNUAL_RUNS	SVWTP_EFF	28-Jun-18	Chlorate, ClO3-	190
T22_ANNUAL_RUNS	SVWTP_EFF	17-Jun-19	Chlorate, ClO3-	100
T22_ANNUAL_RUNS	SVWTP_EFF	24-Jun-20	Chlorate, ClO3-	480
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	14-Jun-16	Chlorate, ClO3-	150
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	19-Jun-17	Chlorate, ClO3-	79
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	21-Jun-18	Chlorate, ClO3-	72
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	17-Jun-19	Chlorate, ClO3-	70
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	15-Jun-20	Chlorate, ClO3-	160
TS_RUNS	HTWTP_EFF_POST	5-Jan-16	Chlorate, ClO3-	168
TS_RUNS	HTWTP_EFF_POST	2-Feb-16	Chlorate, ClO3-	190
TS_RUNS	HTWTP_EFF_POST	1-Mar-16	Chlorate, ClO3-	170
TS_RUNS	HTWTP_EFF_POST	5-Apr-16	Chlorate, ClO3-	155
TS_RUNS	HTWTP_EFF_POST	3-May-16	Chlorate, ClO3-	143
TS_RUNS	HTWTP_EFF_POST	7-Jun-16	Chlorate, ClO3-	220
T22_ANNUAL_RUNS	HTWTP_EFF_POST	21-Jun-16	Chlorate, ClO3-	250
TS_RUNS	HTWTP_EFF_POST	5-Jul-16	Chlorate, ClO3-	210
TS_RUNS	HTWTP_EFF_POST	2-Aug-16	Chlorate, ClO3-	205
TS_RUNS	HTWTP_EFF_POST	6-Sep-16	Chlorate, ClO3-	201
TS_RUNS	HTWTP_EFF_POST	4-Oct-16	Chlorate, ClO3-	140
TS_RUNS	HTWTP_EFF_POST	1-Nov-16	Chlorate, ClO3-	190

Rasprojectno_(Project_ID)	ClSampNo	Sample_Date	Analyte	Final µg/L
TS_RUNS	HTWTP_EFF_POST	8-Dec-16	Chlorate, ClO3-	133
TS_RUNS	HTWTP_EFF_POST	3-Jan-17	Chlorate, ClO3-	101
TS_RUNS	HTWTP_EFF_POST	7-Feb-17	Chlorate, ClO3-	73
TS_RUNS	HTWTP_EFF_POST	7-Mar-17	Chlorate, ClO3-	97
TS_RUNS	HTWTP_EFF_POST	4-Apr-17	Chlorate, ClO3-	117
TS_RUNS	HTWTP_EFF_POST	2-May-17	Chlorate, ClO3-	140
TS_RUNS	HTWTP_EFF_POST	6-Jun-17	Chlorate, ClO3-	120
T22_ANNUAL_RUNS	HTWTP_EFF_POST	19-Jun-17	Chlorate, ClO3-	100
TS_RUNS	HTWTP_EFF_POST	4-Jul-17	Chlorate, ClO3-	180
TS_RUNS	HTWTP_EFF_POST	1-Aug-17	Chlorate, ClO3-	150
TS_RUNS	HTWTP_EFF_POST	5-Sep-17	Chlorate, ClO3-	170
TS_RUNS	HTWTP_EFF_POST	3-Oct-17	Chlorate, ClO3-	160
TS_RUNS	HTWTP_EFF_POST	7-Nov-17	Chlorate, ClO3-	140
TS_RUNS	HTWTP_EFF_POST	5-Dec-17	Chlorate, ClO3-	130
TS_RUNS	HTWTP_EFF_POST	2-Jan-18	Chlorate, ClO3-	111
TS_RUNS	HTWTP_EFF_POST	3-Feb-18	Chlorate, ClO3-	108
TS_RUNS	HTWTP_EFF_POST	6-Mar-18	Chlorate, ClO3-	122
TS_RUNS	HTWTP_EFF_POST	3-Apr-18	Chlorate, ClO3-	110
TS_RUNS	HTWTP_EFF_POST	1-May-18	Chlorate, ClO3-	140
TS_RUNS	HTWTP_EFF_POST	14-May-18	Chlorate, ClO3-	120
T22_ANNUAL_RUNS	HTWTP_EFF_POST	18-Jun-18	Chlorate, ClO3-	150
TS_RUNS	HTWTP_EFF_POST	27-Jun-18	Chlorate, ClO3-	180
TS_RUNS	HTWTP_EFF_POST	3-Jul-18	Chlorate, ClO3-	180
TS_RUNS	HTWTP_EFF_POST	7-Aug-18	Chlorate, ClO3-	210
TS_RUNS	HTWTP_EFF_POST	14-Aug-18	Chlorate, ClO3-	230
TS_RUNS	HTWTP_EFF_POST	4-Sep-18	Chlorate, ClO3-	74
TS_RUNS	HTWTP_EFF_POST	19-Oct-18	Chlorate, ClO3-	180
TS_RUNS	HTWTP_EFF_POST	6-Nov-18	Chlorate, ClO3-	120
TS_RUNS	HTWTP_EFF_POST	12-Nov-18	Chlorate, ClO3-	120
TS_RUNS	HTWTP_EFF_POST	4-Dec-18	Chlorate, ClO3-	85
TS_RUNS	HTWTP_EFF_POST	1-Jan-19	Chlorate, ClO3-	97
TS_RUNS	HTWTP_EFF_POST	5-Feb-19	Chlorate, ClO3-	48
TS_RUNS	HTWTP_EFF_POST	5-Mar-19	Chlorate, ClO3-	65
TS_RUNS	HTWTP_EFF_POST	2-Apr-19	Chlorate, ClO3-	68
TS_RUNS	HTWTP_EFF_POST	7-May-19	Chlorate, ClO3-	68
TS_RUNS	HTWTP_EFF_POST	13-May-19	Chlorate, ClO3-	96
TS_RUNS	HTWTP_EFF_POST	2-Jul-19	Chlorate, ClO3-	220
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2-Jul-19	Chlorate, ClO3-	220
TS_RUNS	HTWTP_EFF_POST	6-Aug-19	Chlorate, ClO3-	100
TS_RUNS	HTWTP_EFF_POST	3-Sep-19	Chlorate, ClO3-	140
TS_RUNS	HTWTP_EFF_POST	1-Oct-19	Chlorate, ClO3-	180
TS_RUNS	HTWTP_EFF_POST	5-Nov-19	Chlorate, ClO3-	74
TS_RUNS	HTWTP_EFF_POST	3-Dec-19	Chlorate, ClO3-	68

Rasprojectno_(Project_ID)	ClSampNo	Sample_Date	Analyte	Final µg/L
TS_RUNS	HTWTP_EFF_POST	7-Jan-20	Chlorate, ClO3-	100
TS_RUNS	HTWTP_EFF_POST	4-Feb-20	Chlorate, ClO3-	98
TS_RUNS	HTWTP_EFF_POST	10-Feb-20	Chlorate, ClO3-	100
TS_RUNS	HTWTP_EFF_POST	3-Mar-20	Chlorate, ClO3-	120
TS_RUNS	HTWTP_EFF_POST	7-Apr-20	Chlorate, ClO3-	110
TS_RUNS	HTWTP_EFF_POST	5-May-20	Chlorate, ClO3-	150
TS_RUNS	HTWTP_EFF_POST	11-May-20	Chlorate, ClO3-	150
TS_RUNS	HTWTP_EFF_POST	2-Jun-20	Chlorate, ClO3-	150
T22_ANNUAL_RUNS	HTWTP_EFF_POST	15-Jun-20	Chlorate, ClO3-	170
TS_RUNS	HTWTP_EFF_POST	7-Jul-20	Chlorate, ClO3-	140
TS_RUNS	HTWTP_EFF_POST	4-Aug-20	Chlorate, ClO3-	150
TS_RUNS	HTWTP_EFF_POST	1-Sep-20	Chlorate, ClO3-	300
TS_RUNS	HTWTP_EFF_POST	6-Oct-20	Chlorate, ClO3-	140
TS_RUNS	HTWTP_EFF_POST	24-Nov-20	Chlorate, ClO3-	370
TS_RUNS	HTWTP_EFF_POST	1-Dec-20	Chlorate, ClO3-	330
TS_RUNS	HTWTP_EFF_POST	2-Feb-21	Chlorate, ClO3-	130
TS_RUNS	HTWTP_EFF_POST	8-Feb-21	Chlorate, ClO3-	130
TS_RUNS	HTWTP_EFF_POST	2-Mar-21	Chlorate, ClO3-	96
TS_RUNS	HTWTP_EFF_POST	6-Apr-21	Chlorate, ClO3-	96
TS_RUNS	HTWTP_EFF_POST	4-May-21	Chlorate, ClO3-	100
TS_RUNS	HTWTP_EFF_POST	10-May-21	Chlorate, ClO3-	120
TS_RUNS	HTWTP_EFF_POST	1-Jun-21	Chlorate, ClO3-	120
T22_ANNUAL_RUNS	HTWTP_EFF_POST	16-Jun-21	Chlorate, ClO3-	98
T22_ANNUAL_RUNS	CS#2_BADEN	14-Jun-16	Chlorate, ClO3-	170
T22_ANNUAL_RUNS	CS#2_BADEN	19-Jun-17	Chlorate, ClO3-	91
T22_ANNUAL_RUNS	CS#2_BADEN	18-Jun-18	Chlorate, ClO3-	78
T22_ANNUAL_RUNS	CS#2_BADEN	17-Jun-19	Chlorate, ClO3-	84
T22_ANNUAL_RUNS	CS#2_BADEN	16-Jun-20	Chlorate, ClO3-	170
T22_ANNUAL_RUNS	CS#2_BADEN	16-Jun-21	Chlorate, ClO3-	55
SFGW_RUNS	SSO#1_N	17-Jun-19	Chlorate, ClO3-	61
SFGW_RUNS	SSO#1_N	9-Jul-20	Chlorate, ClO3-	130
SFGW_RUNS	SSO#2_S	9-Jul-20	Chlorate, ClO3-	140

Table 4-8. Haloacetonitriles, SFPUC, 2000 – 2021 – Drinking Water (Laboratory: MB-Organics)

SamplePointName (Source)	Sample Date	RQualifier (rn3)	Value	Units
Analyte (Synonym): Bromochloroacetonitrile, HAN (HAN_BCAN)				
ALAMEDA_EAST	13-Feb-01	<	0.5	µg/L
ALAMEDA_EAST	11-Jun-01	<	0.5	µg/L
SVWTP_EFF_X12	13-Feb-01		1.3	µg/L
SVWTP_EFF_X12	11-Jun-01		0.9	µg/L
HTWTP_EFF_POST	11-Jun-01		0.7	µg/L
HTWTP_EFF_POST	13-Feb-01	<	0.5	µg/L
CHO	11-Jun-01		0.8	µg/L
CHO	13-Feb-01		1.1	µg/L
UMO#2_S	11-Jun-01	<	0.5	µg/L
UMO#2_S	13-Feb-01	<	0.5	µg/L
Analyte (Synonym): Dichloroacetonitrile, HAN (HAN_DCAN)				
ALAMEDA_EAST	11-Jun-01		0.9	µg/L
ALAMEDA_EAST	13-Feb-01		1	µg/L
SVWTP_EFF_X12	13-Feb-01		1.7	µg/L
SVWTP_EFF_X12	11-Jun-01		4.2	µg/L
HTWTP_EFF_POST	13-Feb-01		0.9	µg/L
HTWTP_EFF_POST	11-Jun-01		0.7	µg/L
CHO	11-Jun-01		0.9	µg/L
CHO	13-Feb-01		1.1	µg/L
UMO#2_S	13-Feb-01		1.3	µg/L
UMO#2_S	11-Jun-01		1.5	µg/L
Analyte (Synonym): Trichloroacetonitrile, HAN (HAN_TCAN)				
ALAMEDA_EAST	13-Feb-01	<	0.5	µg/L
ALAMEDA_EAST	11-Jun-01	<	0.5	µg/L
SVWTP_EFF_X12	13-Feb-01	<	0.5	µg/L
SVWTP_EFF_X12	11-Jun-01		4.2	µg/L
HTWTP_EFF_POST	13-Feb-01	<	0.5	µg/L
HTWTP_EFF_POST	11-Jun-01	<	0.5	µg/L
CHO	11-Jun-01	<	0.5	µg/L
CHO	13-Feb-01	<	0.5	µg/L
UMO#2_S	11-Jun-01	<	0.5	µg/L
UMO#2_S	13-Feb-01	<	0.5	µg/L

Table 4-9. Analyte: Formaldehyde, SFPUC, 2000 – 2021 (Laboratory: SUB-Subcontract)

SamplePointName_(Source)	Sample_Date	Final µg/L
Upcountry Water		
HHR	5-Jun-12	<5
CHERRY_RES	6-Jun-12	<5
CHERRY_WELL	6-Jun-12	<5
EI_RES	6-Jun-12	<5
LK_ELEANOR	6-Jun-12	<5
MOC_RES	5-Jun-12	<5
ALAMEDA_EAST	13-Jun-12	8.1
East Bay		
ALAMEDA_CR_P_F2EA	18-Jun-18	<5
ALAMEDA_CR_P_F3E	27-May-15	<5
COTTONWOOD_CK_RAW	6-Jun-12	<5
CAL_SURF	6-Jun-12	<5
SANT_SURF	6-Jun-12	<5
STONE_DAM_SURF	5-Jun-12	<5
SUNOL_FILTER	13-Jun-12	<5
SVWTP_EFF	13-Jun-12	12
Peninsula		
LCS_SURF	5-Jun-12	<5
PIL_SURF	5-Jun-12	<5
SA_SURF	5-Jun-12	<5
HTWTP_EFF_POST	24-Jul-12	13
Groundwater		
GSR-BSW	12-Jul-12	<5
GSR-BSW	26-Jun-19	<5
GSR-CBW	26-Jun-19	<5
GSR-CBW	8-Jul-20	<5
GSR-FSW	11-Jun-12	<5
GSR-FSW	26-Jun-19	<5
GSR-FSW	8-Jul-20	<5
GSR-HBW	24-Jun-19	<5
GSR-HBW	7-Jul-20	<5
GSR-MSW	25-Jun-19	<5
GSR-MYW	25-Jun-19	<5
GSR-MYW	8-Jul-20	<5
GSR-PDW	24-Jun-19	<5
GSR-PDW	7-Jul-20	<5
GSR-SBW	24-Jun-19	<5
GSR-SDW	25-Jun-19	<5

SamplePointName_(Source)	Sample_Date	Final µg/L
PLEAS_W_F_A_(N)	13-Jun-12	<5
PLEAS_W_F_A_(N)	16-Jun-20	<5
PLEAS_W_F_B_(S)	13-Jun-12	<5
PLEAS_W_F_B_(S)	16-Jun-20	<5
SF_ZOO_WELL_5	5-Jun-12	<5
SFGW-GCW	15-Jul-20	<5
SFGW-LMW	14-Jul-20	<5
SFGW-NLW	16-Jul-20	<5
SFGW-SSW	14-Jul-20	<5
SFGW-SWW	20-Jul-20	<5
SFGW-WSW	15-Jul-20	<5
WSB_CAL_DUP	5-Oct-10	<5
WSB_CAL-18-230	6-Oct-09	<5
WSB_CAL-18-230	10-May-10	<5
WSB_CAL-18-230	7-Oct-10	<5
WSB_CAL-18-425	6-May-10	<5
WSB_CAL-18-425	5-Oct-10	<5
WSB_CAL-18-490	5-Oct-09	<5
WSB_CAL-18-490	6-May-10	<5
WSB_CAL-18-490	7-Oct-10	<5
WSB_CAL-19-475	6-Oct-10	<5
WSB_CAL-22A-290	6-May-10	<5
WSB_CAL-22A-290	12-Oct-10	<5
WSB_CAL-22A-545	5-May-10	<5
WSB_CAL-22A-545	12-Oct-10	<5
WSB_SB-44-1-190	14-Sep-09	<5
WSB_SB-44-1-300	15-Sep-09	<5
WSB_SB-44-1-460	22-Sep-09	<5
WSB_SB-44-1-580	23-Sep-09	<5
WSB_SB-44-1-580	24-Sep-09	<5
WSB_SS_DUP	5-Nov-09	<5
WSB_SS_DUP	1-Dec-10	<5
WSB_SS11SSLP120	5-Nov-09	<5
WSB_SS11SSLP120	1-Dec-10	<5
WSB_SS12SSLP220	5-Nov-09	<5
WSB_SS12SSLP220	1-Dec-10	<5
WSB_SS13SSLP440	9-Nov-09	26
WSB_SS13SSLP440	1-Dec-10	<5
WSB_SS14SSLP520	9-Nov-09	<5
WSB_SS14SSLP520	1-Dec-10	<5

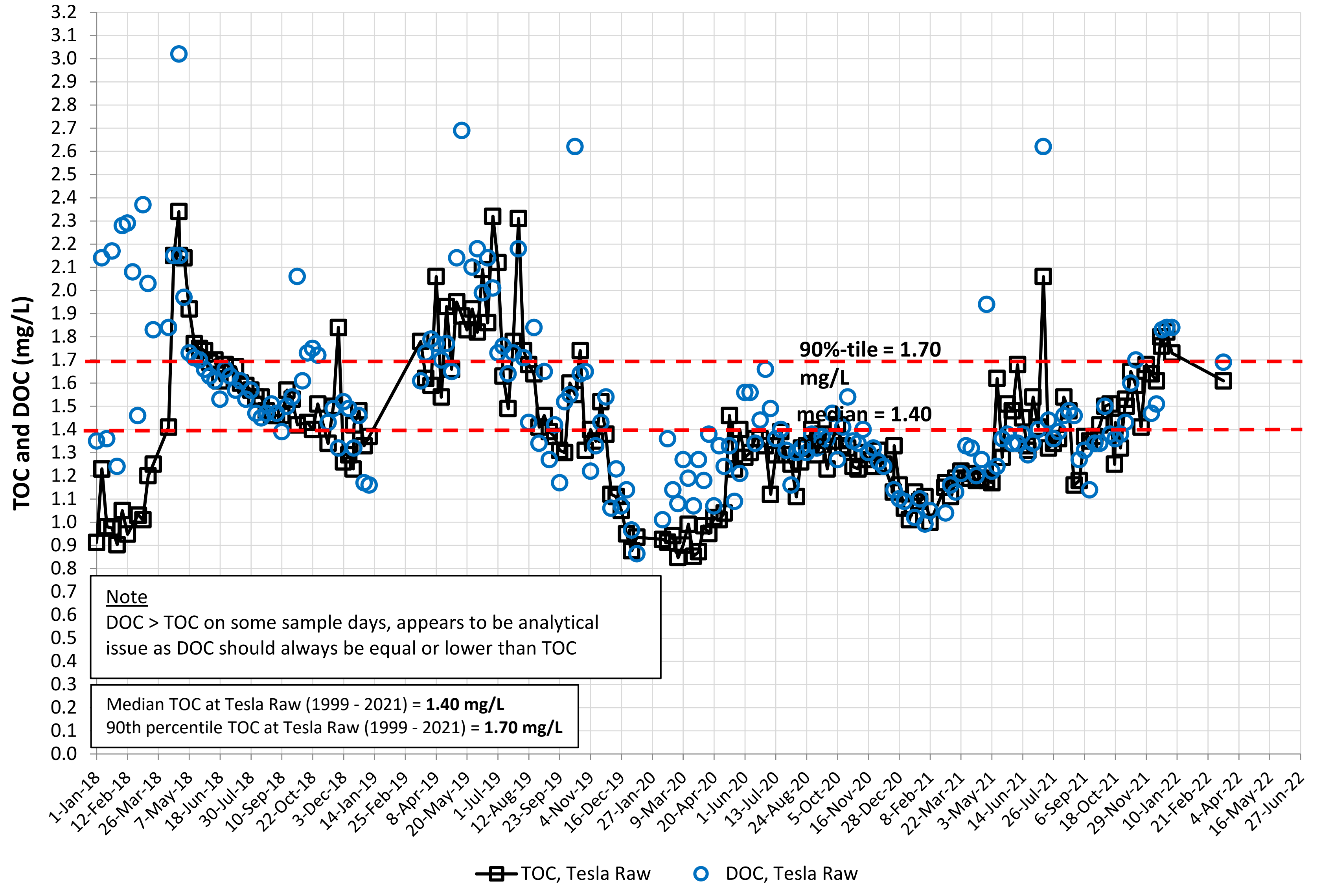
Table 4-10. Analyte: Acetaldehyde, SFPUC, 2000 – 2021

SamplePointName_(Source)	Sample_Date	Final µg/L
Drinking Water (Laboratory: MB-Process		
ALAMEDA_EAST	28-Feb-00	<1
ALAMEDA_EAST	13-Feb-01	1
ALAMEDA_EAST	11-Jun-01	<1
SVWTP_EFF_X12	28-Feb-00	2
SVWTP_EFF_X12	13-Feb-01	4
SVWTP_EFF_X12	11-Jun-01	2
HTWTP_EFF_POST	28-Feb-00	2
HTWTP_EFF_POST	13-Feb-01	4
HTWTP_EFF_POST	11-Jun-01	2
CHO	13-Feb-01	5
CHO	11-Jun-01	2
UMO#2_S	13-Feb-01	4
UMO#2_S	11-Jun-01	<1
Groundwater (Laboratory: SUB-Subcontract)		
WSB_CAL-18-230	6-Nov-12	<1
WSB_SB-44-1-580	13-Nov-12	<1

Table 4-11. Analyte: Chloropicrin, SFPUC, 2000 – 2021 (Laboratory: MB-Organics)

SamplePointName_(Source)	Sample_Date	Final µg/L
Drinking Water (Laboratory: MB-Process		
ALAMEDA_EAST	13-Feb-01	<0.5
ALAMEDA_EAST	11-Jun-01	0.5
SVWTP_EFF_X12	13-Feb-01	<0.5
SVWTP_EFF_X12	11-Jun-01	1.1
HTWTP_EFF_POST	11-Jun-01	0.7
HTWTP_EFF_POST	13-Feb-01	<0.5
CHO	13-Feb-01	0.7
CHO	11-Jun-01	1.2
UMO#2_S	11-Jun-01	0.7
UMO#2_S	13-Feb-01	<0.5

Figure 4-1. TOC and DOC at Tesla Raw, Jan 2018 to Present

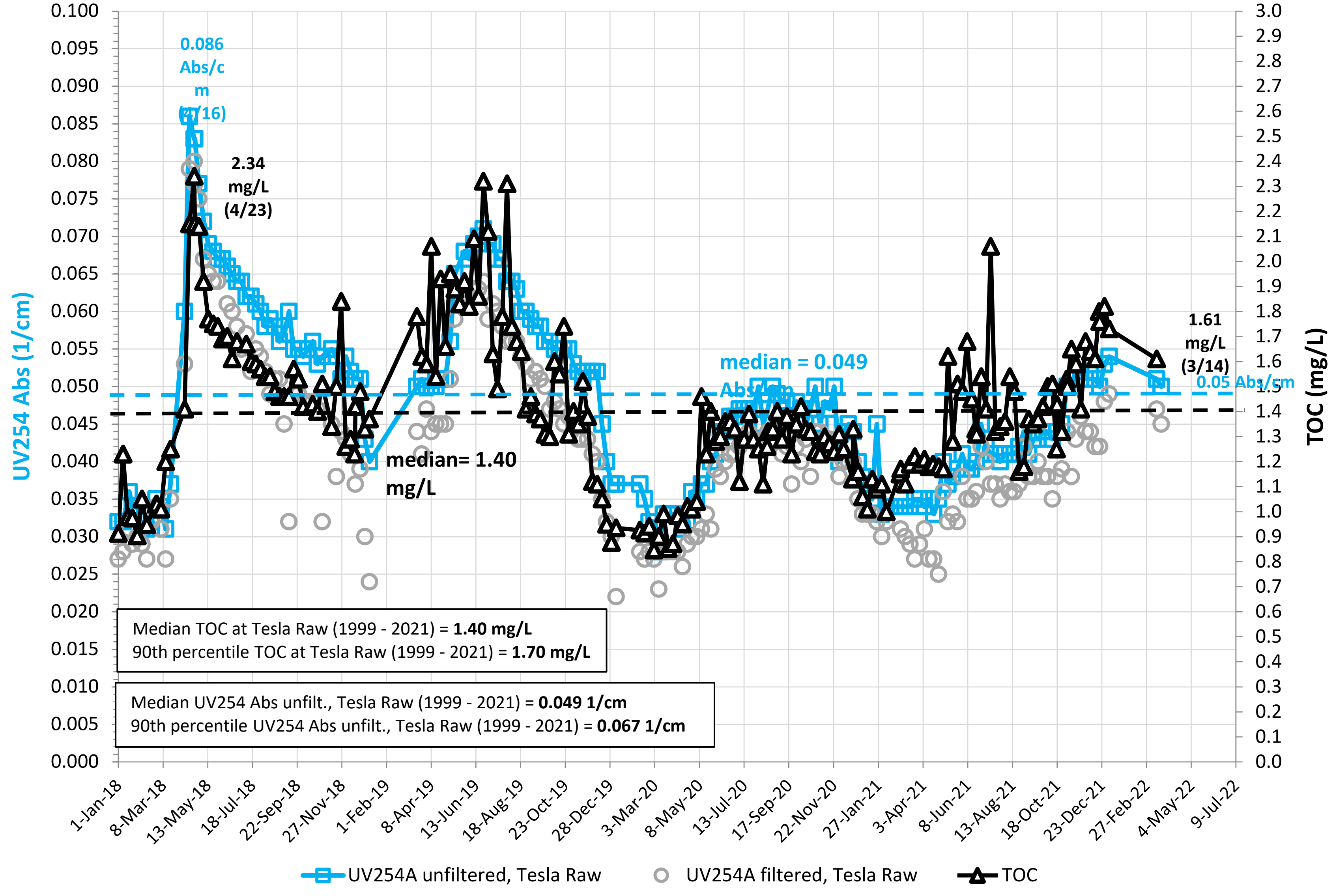


Note

DOC > TOC on some sample days, appears to be analytical issue as DOC should always be equal or lower than TOC

Median TOC at Tesla Raw (1999 - 2021) = **1.40 mg/L**
90th percentile TOC at Tesla Raw (1999 - 2021) = **1.70 mg/L**

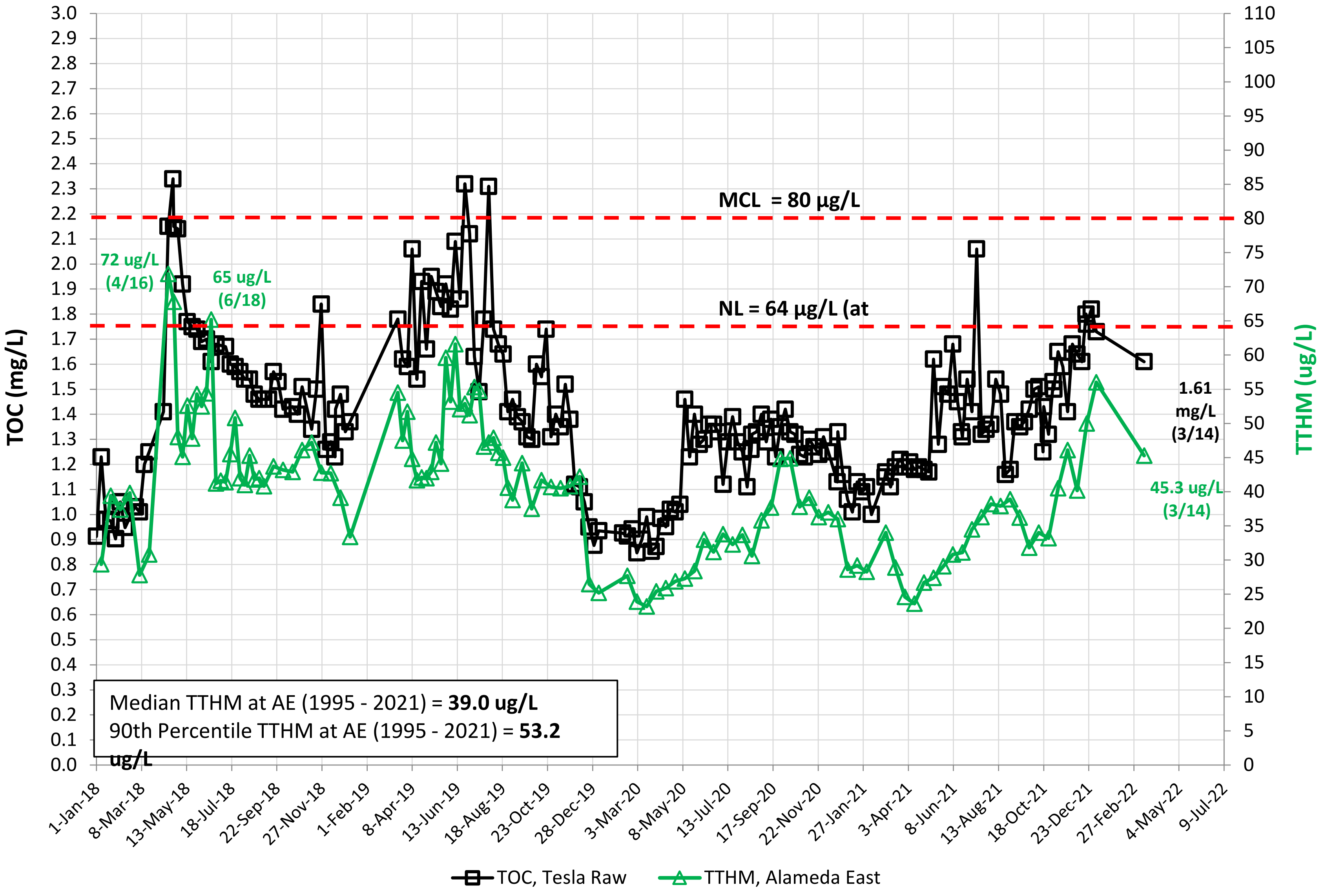
Figure 4-2. UV254 Abs and TOC at Tesla Raw, Jan 2018 to Present



Median TOC at Tesla Raw (1999 - 2021) = **1.40 mg/L**
90th percentile TOC at Tesla Raw (1999 - 2021) = **1.70 mg/L**

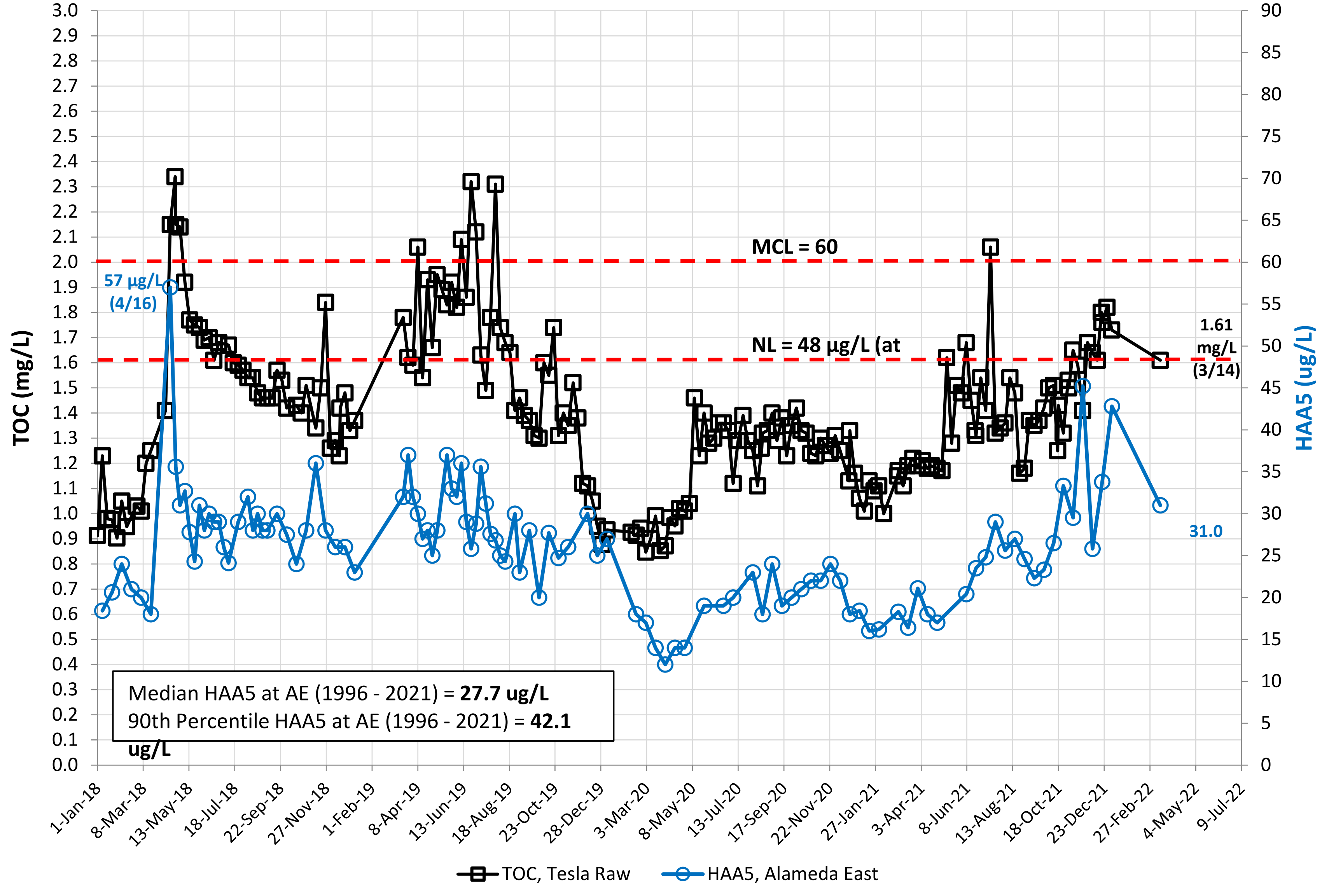
Median UV254 Abs unfilt., Tesla Raw (1999 - 2021) = **0.049 1/cm**
90th percentile UV254 Abs unfilt., Tesla Raw (1999 - 2021) = **0.067 1/cm**

Figure 4-3. TOC at Tesla Raw and TTHM at Alameda East, Jan 2018 - Present



Median TTHM at AE (1995 - 2021) = **39.0 ug/L**
90th Percentile TTHM at AE (1995 - 2021) = **53.2 ug/L**

Figure 4-4. TOC at Tesla Raw and HAA5 at Alameda East, Jan 2018 - Present



Median HAA5 at AE (1996 - 2021) = **27.7 ug/L**
90th Percentile HAA5 at AE (1996 - 2021) = **42.1 ug/L**

Water Quality Division, Technical Review 2016 – 2021

Contaminants of Emerging Concern (CEC) in Drinking Water

Unregulated Disinfection Byproducts

Regulations for selected halogenated DBPs have been introduced in some countries even though they represent only a fraction of all byproducts. These regulations have driven some utilities to switch from free chlorine to chloramine for final disinfection even though a higher proportion of the byproducts associated with chloramination are unidentified compared to those associated with chlorine and their impacts on human health are unknown. (WRF, Farré et al. 2016)

A number of parameters during treatment and in distribution affect DBP concentrations in drinking water. Factors affecting DBP production in water include bromide content and the type and quantity of the natural organic matter. During treatment, factors that affect the type and levels of DBPs formed include the treatment practices used, the water pH and temperature, the type and dose of disinfectants used, and the point in the treatment process at which the disinfectant is added. (Krasner et al. 2016)

DBP Classes. DBP classes include trihalomethanes (THMs), haloacetic acids (HAAs), haloacetonitriles (HANs), haloketones, halonitromethanes, haloamides, halogenated furanones, and non-halogenated carbonyls; to date more than 600 DBPs have been reported in the literature for the major disinfectants used. (Krasner et al. 2016)

Chloramine produces lower levels of THMs and trihalogenated HAAs (TXAAs) but may not adequately minimize the formation of dihalogenated HAAs (DXAAs). Disinfection of waters high in bromide can form more brominated compounds, including THMs, HAAs, and other DBPs. (Krasner et al. 2016)

THM4 and haloacetic acids (HAA) each account for ~10% of TOX

Considered to be the primary organic precursors for DBPs, humic substances in NOM are derived from natural biopolymers, including humic and fulvic acids, but their extensive degradation fosters a diversity of structures that prevents clear characterization. Their poor structural characterization has driven two of the historical challenges in DBP research. First, without the ability to predict DBPs likely to form at high yield by applying chlorine reaction pathways to well-characterized precursor structures, DBP identification has been largely the domain of analytical chemists. Over 600 DBPs have been characterized, most being low molecular weight semivolatile or volatile compounds, due to the availability of gas chromatography-based instrumentation. Yet the subset that has been quantified constitutes only ~30% of the total organic halogen (TOX) in chlorinated waters on a median basis, with THM4 and haloacetic acids (HAAs) each accounting for ~10% of TOX. Given the diversity of precursors, the total number of DBPs likely will far exceed 1,000 in chlorinated drinking waters, highlighting the challenge of closing the TOX mass balance. (Li and Mitch, 2018)

Occurrence of Bromide and Iodide

Non-targeted spatial occurrence and targeted temporal occurrence surveys reported similar bromide concentrations (median = 80 µg/L; N=689 samples from 228 utilities) in 2018-2019 as were observed in the early 1990s during a previous WRF project 825 study at different utilities of bromide (median =62 µg/L; N=164 samples from 88 random + 12 targeted high Br utilities). The current study showed that weekly or monthly variations in bromide concentrations regularly occur within any given source water. However, there is no apparent systematic nationwide long-term increase of bromide concentrations in drinking water treatment plant (DWTP) source waters. Individual utilities experienced large seasonal changes in bromide ion concentrations. Some watershed sources had elevated bromide levels. For example, the median Br^- concentration in wastewater effluents was roughly 4 times that observed in surface waters, indicating impacts of anthropogenic sources into wastewater streams. Installation of on-line bromide sensors at utilities was demonstrated to provide enhanced ability to collect data hourly rather than weekly, monthly, or quarterly. (WRF, Westerhoff et al. 2022)

For iodide occurrence in raw/untreated drinking waters and wastewater treatment plant effluents, samples contained either iodide or iodate, and only 15% of the samples where their co-occurrence exists contained both of these inorganic species. Iodide was detected in 46% of surface waters and 64% of groundwater at or above the detection limit of 1 µg/L. Iodate ion was widely detected in surface water and groundwater. The 75th percentile concentrations of iodide and iodate were 5 and 3 µg/L, but maximum concentrations reached 252 and 145 µg/L, respectively. The sum of iodide plus iodate, collectively representing inorganic iodine species, accounts for nearly 90% of the total iodine in groundwater but only 20% to 50% of the total iodine in surface waters. Surface waters and wastewaters were shown to contain organic iodine, and further research is needed to understand the source, nature, and importance of organic iodine on disinfection DBP formation at DWTPs. (WRF, Westerhoff et al. 2022)

Bromide Incorporation Factor (BIF)

BIF values are calculated on the basis of the relative number of bromine substitutions in the species of a given DBP class to the total number of halogen substitutions. The possible range for THM, DHAA, and THAA BIF values is from 0 to 1, where a value of 0 means there are only species with chlorine substitutions and no bromine substitutions, and a value of 1 means only species with bromine substitutions. (WRF, Westerhoff et al. 2022)

Water systems with groundwater sources tend to have higher BIF values than systems with surface water sources. During 2004-2014, the national median public water system (PWS) quarterly THM BIF value for systems with primarily groundwater sources was 0.267, three times higher than the national median PWS quarterly THM BIF value for systems with primarily surface water sources (0.089). Spatial trends of BIF data were observable across the U.S., with higher BIF values in U.S. Environmental Protection Agency (EPA) Regions 6 and 9. The median PWS quarterly THM BIF value for Regions 6 and 9 was 0.314 and 0.284, respectively. Based on available data, EPA Regions 3 and 4 in the mid-Atlantic and southeastern parts of the U.S. had the lowest BIF values. The median PWS quarterly THM BIF value for Regions 3 and 10 was estimated to be 0.078 and 0.053, respectively. (WRF, Westerhoff et al. 2022)

Total Organic Chlorine (TOCl), Total Organic Bromine (TOBr), and Total Organic Iodine (TOI). Total organic halides (TOX), reported in equivalent units of µg Cl/L, are currently not regulated but represent a larger pool of DBPs beyond TTHM and HAA5 or HAA9, and may provide insight into trends in non-regulated DBP formation. While formation potentials for TOX and individual total organic chlorine (TOCl), total organic bromine (TOBr), and total organic iodine (TOI) species have been reported in raw and some treated waters, little information existed on the change in these parameters in the distribution systems. In this study, the research team observed TOCl as the most abundant TOX specie at the limited number of utilities considered. TOBr levels in distribution systems ranged from 2 to 116 µg/L. Given the significantly higher toxicity of brominated DBPs than their chlorinated analogues, minimizing TOBr formation will minimize the public exposure of brominated organic DBPs (regulated and unregulated). The TOI levels were always below the detection limit of 20 µg/L. Iodate (IO_3^-), a less reactive DBP precursor than I^-, did not form measurable TOI in the distribution system of the drinking water plants which treated high Br^- containing groundwater. (WRF, Westerhoff et al. 2022)

Bromine and Iodine Speciation. In DWTP source waters, Br^- was well correlated with total bromine (Br_T) i.e., followed the 1:1 line. This implied that Br^- was the most prominent bromine species present in drinking water sources, with minimal presence of organic bromine or other forms of inorganic bromine (e.g., bromate). However, for iodine species in drinking water sources, I^- was not correlated with total iodine (I_T). The presence of organic iodine and iodate (IO_3^-) was observed in the drinking water sources. (WRF, Westerhoff et al. 2022)

Because I^- ion can become integrated into I-DBPs, an improved understanding of I-DBPs should focus on utilities with elevated iodide concentrations in raw waters. These utilities should exceed the 95th percentile iodide concentration of 26 µg/L in order to clearly observe I-DBP formation trends. Utilities with elevated I^- tended to be located in EPA Regions 2, 4, 6, 8, or 9. Additionally, information is needed on seasonality and factors influencing the speciation of inorganic (I^- vs IO_3^-) and stability of organic iodine in source waters. (WRF, Westerhoff et al. 2022)

Brominated DBP and Need to Monitor Individual DBP Species

All four chlorinated and brominated THM are regulated as total THM (TTHM) and of the nine HAA, the sum of five HAA (HAA5) are regulated; the four unregulated HAA are all brominated species. (Samson et al. 2017) The current regulatory approach for DBP focuses on class sums (TTHM and HAA5), as opposed to individual DBP species. The regulated HAA5 includes all three fully chlorinated HAA and two fully brominated HAA, but does not include HAA4, of which all are brominated species. Because individual DBP species are understood to pose different health risks, and brominated DBP are of greater health concern as compared with fully chlorinated counterparts, monitoring and assessment of DBP species can inform future regulatory decisions for the protection of public health. This study demonstrated that CWS quarterly 95th percentile TTHM and HAA5 species concentrations could be used sufficiently to estimate HAA9 concentrations and BIF values. (Samson et al. 2017)

Note that because HAA are not regulated in Europe, the occurrence of this class of DBP is quite limited in most European countries. Moreover, the occurrence of HAN in European drinking water has been rarely studied. In the past, many epidemiology studies focused on the association between an adverse health effect and total THM, sometimes considering bromine speciation. (Krasner et al. 2016)

Iodinated DBP. The occurrence of the six iodo-THM (DCIM; DBIM; BCIM; CDIM; BDIM and TIM) is due to the formation of hypoiodous acid (HOI) during treatment, through the oxidation of iodide by oxidants used in the disinfection (e.g. free chlorine, chloramine) and the subsequent reaction of HOI with the natural organic matter (NOM) present in the source water. Formation of iodo-THM during oxidation of waters containing iodine with chlorine dioxide has also been observed during laboratory experiments. Iodide occurs naturally in some source waters, with higher concentrations typically associated with the vicinity of sea water or the presence of inland salt deposits and brines. Iodine concentrations comparable to those typically found in sea waters have also been reported in some inland surface waters. It is interesting to note that iodo-THM (as well as iodo-HAA) have been found in disinfected water from water sources with no detectable iodide (MDL = 0.13 µg/L), leading the authors to presume other organic or inorganic iodine sources may have been involved. (Tuguela et al. 2018)

The Formation of iodo-THM

The formation of iodo-THM in water treated with chloramine tends to be higher than in water disinfected by chlorination. With short free chlorine contact time before the addition of ammonia, the concentration of iodo-THM formed can be of the same order of magnitude as the concentration of regulated THM. Published literature also suggests that iodine containing THM may be more toxic than chlorinated and brominated THM. (Tuguela et al. 2018)

I-DBPs are receiving increasing attention from the scientific community and water regulators because of their high toxicity compared with regulated THMs and HAAs. Balancing pathogen inactivation and DBP formation is a challenge. Optimization of disinfection scenarios, including I-DBP precursor removal and alternative disinfectants, are proposed to reduce I-DBP formation. As organic DBP precursors are difficult to completely remove by coagulation, adsorption, advanced oxidation processes, and even membrane filtration processes, the removal of I− (e.g., oxidation to IO3−) may provide a cost-effective solution. Prechlorination and preozonation are two options that can oxidize I− to IO3− and avoid formation of I-DBPs. However, prechlorination will form regulated DBPs. Therefore, optimizing the prechlorination time prior to ammonia addition (to form chloramines) is important to meet regulated DBP limits while providing effective oxidation of I− to IO3−. (Dong et al. 2019)

I-DBPs can also form in pipes in the distribution system. Corrosion leads to formation of scales on inner surfaces as well as release of metal ions into the water. For example, PbO_2 is present in some lead distribution pipes or lead-containing plumbing materials when chlorine is the disinfectant. Other transition metal oxides (e.g., Fe, Mn, and Cu) can be important forms of mineral scale. In distribution systems, residual I− and disinfectants can participate in reactions involving heterogeneous chemical oxidation, reduction, adsorption, and catalysis, which may eventually affect I-DBP levels in finished drinking water. PbO2 and MnO2 can provide an oxidant reservoir for I-DBP formation in distribution systems. (Dong et al. 2019)

Nitrogen-Containing DBPs. In addition to organic carbon, natural waters also contain dissolved organic nitrogen (DON). In a U.S.-based study, the average DON concentration for 28 water treatment plants was reported to be 0.19 mg/L in raw waters and 0.15 mg/L in finished waters and ranged from <0.05 to 0.45 mg/L. Impaired waters (algal or wastewater-impacted) will contain higher levels of organic nitrogen precursors than pristine waters. Haloacetonitriles (HAN), halonitromethanes (HNM) and haloacetamides (HAcAm) are among the most frequently detected N-DBP in drinking water but are not included in the drinking water guidelines of any country. They can be formed by disinfection with both chlorine and chloramines. The World Health Organization has recommended values of 20 and 70 µg/L for dichloro- and dibromoacetonitrile, respectively. The brominated species are much more cytotoxic than the chlorinated species, and so these numbers should be re-evaluated. (WRF, Farré et al. 2016)

Chlorate. Hypochlorite, especially when stored at high temperatures, can introduce disinfection by-products such as chlorate, perchlorate, and bromate into the drinking water. (Breytus et al. 2017)

Chlorate has a USEPA health reference level (HRL) of 210 µg/L and a WHO guideline of 700 µg/L. Though not currently regulated at the federal level, it was included in the USEPA CCL3. Chlorate is being examined as a part of the microbial and disinfection by-product regulations review. Although chlorate has a notification level of 800 µg/L in the state of California, a federal regulation level is yet to be determined, but it is likely to be between 210 and 840 µg/L. (Breytus et al. 2017)

Indicators

Fluorescence and UV Absorbance 254. Fluorescence of the samples in the fulvic acid-like region as measured by EEMs analysis showed a stronger correlation with THM4, the four haloacetonitriles (HAN) measured (HAN4), haloketone and chloral hydrate formation potential from chlorination than absorbance at 254nm (UV254). This suggests that the use of fluorescence spectroscopy could be used as a monitoring tool to control formation of these DBPs during drinking water treatment. No correlation was found between UV254 or fluorescence parameters and trihalogenated DBP formation potential from monochloramine treatment, so the application of these monitoring techniques to monochloramine treatment would be limited to the dominant dihalogenated species. Concentration-based parameters were more strongly correlated with DBP formation potential than character-based parameters (TOC normalized). The change in UV254 following chlorination showed stronger correlations with DBP formation potential compared to the initial water UV254 (prior to chlorination). The opposite was observed for changes in fluorescence induced by chlorination, where little correlation was found with DBP formation. Therefore, the use of fluorescence with regional integration analysis for predicting DBP formation potential would be most effective when applied to waters prior to final disinfection, whereas UV254 was a better predictor of DBP formation potential when considering the change in absorbance from chlorination. This study showed that fluorescence in the fulvic acid-like region had a stronger correlation than UV254 with THM4, HAN4, haloketone and chloral hydrate formation potential from chlorination. However, no correlation was found between UV or fluorescence parameters and trihalogenated DBP formation potential from monochloramine treatment. (WRF, Farré et al. 2016)

THM are not a reliable surrogate for HAN, which can be measured with the same method as THM.

THM are not a reliable surrogate for HAN, and the misclassification bias associated with the use of THM to measure overall DBP exposure may significantly reduce the ability to discern associations between DBP exposure and adverse health outcomes. Measuring semi-volatile unregulated classes like HAN should not add excessive analytical burden to sampling efforts, as they can be extracted and analyzed using the same method as THM. Furthermore, strategic data collection efforts are needed to identify whether HANs or other easily measured DBP classes are effective surrogates for exposure to a wide array of DBP classes. While previous survey efforts have focused on measuring unregulated DBPs in multiple water systems, this study demonstrates the need for better spatiotemporal resolution within water systems to evaluate the covariance of multiple classes with hydraulic residence time. Future DBP data collection efforts should be designed to achieve statistical significance with multilevel modeling techniques to accurately estimate variance between and within water systems for as many co-occurring DBP classes as possible. (Furst et al. 2021) This study might also be useful for indicating the dependence of HANs on season and type of disinfection (Dr. Mitch, personal communication)

Bromide concentration is not likely to be a reliable indicator for the presence of iodine precursors in the source water. In fact, as we now know that iodine precursors nature (inorganic, organic) and source (sea water influence; brines associated with inland sediments from ancient sea beds, wastewater) are so diverse, it would be surprising if iodide, total iodine and bromide concentrations were correlated. The use of bromide concentration as a sole predictor of potential iodo-THM formation may lead to overlooking some sites with low bromide concentration, yet where iodide and other iodinated precursor concentrations are high enough that, combined with favourable conditions, may result in the formation of iodo-THMs during treatment. (Tuguela et al. 2018)

THM do not Correlate well with Iodo- THM Formation

The fact that iodo- THM formation does not correlate well with THM formation, associated with the predictions that suggests that iodo-THMs may be more toxic than chlorinated and brominated THMs, challenges the basis of using total regulated THM concentrations as a proxy for limiting potential toxic effects of all DBPs. (Tuguela et al. 2018)

Overall, no consistent correlation was observed between total iodo-THM formed and the iodide concentration in the source water. The data indicate that the presence of iodine in the form of iodide in the source water does not appear to be a requirement for the formation of iodo-THM. In one case, three iodo-THM (DCIM; BCIM and DBIM) were found in both winter and summer with the highest concentration (1.1 µg/L-4.6 nM) measured in summer, although iodide was detected at a value close to MDL (0.049 µg/L - 0.4 nM) in the winter and undetectable in the summer. There may be other inorganic or organic sources of iodine beyond the inorganic iodide measured in the source waters. The source water was a river and the source of iodinated precursors may be anthropogenic input (based on measurement of markers). It appears that total iodine concentration, which is stable throughout the year and includes both inorganic and organic potential iodine sources, may be a better parameter than iodide to describe iodine availability for iodo-THM formation. However, total iodo-THM concentrations did not correlate well with total iodine concentrations in the source water, showing that, although total iodine can prove the existence of the necessary iodinated precursors, the extent of iodo-THM occurrence is heavily influenced by other water quality and treatment factors. (Tuguela et al. 2018)

Bromide concentration has previously been proposed as a marker for iodide concentration, since iodide concentration in source waters is rarely measured in Canada. However, bromide concentration has been reported to have a poor correlation with iodide concentrations in many source waters. Our findings from this Canadian survey support the observation that there is no meaningful correlation between bromide and iodide concentrations in source waters. Total iodine appears to be both a better descriptor of iodine availability for the formation of iodo-THM and to be a more conservative parameter. (Tuguela et al. 2018)

Measuring Total Organic Halide (TOX)

A necessity for calculating BIF values for all DBP classes is to have standards of all the brominated, chlorinated, and potentially iodinated DBP species, which is challenging when analyzing the growing number of emerging DBPs in drinking water. An alternative strategy linking Br^- or I^- occurrence to DBP formation relies on total organic halide (TOX) analysis and split analysis of total organic chlorine (TOCl), total organic bromine (TOBr), and total organic iodine (TOI). Although THMs and HAAs are the most abundant halogenated DBPs resulting from chlorination, they account for only modest fraction of TOX formed in chlorinated or chloraminated waters. Measuring TOX provides an estimate of the total amount of organic compounds containing covalently-bound chlorine, bromine, and iodine—including both known and unknown DBPs formed during treatment—in a water sample. (WRF, Westerhoff et al. 2022)

Cytotoxicity and genotoxicity of drinking water have been reported to correlate with TOI but not with TOCl, indicating that TOI may be a good surrogate for the overall toxicity of DBPs in waters impacted by I−. (Dong et al. 2019)

Another concept recently discussed is whether we should switch from chemical-by-chemical regulation to surrogates. This could help simplify future regulations, such that easy-to-measure surrogates are used rather than creating longer and longer lists of DBPs to regulate. Examples would include using total organic bromine (TOBr) and total organic iodine (TOI), measured using combustion-ion chromatography, which could account for the known, toxic Br^- and I-DBPs, as well as unknown Br^- and I-DBPs not yet identified. The total nitrosamine (TONO) assay could be used as a surrogate measure for all nitrosamines, including ones we currently know and those still unknown. Finally, total organic nitrogen (TON) might also be a way of capturing the more toxic N-DBPs. However, these surrogate approaches would invariably incorporate many low-toxic or non-toxic compounds into the measurement and will likely include DBPs that may not pose significant health risks. (Richardson and Plewa, 2020) This point is important. Among known DBPs, regulated THMs have the smallest contribution to toxicity, but dominate TOX. When you switch disinfectants to minimize THMs, you can form other DBP classes that are more toxic at lower concentrations. For example, ozone forms HNMs. You would likely see a decrease in TOX though since THM concentrations would decrease (Dr. Mitch, personal communication).

Regulatory Developments

Despite all the toxicity and occurrence data showing the widespread presence of these DBPs in drinking water, no new regulations were promulgated. The U.S. EPA appeared to be on the brink of potentially regulating nitrosamines about 10 years ago, based on national occurrence data and carcinogenicity data, but appears to have backed off for now. And, while EPA announced that it would regulate perchlorate several years ago, there is still no maximum contaminant level (MCL) established and no new regulation. (Richardson and Plewa, 2020)

There are 9 DBPs (non-nitrogenous) and two indicators on the USEPA UCMR4:

- HAA5 (regulated)
- HAA6Br
- HAA9
- Total Organic Carbon (TOC)
- Bromide

DBPs on draft CCL5:

- 4 Brominated HAA
- 2 Haloacetonitriles
- 3 Halonitromethanes
- Formaldehyde
- 6 Iodinated THM
- Chlorate

California SWRCB Proposed Priorities for Regulatory Development. In February 2020, OEHHA issued final revised PHGs for individual trihalomethanes bromoform, chloroform, bromodichloromethane, and dibromochloromethane. Draft PHGs have been developed for five haloacetic acids—monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid (collectively, HAA5)—and are expected to be finalized this year. MCL revisions for all nine of these contaminants will likely be grouped for concurrent, coordinated development in 2023. (SWRCB, 2022)

There exist some guidelines and threshold levels for HAN, AL, and NA by many organizations and states, indicating the importance of these unregulated DBPs. Nonetheless, there are still no guidelines or threshold limits set for other unregulated DBP groups, i.e., HK, HNM, and HAM.

Table 4-12 presents DBPs guidelines and threshold values according to different organizations and states.

Table 4-12. Unregulated DBPs Guidelines and Threshold Values According to Different Organizations and States (Mian et al., 2018)

UR-DBPs Group	UR-DBPs Species	Guideline Values (μg/L)	Organizations/States
HANs	DCAN	20	WHO
		6	US EPA
		40	Japan
		20[b]	New Zealand Ministry of Health
	DBAN	70	WHO
		20	US EPA
		60	Japan
		80[b]	New Zealand Ministry of Health
	BCAN	20	ECHA
	TCAN	1	WHO
HALs	TCAL	100	ADWC
		200[a]	Health Canada
		10[b]	China (CB-2006)
NHALs	FAL	500	ADWC
		900[b]	China (CB-2006)
		80[b]	Japan
NAs	NDMA	0.10	WHO
		0.007	US EPA
		0.10	ADWC
		0.01[b]	Drinking Water Inspectorate (UK)
		0.04	Health Canada
		0.012	Netherlands
		0.01[b]	Germany
		0.009	Ontario Drinking Water Quality Standard
		0.01	California (SWRCB)
	NMEA	0.02	US EPA

UR-DBPs Group	UR-DBPs Species	Guideline Values (µg/L)	Organizations/States
	NDEA	0.008	US EPA
		0.009	Ontario Drinking Water Quality Standard
		0.01	California (SWRCB)
	NPYR	0.16	US EPA
	NDBA	0.063	US EPA
	NDPA	0.05	US EPA
		0.009	Ontario Drinking Water Quality Standard
		0.01	California (SWRCB)
	NMOR	0.01[b]	Germany
CNX	CNCl	70	WHO
		80	ADWG
		10[b]	Japan
		70[b]	China (CB-2006)

a. This value may indicate some health effects and at this level there is a need of investigation.

b. Part of drinking water quality standard list in some countries.

Analytical Considerations

Iodate and Total Iodine Analysis. Bromide (MDL = 5 µg/L) and iodide (MDL = 0.018 µg/L) ions were determined in source and treated water samples using an ion chromatography-conductivity detector and electrochemical detector, respectively. Total iodine (as elemental iodine from both inorganic and organic iodine-containing compounds in the water sample) (MDL = 0.14 µg/L) was determined in source water, treated water and in mid-point distribution water. The measurements of total iodine concentrations were performed by Inductively Coupled Plasma Mass Spectrometry e ICPMS, using a Perkin Elmer Elan 5000a model. (Tuguela et al. 2018)

DBPs currently quantified account for <50% of the total organic halogen (TOX) measured in drinking water; thus, uncovering unknown DBPs is of increasing interest. This is challenging for I-DBPs because their typically lower concentrations relative to other DBPs, their absence in mass spectral library databases, lack of analytical standards (most commercially available I-DBPs are only available due to previous synthesis efforts), and iodine's lack of multiple stable isotopes. Iodine only has a m/z 127 isotope, which does not produce isotopic patterns like those of chlorine and bromine, making I-DBPs more difficult to spot from their electron ionization or electrospray ionization (ESI) mass spectra and making them more difficult to identify. Although developments in mass spectrometry have facilitated the identification or characterization of unknown I-DBPs in drinking water, it is still impossible to identify all halogenated DBPs formed, synthesize standards, measure concentrations, and evaluate toxicity for each of them. Hence, TOI analysis, which provides a surrogate measure of I-DBPs, is important. Ion chromatography has been adopted to separate and measure individual halides, which allows the calculation of total organic chlorine (TOCl), total organic bromine (TOBr), and TOI. (Dong et al. 2019)

HEALTH

Toxicological, epidemiological, and mechanistic studies of disinfection byproducts have provided strong evidence for the carcinogenicity of DBP. At the same time, individual DBP show differences in both cancer potency and overall toxicity. This differential toxicity is reflected in the diversity of carcinogen classifications for individual DBP substances published by the U.S. EPA, National Toxicology Program Report on Carcinogens, and International Agency for Research on Cancer.

Many of unregulated DBPs are unstable or reactive intermediates, and therefore may not persist long enough to reach the consumer's tap (WRF, Reckhow et al. 2016). Humans are exposed to DBPs not only through ingestion (the common route studied), but also through bathing, showering, and swimming. Inhalation and dermal exposures are now being recognized as important contributors to the overall human health risk of DBPs (Richardson and Postigo, 2012).

THM4 and HAA5 versus other DBP Classes. Epidemiological studies have focused on the possible association between exposure to DBPs (typically based on total THMs) in chlorinated water and the incidence of human cancer and potential adverse reproductive and developmental effects such as low birth weight, intrauterine growth retardation, and spontaneous abortion. Increased risk of various congenital anomalies has been reported to be associated with THM exposure in the water supply. Recent studies examined polymorphisms, DBPs, and the risk of bladder cancer in Spain. The results of this study strengthened the hypothesis that DBPs cause bladder cancer and suggested possible mechanisms, as well as the classes of compounds (e.g., bromine containing DBPs) that were likely to be implicated. Likewise, bromine-containing DBPs are believed to be of a higher health concern than the chlorine-containing analogues based on toxicology research. Moreover, certain nitrogenous DBPs (e.g., HANs) are considered more cytotoxic and genotoxic than the regulated THMs and HAAs, although nitrogenous DBPs are rarely examined in epidemiology studies. (Krasner et al. 2016)

Total THMs have been used as a surrogate for halogenated DBPs in most epidemiology studies. However, in this study, the occurrences of THMs and HAAs were found to vary from each other on either a seasonal or year-to-year basis. Despite the differences in the occurrence patterns of the THMs and HAAs, speciation of the THMs was a good surrogate, in general, for the speciation of the HAAs or HANs. Individual THM species were shown to be good indicators for the occurrence of other bromine containing DBPs of health concern. This was especially important in Spain, where a recent bladder cancer study suggested the importance of bromine containing THMs. The present study showed that some of the Spanish waters not only had a high concentration of brominated THMs, but also high levels of brominated HAAs and HANs, especially TBAA and DBAN, which are usually not detected at significant levels in other studies. (Krasner et al. 2016)

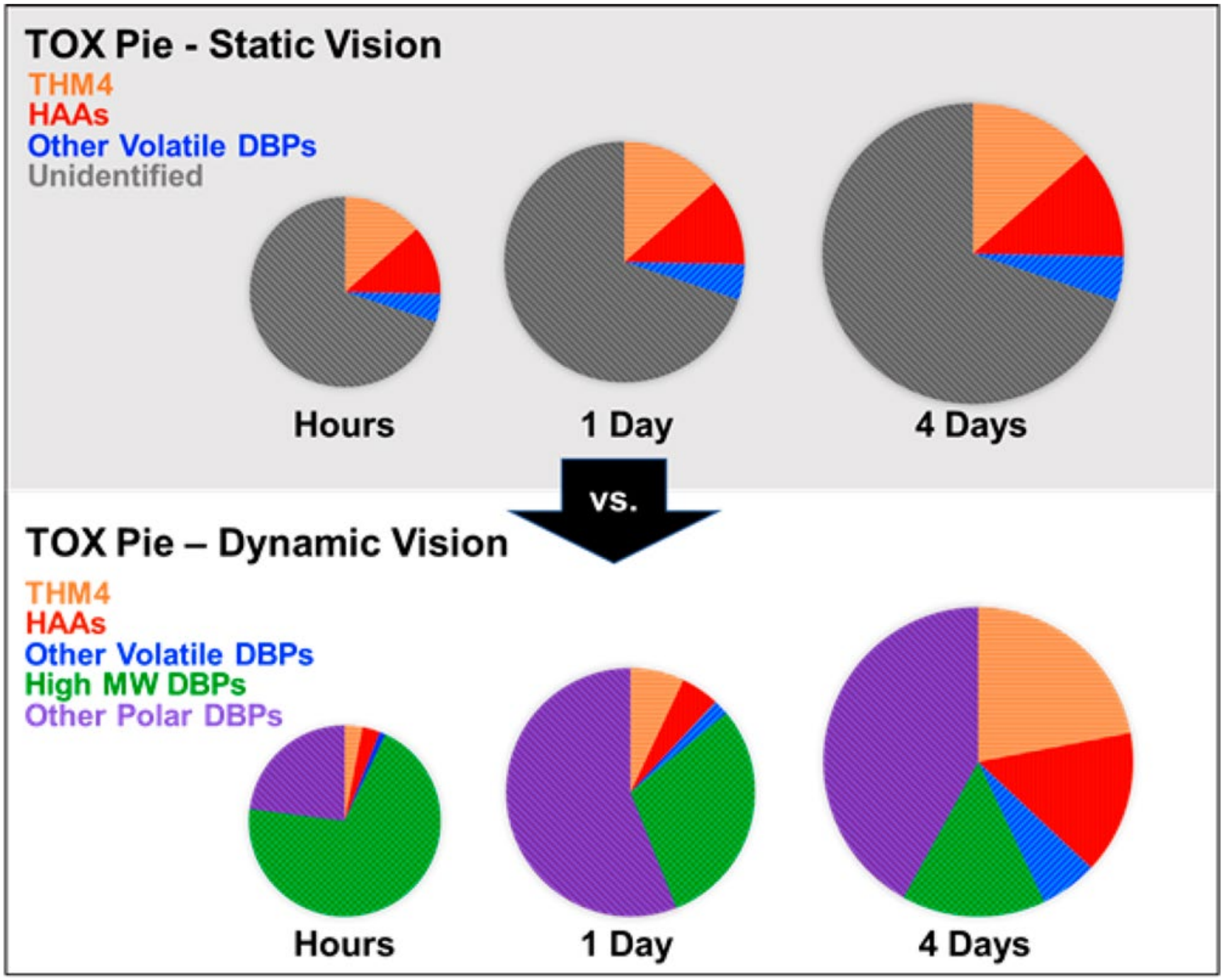
Toxicological Assessment of THM4, HAA5 and HAA6Br

Toxicological assessment indicates HAA have overall greater cancer potency than THM. We found that the group of five regulated HAA is associated with a smaller number of attributable cancer cases compared to the HAA6Br group, suggesting that in addition to HAA5, levels of other HAA should be lowered in drinking water in order to protect public health. (Evans et al. 2020)

Adverse Pregnancy Outcomes. Mothers' exposures to THM, HAA in drinking water are associated with adverse pregnancy outcomes. Evidence of any association between other drinking water DBPs Haloacetaldehydes (HA), Haloacetonitriles (HAN) and adverse pregnancy outcomes is still inconclusive. However, the absence of association results does not demonstrate the absence of health effects on pregnancy outcomes. Likewise, a statistical significance does not always suggest clinical importance. Difficulty in measuring exposure, inappropriate time of measurement and interaction between drinking water DBPs may have resulted in absence of association in most studies. (Mashau et al. 2018)

THM4 concentrations have been targeted to measure exposure to DBPs not because they have been demonstrated to be the primary drivers of cancer risk, but because THMs are carcinogens and their concentrations were assumed to correlate with those of other DBPs. This assumption is questionable for two reasons. First, the emerging concept of the dynamic transformation of NOM over time scales relevant to drinking water distribution would suggest that the percentage contribution of THM4 to TOX is not static **(see Figure 4-5 below, from Li and Mitch, 2018)**. Consumers close to the drinking water facility may consume a different array of DBPs (e.g., more [of] higher molecular weight polar DBPs) than those at the ends of the distribution system (e.g., a higher percentage contribution to TOX by low molecular weight (semi)volatile DBPs like THM4). Second, the shift in disinfection practices from chlorination to combinations of alternative primary disinfectants and chloramination for secondary disinfection can reduce THM4 while promoting nitrosamines, iodinated DBPs and other DBP classes. (Li and Mitch, 2018)

Figure 4-5. Evolving Understanding of the Constitution of TOX* (Li and Mitch, 2018)



*Previously, the TOX concentration was considered to increase with disinfectant contact time in the distribution system, but the percentage contribution of DBP classes, including THM4, to the total was considered static. The emerging dynamic vision considers an evolution of DBP speciation from high molecular weight DBPs through polar DBPs to low molecular weight (semi)volatile DBPs as end products.

HAN are substantially more toxic than THM or HAA. They can be measured simultaneously with THM

When applied to conventionally [treated] European drinking waters, chlorinated or chloraminated high salinity groundwaters, or chloraminated potable reuse effluents, calculations indicate that unregulated halogenated DBP classes, particularly haloacetonitriles, may be greater contributors to the DBP-associated toxicity of disinfected waters than the THM4, HAA5, and nitrosamines of current regulatory interest. (Li and Mitch, 2018)

The results of this study indicate the importance of measuring other classes of DBPs for epidemiology studies. Not only should HAAs be considered but also HANs, which are substantially more toxic than THMs or HAAs. In this study, a method that measured both THMs and HANs was used, which allowed for the simultaneous investigation of both classes of DBPs. (Krasner et al. 2016)

Iodinated DBP. Among the discovered halogenated DBPs, in vitro and in vivo studies have identified a trend in cyto- and genotoxicity: I- > Br- ≫ Cl-DBPs. For example, IAAs are 1−2 orders of magnitude more cytotoxic and genotoxic than their chlorinated analogs. Additionally, recently discovered phenolic/aromatic I-DBPs show significantly higher developmental toxicity and growth inhibition than aliphatic I-DBPs. With elevated demand on limited fresh water sources coupled with the change from chlorination to chloramination in compliance with regulatory guidelines, the potential for occurrence of I-DBPs in finished drinking water is increasing. (Huang et al. 2018)

Chlorate. Chlorate is a toxic compound that can enter the body through water and food intake, although the main exposure is from water. It has been shown in animal studies that chronic and subchronic exposure to chlorate have an adverse health impact. Chlorate inhibits iodide uptake by the thyroid, interfering with the production of essential thyroid hormones. It is also capable of causing a breakdown of red blood cells, which lowers the oxygen transfer capacity in the body. Additionally, chlorate was connected to an increased risk of obstructive birth defects (Breytus et al. 2017)

DBP in Pools and Spas

Increased incidences of asthma and other respiratory effects were found in several epidemiologic studies of Olympic swimmers and pool workers, with less clear evidence for recreational adult swimmers and children. There are also recent reports of increased ocular, respiratory, and cutaneous symptoms for swimmers and pool workers, as well as sore throat and phlegm reported more frequently for lifeguards and swimming instructors. Short-term changes in respiratory biomarkers were also reported for swimmers in a chlorinated pool. In addition, an association was found between testicular hormones at adolescence and attendance at chlorinated swimming pools during childhood, with swimmers strongly associated with lower levels of serum inhibin B and total testosterone. Increased bladder cancer and genotoxic effects were also reported in swimmers. A new study in rats showed effects on their health, training, and metabolic profiles when tested in a 12-week swimming training program in simulated chlorinated pools. (Daiber et al. 2016)

Trichloramine, formed by the reaction of chlorine with constituents of human urine and sweat, is suspected to be associated with asthma and other respiratory effects, but causality is not yet proven. Trichloramine has a high Henry's law constant, so it is present at high concentrations in pool air. Indoor swimming pool air shows similar inflammatory effects. However, it is likely that other air contaminants (i.e., DBPs) also contribute. (Daiber et al. 2016)

Very High Concentrations of DBPs in Pools and Spas

Trihalomethanes (THMs) were the first class of DBPs studied in pools, and now there are quantitative data for many other classes. Although DBPs are regulated in drinking water, only Germany has a regulation for pools, with a maximum level of 20 µg/L for total THMs. France recently set a recommended limit of 100 µg/L for total THMs. For DBPs quantified in pools, HAA concentrations are among the highest, up to 6800 µg/L for dichloroacetic acid. HAAs are not volatile and will accumulate in pool waters. Concentrations of the 21 target DBPs were higher in spas than in pools. This was possibly due to higher temperatures of spa vs pool water, which increases chemical reaction rates. Although spas are typically drained and cleaned occasionally, pools are almost never drained. Thus, different temperatures and the way waters are managed may play a role in the higher DBP and mutagenicity levels found in spas vs pools. (Daiber et al. 2016)

Consistent with studies showing that Br-DBPs are generally more mutagenic and genotoxic than Cl-DBPs, our data show that brominated pool/spa waters are more mutagenic than chlorinated ones. Our data in pools/spas confirm previous work with drinking water showing that ozonated water is less mutagenic than ozonated/chlorinated water, which is less mutagenic than chlorinated water. Our study shows that mutagenicity of pool/spa waters is generally increased by human inputs. Thus, encouraging practices that reduce these inputs, such as frequent cleaning of spas, more frequent exchange of water in pools, showering before entering pools/spas, and not urinating or wearing personal-care products while in pools/spas, should have a beneficial effect on public health. Positive health effects gained by swimming could be increased, and potential health risks reduced, by implementation of these practices. (Daiber et al. 2016)

OCCURRENCE

Unregulated DBPs have been detected in many U.S. drinking waters. Occurrence studies include Weinberg et al. (2002), Krasner et al. (2006), Richardson et al. (2007), Bond et al. (2011), and Krasner (2012).

Average Concentrations of THM4, HAA5, HAA6Br and HAA9 in the US Based on UCMR4

The UCMR4 dataset does not include concentration data for individual compounds and only reports group concentrations for the regulated HAA5 group, the HAA6Br group of six brominated HAA, and HAA9, which includes all nine chlorinated and brominated HAA. Based on UCMR4 data, the calculated population-weighted averages are 24.9 µg/L for HAA9, 19.1 µg/L for HAA5, and 7.0 µg/L for HAA6Br for the systems included in UCMR monitoring. The population-weighted average of THM4 in the United States community water supplies are 26 µg/L. While relative concentrations of individual disinfection byproducts depend on multiple water chemistry conditions, there is an overall correlation between THM and HAA, as anticipated. (Evans et al. 2020)

Brominated HAA. Source water bromide concentrations are influenced by anthropogenic and climatic inputs. Higher bromide concentrations increase brominated DBP species formation, consequently increasing DBP formation with respect to mass and molar concentration. Anthropogenic sources of bromide in source waters include effluent from coal-fired power plants, hydraulic fracturing, wastewater from oil production, and textile production. (Samson et al. 2017)

DBP formation in European groundwaters. DBP levels were the lowest or not detected in Northern Italy, Heraklion, Kaunas, and Bedford. Most groundwater plants typically produced very low amounts of DBPs as a result of the presence of low levels of DBP precursors. For example, in most of the regions studied in Northern Italy where the HIWATE epidemiological studies were conducted, the drinking water was usually of high quality, was mostly groundwater, and low disinfectant doses were used; therefore, DBP formation was limited. Moreover, chlorine dioxide was usually adopted as the main disinfectant in the largest water distribution systems. The main DBPs in these regions were related to chlorine dioxide disinfection—i.e., chlorite (median, 75th percentile, 90th percentile, and maximum were 0, 67, 119, and 523 µg/L, respectively) and chlorate (11, 23, 44, and 399 µg/L, respectively). In addition, bromate was sometimes detected (90th percentile was 0; when detected, the median and maximum were 4 and 14 µg/L, respectively). However, some groundwaters with substantial amounts of bromide, such as in Heraklion, were extracted from aquifers in nearby coastal areas. TOC was low (median = 0.5 mg/L; 90th percentile = 0.8 mg/L), whereas bromide was often high (median = 0.8 mg/L; 90th percentile = 3.5 mg/L), which suggests intrusion of seawater into these karstic aquifers. Nonetheless, DBP formation was generally low (90th percentile THM4 = 15 µg/L). (Krasner et al. 2016)

Bromine speciation in Europe. In this study, three types of bromine speciation patterns were present, where most regions were dominated by chlorine containing DBP species. In certain regions in Spain (Granada, the Basque Country, Asturias, and in some areas of Catalonia), in three regions of the United Kingdom, and in the regions studied in Lithuania and Italy, chloroform (TCM) was the dominant THM species, bromodichloromethane was formed to a lesser extent, whereas usually little to none of the other bromine-containing species were detected, indicating the low-bromide content of these waters. In most of Catalonia, and in Heraklion, THMs were dominated by bromine-containing species, where bromoform (TBM) was the dominant THM species, the mixed bromochloro THMs were formed to a lesser extent, and TCM was present at a much lower level, indicating high-bromide waters or waters with a high ratio of bromide to TOC. Finally, in the regions of Valencia, Nottingham, and Rennes, the two mixed bromochloro THMs were the dominant THM species, being close to or >50% of the THM4 on a weight basis. TCM and TBM were detected at lower levels. This speciation pattern for the four THMs is characteristic of moderate bromide waters or waters with a moderate ratio of bromide to TOC. (Krasner et al. 2016)

Nitrification. Consistent trend of elevated concentrations of NDMA, TONO, and halogenated DBPs in the nitrifying storage facilities within several full-scale chloraminated distribution systems, suggesting a potentially significant source of precursors. Regarding mitigation of nitrification, boosting chloramine residuals in the nitrifying storage facilities can further increase the concentrations of NDMA, TONO, HANs, and HAMs, likely because nitrifying biofilms release precursors for these compounds, but their conversion to DBPs is hindered by diminished chloramine residuals during nitrification. Periodic treatment of storage facilities with BPC only temporarily controls nitrification. Although BPC appears to reduce the release of precursors for N-nitrosamines, 1,1-DCP, TCAL, HANs, and HAMs, it increases the concentrations of both regulated and unregulated halogenated DBPs in storage facilities while a free chlorine residual is maintained. Moreover, nitrite levels began to rise within 2 weeks, suggesting the rapid re-establishment of nitrification. If the pipelines connecting storage facilities serve as a source for nitrifying bacteria, periodic BPC of the entire distribution system may be more effective at mitigating nitrification, and thereby reducing DBP formation. (Zeng and Mitch, 2016)

Haloacetonitriles (HAN). Haloacetonitriles are produced by chlorination, chloramination and using chlorine dioxide as disinfectants in drinking water treatment. Facilities that use chloramines typically have lower HAN concentrations. Their HAN/THM ratios increase only because THM concentrations decrease to an even greater extent (Dr. Mitch, personal communication). Some species of HAN are recognized as toxic. An increased concentration of HAN was observed in distribution systems due to decreasing pH and increasing temperature conditions. According to the data collected for this literature review, the concentration level of HAN in drinking water ranged between 0.6-24 µg/L. Dichloroacetonitrile (DCAN) is the most prominent species among HAN, detected in drinking waters. (Mian, 2021)

Halonitromethanes (HNM). There are nine HNM species. Among all HNM, common species are trichloronitromethane (TCNM), dichloronitromethane (DCNM), and bromochloronitromethane (BCNM). TCNM is the most commonly detected HNM. The HNM concentrations increase due to pre-ozonation before chlorine or chloramine disinfection. The concentrations of HNM were between 0.16-1.50 µg/L. (Mian, 2021)

Haloketones (HK). Haloketones are considered volatile DBP group and there are six species of HK identified in distribution systems. Trichloropropanone (TCP) and dichloropropanone (DCP) are the most commonly occurring HK. In general, HK concentrations vary throughout the distribution systems due to base-catalyzed hydrolysis reactions and are not stable in high pH (>7) environments. HK are carcinogenic and mutagenic, but there is no threshold value developed for HK in drinking water. The concentration of HK ranged from 1.23-8.6 µg/L. (Mian, 2021)

Haloacetamides (HAM). Haloacetamides is another DBPs group that has been identified in both distribution systems and laboratory studies. Roughly 13 species of HAM have been identified so far and the commonly found species are dibromoacetamide (DBAcAm), dichloroacetamide (DCAcAm), and trichloroacetamide (TCAcAm). HAM are generally produced by chloramination and ozonation without biofiltration. The concentration of HAM ranged from 1.50-7 µg/L. (Mian, 2021) This is an important class toxicologically. HANs, HAMs and HALs can be ranked as the most important. The dihalogenated species (dibromo, bromochloro and dichloro) are the most prevalent. The trichloro is relatively rare (Dr. Mitch, personal communication).

DCAM was observed at higher concentration levels compared to other species (MCAM, DCAM, TCAM, MBAM, and DBAM), with a maximum concentration of 5.6 µg/L in a finished water plant effluent sample. Six additional species of HAM (BCAM, BDCAM, DBCAM, TBAM, CIAM, and BIAM) were first reported in a 2012 drinking water study in China. HAM were also observed in European countries. In a 2015 Greek study, DCAM was reported in a range of 0.28-2.8 µg /L in Athens drinking water. That study also reported MCAM was detected at a maximum value of 6.1 µg /L while the average was below the detection limit. (Wu, 2017)

HAM were first regarded as hydrolysis products of HAN. Amino acids and humic acids were found to be important precursors of HAN and HAM. Evidence suggests that there are alternative formation pathways of HAM without HAN in chloraminated water. (Wu, 2017)

Aldehydes (AL). AL are categorized into two sub-groups, including halogenated AL (HAL) and non-halogenated AL (NHAL). Both groups are assessed separately according to the established criteria. HAL are an important DBP sub-group, which are the third largest by weight according to a US Nationwide DBP Occurrence Study. There are ten species of HAL that have been identified for this literature review. Trichloroacetaldehyde (TCAL) and dichloroacetaldehyde (DCAL) are the most commonly occurring species of HAL. There are some established threshold limit values for TCAL. In general, dihalogenated species of HAL are prone to be formed with the presence of chloramine and ozone. Trihalogenated species of HAL occur more frequently when using chlorine instead of chloramine. The other sub-group (NHAL) includes formaldehyde (FAL) and acetaldehyde (AAL). The formation of NHAL is due to the combined use of chlorine and other oxidants. In general, the occurrence and formation of NHAL are similar with different types of disinfectants. The threshold values of FAL have been established in some states in the US, as shown in Table 3-7. Despite a significant health risk, aldehydes' adverse health effects are still poorly understood as only a few species of aldehydes have established toxicity values. (Mian, 2021). NHAL are really promoted by ozone, and hence the benefit of adding BAC or BAF afterwards to remove (Dr. Mitch, personal communication).

Cyanides (CNX). There is only one species in the cyanides (CNX) group, cyanogen chloride (CNCL), which is considered the commonly occurring unregulated DBP. CNCL has been found in drinking water, usually at a concentration level below 10 µg/L. High concentration levels of CNCL were reported as a result of using chloramination compared to chlorination. Chlorine reacts rapidly with CNCl, degrading it (Dr. Mitch, personal communication). CNCL has acute toxic effects (i.e., skin and eyes irritation, dizziness, and shortness of breath) through oral, inhalation, and dermal exposure pathways. However, the related chronic effects on human health are not well established yet. The average concentration level of CNCL in distribution systems was around 4 µg/L. (Mian, 2021)

Iodinated-DBPs (I-DBP). The concentration levels reported for I-DBP in drinking water are either in ng/L or low µg/L. In general, I-DBP can be found in drinking water treated with chlorine, chloramine, and ozone in the presence of iodide. Besides, the water from coastal areas subject to salt-water intrusion can increase the formation of I-DBP. I-DBP include species of iodo-acids and iodo-THM. According to existing literature, there are five species of iodo-acids and six species of iodo-THM that have been identified. The commonly occurring ones include iodoacetic acid (IAA) and iodoform (IF). The concentration level of I-DBP ranged between 0.54-0.9 µg/L. (Mian, 2021) Dichloroiodomethane is more common than iodoform. Also, I-DBPs are really associated with chloramines, not chlorine or ozone. Sometimes TIM dominates, but these would be outlier sites with extremely high iodide and minimal free chlorine contact (Dr. Mitch, personal communication).

Iodide exists naturally in many surface and groundwater sources. Source waters can have elevated iodide concentrations due to impacts by natural and anthropogenic drivers such as salt water intrusion, geomorphological deposits, hydraulic fracturing activities, or wastewater discharge. Chloramination oxidizes iodide to the reactive hypoiodous acid (HOI), whereas chlorination can further oxidize HOI to iodic acid (HIO3) that does not react with DOM. As a result, chloramination promotes greater formation of I-DBP than chlorination. So far, several I-DBP have been identified in drinking water. In a study covering the drinking water distribution systems of 23 cities in the United States, highly toxic IAA and I-THM were detected with concentrations ranging from sub µg/L to several µg/L levels. Polar I-DBP, including mainly polar I-aromatic acids and I-phenols, have been detected in simulated drinking water prepared using commercial natural organic matter standard reference materials. Compared to chlorinated DBP, far fewer studies have reported the precursors or occurrence of I-DBP. A primary reason may be that unlike chlorinated compounds, iodinated organic compounds lack distinct isotopic patterns, making them more difficult to identify at low concentrations in water with mass spectrometry. To reveal unknown I-DBP, an effective approach is to examine the precursors in source water and monitor their reactions with disinfectants for the potential generation of iodinated byproducts. Currently, humic substances are known precursors of polar iodinated compounds not only during water disinfection processes, but also in other natural processes such as photoiodination due to their available carboxylic or phenolic groups. Phenol can generate Iphenols in drinking water in the presence of iodide. (Huang et al. 2018)

I-DBP are highly toxic, but few precursors of I-DBP have been investigated. Tyrosine-containing biomolecules are ubiquitous in surface water. Here we investigated the formation of I-DBP from the chloramination of seven tyrosyl dipeptides (tyrosylglycine, tyrosylalanine, tyrosylvaline, tyrosylhistidine, tyrosylglutamine, tyrosylglutamic acid, and tyrosylphenylalanine) in the presence of potassium iodide. HPLC-MS/MS analysis of tap and corresponding raw water samples, collected from three cities, identified four iodinated peptides, 3-I-/3,5-di-I-Tyr-Ala and 3-I-/ 3,5-di-I-Tyr-Gly, in the tap waters but not in the raw waters. The corresponding precursors, Tyr-Ala and Tyr-Gly, were also detected in the same tap and raw water samples. This study demonstrates that iodinated dipeptides exist as DBP in drinking water. (Huang et al. 2018)

Bromide, iodide and total iodine in a survey of 65 Canadian water systems

Bromide concentration in the source waters ranged from under the MDL (5 µg/L) to 733 µg/L. The highest bromide concentration was found in a ground water sample (winter) from a coastal location. At this location a marked increase (740%) in the bromide concentration in winter compared with the concentration in summer was observed and was attributed to sea water intrusion. Of the 7 sites with source waters containing >100 µg/L bromide, 2 were coastal sites and 5 were situated in regions with known high salinity soils. (Tuguela et al. 2018)

Iodide concentration in the source waters ranged from under the MDL (0.018 µg/L) to 131.36 µg/L. The highest iodide concentration was found in a summer sample from an inland ground water source. The 7 sites with the highest iodide concentration in source waters (>10 µg/L iodide) include 2 coastal sites and 5 inland sites. (Tuguela et al. 2018)

Total iodine concentration in the source waters ranged from below the MDL (0.14 µg/L) to 132 µg/L, with the highest concentration found in winter. Of the 9 sites with the highest total iodine concentration (>10 µg/L) 3 were coastal sites and 5 were various inland sites across the country. (Tuguela et al. 2018)

Iodo-THMs in Canadian drinking water. Iodo-THM are occurring in Canadian drinking water, albeit at low concentrations, and more information is needed about the toxicological properties of the individual iodo-THMs in order to evaluate the potential health risk for the Canadian population using the drinking water. The potential for the formation of significant concentrations of some iodo-THM, that would challenge, at minimum, the aesthetic objectives for drinking water quality, has been demonstrated. (Tuguela et al. 2018)

The highest total iodo-THM concentrations were found in 2 systems with the highest total iodine (as well as iodide) concentrations in the water source. However, in these two cases, other factors beside the availability of the precursor may have contributed to the formation of the higher iodo-THM concentrations, more specifically: both water sources also contained high bromide concentrations and naturally occurring ammonium. As mentioned before, the high bromide and iodide concentrations in ground water appear to be due to their situation in sediments from former sea beds. It is remarkable that the total iodine and the iodide/iodate (w/w) ratio in these source waters (iodate concentration was calculated as the difference between total iodine and iodide concentrations, with no significant contribution from organic iodinated compounds assumed at these sites) is higher than the average values for sea water. However, this is not unique, as iodide has been found to be tremendously enriched in some brines associated with sediments by comparison to the normal evaporite-associated brines. (Tuguela et al. 2018)

Total iodine concentrations also do not appear to be well correlated with bromide concentrations the formation of higher iodo-THM concentrations is related to the ab initio formation of chloramines, as predicted by theory and shown in laboratory experiments. A similar case was also observed during a previous survey targeting water systems that applied chloramines to treat source waters with high bromide content. For the 10 WTS using chloramines where low levels of iodo-THM were formed, chlorine was added to the water before ammonia; therefore, HOI was quickly oxidized to iodate, limiting the formation of iodo-THM. Only two of the 12 WTS using chloramines in the treatment process had iodo-THM concentrations over 1 µg/L, and those 2 WTS also had naturally occurring ammonium in the source water, high iodide and total iodine concentrations and molar bromide/iodide ratios between 5 and 17. In these cases, chloramines were formed at the first addition of chlorine, and were the only disinfectants used throughout the process. The HOI was able to react with NOM for a prolonged period and consequently, a variety of iodo-THM, including TIM, were formed in the treated water. Total iodo-THM formed in water from WTS were the highest measured in this survey and TIM was the congener with the highest contribution to the total concentration. (Tuguela et al. 2018)

In most treated and distributed waters from WTS using either chlorine or chloramine, the total iodo-THM concentrations were well under 1 µg/L. However, at 8 locations, including WTS using chlorine and WTS using chloramine for secondary disinfection, total iodo-THM concentrations were found to be in the same range as typical total regulated THM concentrations. In fact, the total iodo-THM concentrations tended to be higher than total regulated THM concentrations. (Tuguela et al. 2018)

Data in this survey show that, as predicted by theory, naturally occurring ammonium in the source water can significantly increase the potential for the formation of iodo-THM during disinfection, especially if chloramine is used as disinfection agents. Ammonium concentration in the source water is, therefore, an important parameter to be considered when disinfection processes are designed and adding ammonium to the list of routinely tested parameters should be encouraged. (Tuguela et al. 2018)

Chlorate

In the USEPA UCMR3, chlorate was detected more frequently than any other compound at concentrations above its health reference level (210 µg/L) (Gorzalski, 2015). 16% of all samples exceeded 210 µg/L and 37% of public water systems had at least one sample above 210 µg/L.

TREATMENT

Ultimately, there would need to be treatment strategies to lower the DBP levels, whether regulated individually or through surrogates. Promising approaches include the use of granular activated carbon (GAC) or membranes to remove DBP precursors (then applying a lower dose of chlorine for disinfection), using UV followed by a lower dose of chlorine, or using chlorine dioxide, which tends to generate fewer DBPs overall. Finally, finding an inexpensive way to remove bromide and iodide would go a long way toward reducing toxic Br^- and I-DBPs. (Richardson and Plewa, 2020)

Controlling Formation of DBP Based on Operational Strategies is Difficult

DBP species behave differently during treatment and distribution. Most DBPs are formed during treatment, not distribution. Consequently, for the drinking water supply system under study, efforts to reduce regulated and non-regulated DBPs must focus primarily on WTP operations. Operational changes to the treatment chain that include tank management (e.g., reduction in free chlorine doses added or in the residence time in the tank) could be made to minimize the presence of regulated DBPs. However, possible modifications must be undertaken without increasing the presence of non-regulated DBPs, given the potential adverse effects of some of these DBPs. This study shows that controlling the formation of DBPs based on operational strategies is a challenging task, given the different spatial and temporal behavior of the different species that form flowing chlorination. correlations between non-regulated DBP species, stemming from the same family or not, vary during treatment and distribution. Consequently, the relevance of using a specific DBP species as an indicator for the others is questionable according to the species studied and the targeted measurement location within the water supply system. Finally, this study highlights the difficulties that drinking water supply managers must face in monitoring the presence of DBPs and, namely, in selecting the parameter to consider (individual species or family of DBPs), as well as the location and the sampling frequency. (Marcoux et al., 2017)

Removal of TOC and TON Precursors of DBP

The total organic nitrogen (TON) concentrations in the studied source waters were higher on average than levels reported in most previous studies. The average raw water TON concentration in this study was 0.34 mg/L-N, compared to 0.20 mg/L-N in a study of 28 U.S. WTPs and 0.29 mg/L-N reported by another U.S. study that targeted algae- and wastewater impacted sources. However, greater TON removal through treatment was achieved in this study than past work had demonstrated. The average TON removal across all WTPs here was 56%, while past studies reported a reduction of only 20–30%. Advanced WTPs that used ozone and BAC achieved greater removal of TON compared to conventional WTPs (65% vs. 51%, respectively). The average total organic carbon (TOC)/TON ratio in raw waters was 25.1 mg

C/mg N, suggesting that the NOM in these source waters was more allochthonous, plant- and soil-derived material (rather than microbial-derived). Therefore, the organic nitrogen in these source waters was likely contained in the more hydrophobic, plant- and soil-derived NOM, which could explain the higher removal of TON compared to previous studies. (WRF, Farré et al. 2016)

Limited Removal of Organic Nitrogen by Conventional Treatment

Historical data show high concentrations of dissolved organic nitrogen (DON) (i.e., 0.3-1 mg/L) in some South East Queensland drinking water sources. Most of the treatment plants use coagulation, sedimentation and filtration processes that are optimized for the removal of turbidity, color, manganese, algae and trihalomethane (THM) precursors. These processes have previously been reported to have limited effect on the removal of N-DBP precursors, which, because of the water DON content, are expected to contribute to significant N-DBP formation. Generally, N-DBPs are suspected to be more toxic than carbon-based DBPs. (WRF, Farré et al. 2016)

Regulated DBPs in finished waters leaving the WTPs were below Australian Drinking Water Guideline (ADWG) values. Advanced WTPs employing ozone/BAC treatment achieved greater removal of DBP precursors, resulting in lower finished water DBP concentrations compared to conventional WTPs. The known adsorbable organic halogens (AOX), which is the percentage of AOX that can be accounted for by the halogen equivalents of measured DBPs, was calculated. The average unknown AOX for all WTPs was 34% and ranged from 12% to 62%. Chloramination generally produces a greater percentage of unknown AOX compared to chlorination, but this trend was not observed at the two WTPs that use in situ-formed chloramines for distribution, likely due to the initial contact time with free chlorine. Formation potentials of several by-products (halonitromethanes, haloketones, chloral hydrate) was increased by ozonation but reduced by subsequent BAC filtration. However, BAC was less effective at decreasing tribromonitromethane, and on average, halonitromethane formation potential increased slightly across advanced WTPs. Halonitromethanes are not included in the ADWG and do not have regulatory or guideline values elsewhere, but they are thought to be more geno- and cytotoxic than THM4. The trade-offs between significant decreases in some DBPs and increases in other by-products (i.e., halonitromethanes) using ozone/BAC treatment requires more research. **Table ES.1** in that reference summarizes the effect of different treatment processes on precursors, DBP formation potential from chlorine, and NDMA formation potential from chloramination. (WRF, Farré et al. 2016)

Molecular Ozone versus OH Radical Reactions. The effects of ozonation conditions on formation potentials of C-DBPs, N-DBPs, adsorbable organic halogens (AOX), and associated toxicity after chlorine disinfection were also investigated. It was observed that ozonation at conditions favoring molecular ozone over the •OH pathway promoted reduction of halogenated DBP formation potentials from subsequent chlorination. This observation also applied to DBPs that are known to form as a result of preozonation and subsequent chlorination such as chloral hydrate and haloketones. Increasing ozone dose without changing other conditions (e.g., pH, no addition of t-BuOH or H2O2) resulted in a mixture of effects brought about by additional O3 and •OH reactions. The results for the AOX followed the trend for the DBPs analyzed. Subjecting samples to conditions favoring the ozone reaction pathway resulted in lower AOX formation potentials but a higher percentage of unknown AOX. (WRF, Farré et al. 2016)

Effect of Biofiltration. The first order kinetics of DBP formation potentials during biofiltration at different empty bed contact times (EBCTs) included a steady-state concentration that approached the minimum or maximum filter effluent concentrations after a certain EBCT (e.g., > 20 min). This study also demonstrated the importance of EBCT as a key design parameter for biofiltration. Reduction of DBP formation potentials vary with respect to species, indicating the influence of DBP precursor structure and reactivity on biodegradability. However, brominated DBPs increased after biofiltration, with a much higher increase at longer EBCTs. This could be explained by the increase in bromide to carbon ratio during biofiltration, which increased by up to 50–70% at EBCTs of > 20 min, in our case. (WRF, Farré et al. 2016)

Both GAC and BAC showed promising overall reductions of total DBP formation. Filter age had greater impacts in GAC systems, where the youngest GAC filters performed best. BAC systems had less pronounced differences in DBP concentration between filter ages, as the filters had reached steady-state. Preformed DBPs in both types of systems were well removed, while some compounds were poorly removed or increased in either GAC or BAC. For example, THMs are well removed in GAC systems, but were poorly removed by BAC, which is also supported by previous literature. DBP formation and calculated toxicity is highly dependent on source water precursor material and disinfectant type, making comparisons between plants difficult. Regardless, both studies showed that total DBP reduction does not necessarily correlate with calculated toxicity. Calculated cytotoxicity and genotoxicity was not driven by regulated DBPs in either study. (Cuthbertson et al. 2020)

Key findings of this study include:

- Most of the preformed regulated and unregulated DBPs were removed by BAC, likely due to biodegradation
- BAC reduced regulated and unregulated DBP precursors as determined by SDS testing

- Some DBP levels increased following BAC (chloroacetaldehyde, dichloronitromethane, bromodichloronitromethane, NDMA, dibromochloromethane, tribromomethane, dibromochloroacetic acid, and tribromoacetic acid) following SDS testing
- Reductions in cytotoxicity across BAC filters did not correlate with decreases in DBP concentrations
- BAC showed promising reductions in calculated genotoxicity across 6 different BAC filter ages, while calculated cytotoxicity was more variable
- A large portion of total organic halogen remains unknown in chloraminated waters pre- and post-BAC, therefore future studies must include unknown analysis to close the mass balance on these systems
- The TIC-Tox method is a useful comparative tool, but it is based on in vitro toxicity studies and does not account for metabolism of these compounds. Future studies should include real toxicity measurements to assess whole water mixtures, especially since quantified DBPs only account for a portion of the overall TOX. (Cuthbertson et al. 2020)

Removal of Bromide

Currently, there are no commercial technologies employed by drinking water utilities to remove bromide from drinking water. The research team explored the use of various silver-impregnated adsorbents, silver-amended coagulation (SAC) processes, and ion-exchange processes (packed bed, or MIEX-like processes). These work well in low conductivity waters and waters with low chloride (Cl^{-}< 10 mg/L). However, when the Cl^{-}/Br^{-} ratios are high (median ~314 mg/mg), Cl^{-} competes for Br^{-} removal and increases the removal cost. However, some utilities near the 5th percentile for Cl^{-}/Br^{-} ratios (< 120 mg Cl/mg Br) are enriched in bromide and would gain insights from conducting bench-scale jar tests using the bromide removal processes explored in this project. (WRF, Westerhoff et al. 2022)

Removal of Bromide Ion would be of Significant Benefit

While decades of research have found strategies to cost-effectively reduce organic precursors (i.e., NOM) that influence DBP formation, additional focus on technologies to selectively lower inorganic DBP precursors (i.e., Br^- ion) could have tremendous benefits for the water industry. Discovering and developing a viable treatment technology is needed to remove Br^- from drinking waters for utilities that exceed TTHM and HAA5 regulatory levels or have high HAA9 levels. Such waters have elevated BIF levels (>0.2) and could achieve dramatic reduction in TTHM or HAA5 mass-based concentrations (µg/L). Such a technology should economically remove Br^- from water when Br^- concentrations range from 100 to 1000 µg/L and co-occur with Cl^- ion in waters containing ~300 mg Cl/mg Br. (WRF, Westerhoff et al. 2022)

Granular Activated Carbon

Regulated and unregulated DBP, including nitrogenous DBP such as nitrosamines, haloacetamides (HAM), haloacetonitriles (HAN), and halonitromethanes (HNM) were evaluated. Additional carbonaceous DBP that were studied included haloacetaldehydes (HAL), haloketones (HK), iodinated trihalomethanes (I-THM), iodinated haloacetic acids (I-HAA), and each of the chlorinated and brominated haloacetic acids (HAA9, including 5 regulated and 4 unregulated HAA). In addition to the regulated THM and HAA, 61 emerging DBP were examined in this study, including 4 unregulated HAA, 10 HAL, 8 HAN, 9 HK, 7 HNM, 13 HAM, 6 I-THM, and 4 I-HAA. In addition to these DBP, total organic chlorine (TOCl), total organic bromine (TOBr), and total organic iodine (TOI) were measured to capture the complete halogenated organic DBP picture, including both measurable DBP and unknown DBP. (WRF, Stanford et al. 2019)

Removal of DBP Precursors by GAC from Algae Impacted Waters. In the batch experiments for this project, GAC provided reduction of DBP precursors under both chlorination and chloramination conditions. Chlorination of algae-impacted water under uniform formation conditions (UFC) yielded substantial levels of TOX, but low levels of target halogenated DBPs measured in this study and no measurable NDMA; GAC treatment was effective for TOX precursor removal (67% removal). Chloramination of algae-impacted water under formation potential (FP) conditions yielded high levels of TOX, halogenated DBP (including emerging DBP), and some NDMA; GAC treatment removed ~25-30% of TOX, halogenated DBP, and NDMA precursors. (WRF, Stanford et al. 2019)

Removal of DBP Precursors by GAC Tracked with TOC Breakthrough. Bromine Incorporation

GAC is able to remove DBP precursors for many types of C-DBPs and N-DBPs. The overall level of DBP precursors (quantified by DBP formation tests) was reduced following GAC treatment. Removal of each DBP precursors (HAAs, THMs, HANs, HNM, HALs, HKs, HAMs, I-THMs, I-HAAs), with the exception of nitrosamine precursors, track with TOC breakthrough. Therefore, GAC provides at least some level of reduction of unregulated DBP formation relative to non-GAC treated water. It was observed that control of regulated DBPs somewhat corresponded with control of unregulated DBPs, though the exact behavior of an individual DBP species may be site-specific. The bromine incorporation factor post-GAC increased relative to non-GAC treated water. That is, the more cytotoxic and genotoxic brominated DBPs are preferentially formed (as a greater percentage of total DBPs) post-GAC than their chlorinated analogs. However, even with the preferential formation of brominated-DBPs post-GAC, the total concentration of DBPs is lower than in non- GAC treated water. It was also observed that despite this study analyzing 70 DBPs, there was still a large unidentified fraction of total organic halogens (TOX) present in post-GAC chlorination and chloramination tests. (WRF, Stanford et al. 2019)

Limited Removal of DBP Precursors from Polymers by GAC. GAC treatment provided limited removal of DBP precursors associated with polymers, namely polyDADMAC and polyamide. The control of nitrogenous DBP precursors was generally less effective than for THM, HAA, and other carbonaceous DBP precursors. (WRF, Stanford et al. 2019)

Effect of Preozonation. For bulk DOC, pre-ozonation seemed to provide longer time-to-breakthrough (i.e., better removal). Precursors of emerging DBPs (i.e., HALs, HAMs, HANs, and HKs) that were reactive towards chlorine and chloramine exhibited later breakthrough from GAC when ozonation was applied prior to GAC. Among the precursors of emerging DBPs, it was observed that use of pre-ozonation increased HNMs formation. Prechlorination did not have a notable effect on GAC performance for the removal of total emerging DBP formation. As noted above, however, pre-formed THMs will begin desorbing from GAC after breakthrough occurs, so any pre-oxidation strategy should be carefully monitored for potential release of DBPs. (WRF, Stanford et al. 2019)

Effect of Treatment on Iodo-THM

The use of chloramines, even when iodine was present, did not appear to be the main determining factor in the formation of iodo-THM. The proportion of WTS with detectable levels of iodo-THM is certainly higher among WTS using chloramine as secondary disinfectant; however, the average and median total iodo-THM concentrations are very similar for WTS using chlorine and chloramines. It should be noted that information about the chlorine contact time before the addition of ammonia for WTS using chloramine was not available in this study. Both the proportion of WTS where iodo-THMs were found, as well as the average and median total iodo-THM concentrations increased considerably for the WTS using source waters with naturally occurring ammonia, whether the secondary disinfectant used is chlorine (breakpoint chlorination) or chloramine. (Tuguela et al. 2018)

Chlorate

Hypochlorite filtration improves hypochlorite's overall quality through transitional metals removal, which prevents accelerated hypochlorite decomposition. On the basis of the limited results of this study, it did not appear that metal catalysis was taking place in either of the two products investigated. One supplier had consistently higher levels of chlorate in the delivered chlorine compared with the other supplier. The study showed consistency with previous studies, affirming that reduction of hypochlorite storage temperatures and storage time will minimize hypochlorite decomposition. Another effective measure to reduce hypochlorite decomposition, as also confirmed by previous studies, is hypochlorite dilution. (Breytus et al. 2017)

RECOMMENDATIONS

The decision to convert GAC to biologically active GAC (i.e., BAC) is one that should be made based on considerations other than DBP control. For some facilities, implementation of BAC may be beneficial for managing taste and odor events or other water quality challenges. However, results from this study indicate that BAC provides mixed performance in the overall reduction in regulated and unregulated DBP formation potential, with or without prechlorination strategies in place. While there appears to be a net decrease in the sum of all preformed DBPs (i.e., NDMA, HAAs) and DBP precursors (THMs, HAAs, NDMA, etc.) measured in this study across the BAC filters, the performance in DBP reduction is not nearly as significant as with GAC that is operated in adsorptive mode with replacement intervals on the order of <1 year, and there are parameters, such as TOX formation potential and individual species, that may remain unchanged across biofilters. (WRF, Stanford et al. 2019)

Some utilities collect nearly weekly Br^- on multiple WTP intakes and have datasets for over 10 years. Such frequency and long-term datasets provide invaluable insights and ability to make assessments about changes occurring within watersheds (changing source contributions, changing hydrology, etc.). There was no single parameter found to be predictive of Br-, and it is recommended that utilities collect bromide on a regular schedule (weekly). (WRF, Westerhoff et al. 2022)

For utilities with Br^- levels above the median concentration observed in this study (80 µg/) or earlier studies (74 µg/L), Br^- is a key determinant in formation of TTHM and HAA5. The research team recommends tracking the bromide incorporation factor (BIF) in regulated DBPs to understand the relative contribution of bromide. (WRF, Westerhoff et al. 2022)

Measuring TOX provides an estimate of the total amount of organic compounds containing covalently-bound chlorine, bromine, and iodine—including both known and unknown DBPs formed during treatment—in a water sample. (WRF, Westerhoff et al. 2022)

Total iodine was found to be the best indicator for the presence of iodine precursors that favor the formation of iodo-THM. However, neither total iodine, nor bromide analysis of source waters, at the level of sensitivity required, are currently routinely performed for screening water sources for iodo-THM formation potential. As such analytical procedures are now available from commercial laboratories; they could be used more often and would bring important contributions to the evaluation of iodo- THM formation potential and the optimization of the disinfection. (Tuguela et al. 2018)

Currently, I-THMs, I-HAAs, and other I-DBPs are not regulated in any country. On the basis of current knowledge gaps and challenges, we propose the following future research directions:

identify I-DBPs driving the toxicity of drinking water; elucidate their precursors and formation pathways; and take a systems engineering approach for their effective abatement in drinking water. (Dong et al. 2019)

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5. Algal Toxins

Algal Toxins, or cyanotoxins, are a diverse group of chemical substances produced from cyanobacteria, also called blue-green algae. Blue-green algae are photosynthetic bacteria that grow in both fresh and marine water and have been linked to human and animal illness around the world. A harmful algal bloom (HAB) is an algal bloom that causes negative impacts to other organisms via production of natural algae-produced toxins.

MEDIUM PRIORITY FOR SFPUC

Though rare, adverse health impacts to people from algal toxins in drinking water associated with severe algal blooms have been reported elsewhere (though not for SFPUC). Algal toxins are of interest due to ongoing health and regulatory review and awareness of the potential for algal blooms in reservoirs. Vulnerability of SFPUC surface water supplies to algal toxins is low to medium for local water sources and negligible/low for the Hetch Hetchy supply. SFPUC treatment plants' influent/effluents are regularly monitored for the presence of algal toxins and so far toxins have not been detected in drinking water. SFPUC has a comprehensive algal management program plus an algal toxin response plan in the event of agal toxin detection in drinking water.

Algal toxins are considered medium priority because algae types and levels and algal toxin concentrations could change over time due to climate change or other environmental factors.

This section presents: (1) Screening Evaluation Table, (2) SFPUC Monitoring Review 2016-2021, and (3) Technical Review 2016-2021 of available scientific studies.

Table 5-1. Screening Evaluation Table for Algal Toxins

GENERAL INFORMATION ON CEC	
Instructions	This Screening Evaluation may be applied to a CEC group or an individual CEC. The purpose of this section of the Evaluation is to develop background information on the CEC or CEC group.
CEC Name	**Algal Toxins and Harmful Algal Blooms (HAB)**
CEC Description Is CEC a group? If individual CEC, which group is CEC part of?	Algal Toxins, or cyanotoxins, are a diverse group of chemical substances produced from cyanobacteria, also called blue-green algae. Blue-green algae are photosynthetic bacteria that grow in both fresh and marine water and have been linked to human and animal illness around the world. There are many strains of blue-green algae. Types of cyanotoxins produced by blue-green algae include neurotoxins (affecting the nervous system), hepatotoxins (affecting the liver), and others (CDC, 2010; USEPA, 2015a). A harmful algal bloom (HAB) is an algal bloom that causes negative impacts to other organisms via production of natural algae-produced toxins – usually caused by blue-green algae. The SFPUC Algae Monitoring and Mitigation Plan (2011) updated in 2019, which is still in place, includes additional information on sources, occurrence, and toxicity of algal toxins.
CEC Grouping What is the basis for grouping? *(Grouping factors are: common health effects, treatment, and analytical method, and/or compound co-occurrence)*	Algal toxins are a group. The basis for the grouping is common source (blue-green algae) and compound co- occurrence. The majority of algal toxins (cyanotoxins) are associated with well-known planktonic and bloom- forming blue-green algae that float on the water surface or are dispersed through the water column (WQRA, 2010;USEPA, 2014). Additionally, common treatment provides another basis for grouping, given that reservoir algae management practices should be effective in controlling cyanobacterial blooms. HABs can be grouped by the reservoir management strategies that are effective for them or types of blue-green algae usually associated with them, related to conditions for promotion of taste and odor (T&O).

Examples and Indicators If group, what are notable examples? Are there possible indicator constituents? *(A suitable indicator occurs at quantifiable levels and may co-occur with other CEC, exhibit similar treatment and fate in environment)*	Examples of algal toxins include microcystins (MCs) and cylindrospermopsin, which are hepatotoxins (i.e., liver toxins),and anatoxin-a and saxitoxin which are neurotoxins. Microcystins and anatoxin-are the most commonly detected algal toxins in California (SWRCB, 2019). Indirect indicators (surrogates) for cyanotoxins include blue-green phytoplankton counts (cells/mL or natural units/m3), chlorophyll-a (µg/L), phycocyanin, pH, turbidity, total phosphorus, ammonia, nitrate, thermal stratification, determination of dominant taxa (AWWA, WRF, 2016). Site inspection for the formation of scum is also recommended. Satellite pictures of water bodies can be used for warning. Ohio EPA reviews satellite images to determine the algal blooms in source water and notifies water utility (AWWA, WRF 2016).
Health Advisories Does CEC have a USEPA Health Advisory (e.g., Drinking Water Equivalent Level [DWEL]) or California Notification Level?	Yes. The USEPA has issued 10-day Drinking Water Health Advisories (health advisories are the non-regulated concentrations for drinking water contaminants at or below which health effects are not anticipated to occur over specific duration e.g. one day, 10-day, lifetime) for MCs and cylindrospermopsin(USEPA, 2015b). The Health Advisory for total MCs is 0.3 µg/L for those younger than 6 years old and 1.6 µg/L for all others. The Health Advisory for cylindrospermopsin is 0.7 µg/L for those younger than 6 years oldand 3.0 µg/L for all others. The EPA published a health effects support document for anatoxin-a but concluded there was not adequate information available to support a health advisory for this toxin. In May 2021, the California Office of Environmental Health Hazard Assessment (OEHHA) recommended an interim Notification Levels for saxitoxins – 0.6 µg/L, MCs – 0.03 µg/L and cylindrospermosin – 0.3 µg/L, anatoxin-A of 4.0 µg/L in drinking waters until it completes its review based on recent toxicity study (Cal., OEHHA, 2021).
Regulatory Development Status Is CEC on USEPA Candidate Contaminant List (CCL), Unregulated Contaminant Monitoring Rule (UCMR) list, or California Public Health Goal (PHG) list?	USEPA included 10 cyanotoxin chemical contaminants (algal toxins) on the Unregulated Contaminant Monitoring Rule 4 (UCMR4) list: Total MCs, MC-LA, MC-LF, MC-LR, MC-LY, MC-RR, MC-YR, nodularin, anatoxin-a, Cylindrospermopsin. In 2016, Ohio EPA implemented regulation for algal toxins. The rule required PWS to develop MCs action levels in drinking water, monitoring requirements, treatment technique requirements, public notification, Consumer Confidence Report (CCR) requirements, recordkeeping requirements, and laboratory certification requirements (Ohio EPA, 2016). 4 algal toxins (cyanotoxins) are included in draft CCL5 which is under review. The list of cyanotoxins included, but is not limited to (USEPA 2021b): anatoxin-a, cylindrospermopsin, MCs, saxitoxin.

CONTEXT OF CEC EVALUATION AT SFPUC	
Instructions	The purpose of this section is to report SFPUC experience with the CEC or CEC Group, including occurrence data for each source water if available.
Purpose Why is investigation undertaken? What is new about the issue that is considered 'emerging' (e.g., new chemical, new effect)?	Algal toxins are of interest due to ongoing health and regulatory review and awareness of the potential for algal blooms in reservoirs. Vulnerability of SFPUC water supplies to algal toxins is low to medium for local water sources and negligible/low for the Hetch Hetchy supply. Presence of algal toxins in drinking water impose harmful health effects on humans, which are very well documented, hence it becomes necessary to control algal blooms in source water. As mentioned above, USEPA has developed Health Advisory levels for certain harmful algal toxins in drinking water, hence it is important to monitor these toxins regularly (USEPA, 2015b).
Customer Interaction Widespread public concerns? Media coverage?	There have not been widespread public concerns or media coverage about algal toxins in the SFPUC drinking water system; however, there is an increased awareness of presence of algal toxins in recreational lakes. The California Water Board monitors the algal blooms in California and the information is available in the form of incident report map on their website on the lakes that have algal blooms. The incident report map can be accessed at https://mywaterquality.ca.gov/habs/where/freshwater_events.html In the SF Bay Area during the summer of 2015, East Bay Regional Park District closed 6 recreational lakes due to elevated algal toxins (MCs).
Expected Outcomes What are the likely benefits of the investigation to SFPUC and its customers?	Currently, in 2021/2022, the program to manage algal toxins in SFPUC source water is very well established. Database for algal toxins is maintained in StarLims. WQD Millbrae Laboratory has analytical capabilities, and WQD and NRD staff are experienced in monitoring and responding to cyanobacterial blooms. Response plan for source waters and treatment plants is in place (SFPUC, 2011 and 2019). The monitoring plan for total microcystins is focused primarily on source water reservoirs in Alameda and Peninsula watersheds as well as on treated drinking water effluents at SVWTP and HTWTP.

Occurrence Data (US and SFPUC) What occurrence information is available? Have detections, if any, been confirmed by follow-up sampling and/or QA/QC review?	From 2018-2021, 26 monitoring stations in SFPUC source waters, treated and distribution system were monitored for MCs, cylindrospermopsin, anatoxin-a, saxitoxin (as a part of UCMR4 from 2018 – 2020). All data downloaded from StarLims from 2018 to date is included in the report electronically. This detailed monitoring was concluded at the beginning of 2020 and replaced with more focused monitoring of primarily total MCs (occasionally other toxins) at select locations. Other Toxins are monitored quarterly. The occurrences and frequency of total MCs in East and West Bay Reservoirs is given in the Tables 5-2, 5-3, and 5-4. MCs are commonly detected in Calaveras Reservoir during fall months with highest concentration observed at 23 µg/L on 11/5/2018. Total MCs were detected in San Antonio Reservoir particularly during summer months of 2019, with highest concentration observed at 0.8 µg/L. SVWTP TRW Effluent treated effluent samples were all non-detect in 2018-2021 for total MCs (<0.15 µg/L). The occurrence of total MCs in Lower Crystal Springs (LCS) Reservoir was mainly observed in 2019 at 0.92 µg/L, whereas San Andreas Reservoir had highest concentration of total MC in 2019 at 4 µg/L. Pilarcitos Reservoir were non-detect except one sample at 0.5 µg/L in 2020. HTWTP Raw had detectable concentrations of total MCs in Dec 2018, Jan 2019, and May 2019 up to 0.5 µg/L, however, HTWTP treated effluent samples were all non-detect in 2018-2021 for total MCs (<0.15 µg/L).
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DIAGNOSTIC QUESTIONS TO SUPPORT CEC PRIORITIZATION

Instructions	The purpose of the Diagnostic Questions is to determine whether the CEC or CECs Group are significant to SFPUC drinking water and whether they merit further evaluation and/or action. All answers require explanation except those clearly not applicable. The Diagnostic Questions are divided into Health, Occurrence, and Treatment sections. The more questions are answered with a "Yes", the higher the probability that the CEC is a high priority or that a proactive approach should be taken.

HEALTH EFFECTS FROM SCIENTIFIC STUDIES

Question	Answer	Explanation and Comments
Is scientific knowledge on CEC health effects well developed?	**Yes**	Potential health concerns arise from exposure to the toxins through ingestion of drinking water, during recreation, through showering and potentially through consumption of algal food supplement tablets. Repeated or chronic exposure is the primary concern of the cyanotoxins; in some cases, however, acute toxicity is more important. Human fatalities have occurred through use of inadequately treated water containing high cyanotoxin levels for renal dialysis. Dermal exposure may lead to irritation of the skin and mucous membranes and possibly to allergic reactions (WHO 2017). Per the syndromic surveillance data (to study the extent of harmful algal blooms associated illnesses, increase awareness among people of algal bloom exposure), 321 algal bloom–associated emergency department visits occurred during January 1, 2017–December 31, 2019 mainly in summer months (June – October) (Lavery et.al 2021). Animals can be exposed when they drink from, swim in, or lick fur or hair containing cyanotoxins. Animals are more likely than humans to be exposed because they do not always avoid entering and ingesting green, foul-smelling water (MDH, 2020).

Question	Answer	Explanation and Comments
Based on current scientific understanding, does the CEC pose potential health risk at the levels typically found in drinking water in the US?	Yes	A study conducted over seven years by 109 scientists in 35 countries found that HAB events have increased in some regions, and decreased or have stayed steady in other regions, which could be related to climate change (UNESCO 2021). A data on HAB events occurring globally can be found in UNESCO's report. A research conducted using Landsat 5 satellite imagery for 3 decades found rise in algal blooms in 71 large lakes globally (Ho et.al 2019). A study conducted to determine the implication of algal toxins on human health indicates health costs included healthcare and medication expenses, loss of income due to illness, cost of pain and suffering, and cost of death. (Kouakou et.al 2019). Hence, presence of algal toxins in drinking water poses risk to human health.
Adverse health impacts observed in other drinking water systems? Are public health studies documenting human health impacts (disease or outbreaks) available?	Yes	Relatively few incidents of adverse health impacts to humans from drinking water have been reported (Health Canada, 2008; USEPA, 2015a). Young children exhibit greater sensitivity; during one disease outbreak associated with cylindrospermopsin in drinking water, 93% of the 148 reported cases were children (USEPA, 2015a). More commonly, adverse health impacts have been reported due to recreational exposures (USEPA, 2012; USGS, 2009).
Existing regulations or guidelines outside of US (e.g., WHO, EU)?	Yes	WHO developed a provisional, health-based guideline of 1 µg/L (based on lifetime of daily exposure) for MC-LR in drinking water (WHO, 2003 and 2017). Canada has established a seasonal maximum acceptable concentration of 1.5 µg/L for total MCs, the Australian National Health and Medical Research Council established a guideline of 1.3 µg/L for total MCs in drinking water (Health Canada, 2021; ADWG, 2021).
Existing US health advisories or CA notification levels?	Yes	In June 2015, USEPA issued 10-day Health Advisories for total MCs and cylindrospermopsin of 0.3 ug/L and 0.7 ug/L, respectfully. In May 2021, the California Office of Environmental Health Hazard Assessment (OEHHA) recommended an interim Notification Levels for saxitoxins – 0.6 µg/L, microcystin – 0.03 µg/L and cylindrospermosin – 0.3 µg/L, anatoxin-A of 4.0 µg/L in drinking waters until it completes its review based on recent toxicity study.

Question	Answer	Explanation and Comments
Likely US regulation in the next 10 years? Is CEC on a regulatory development list, such as CCL? Is there a pending regulation or California PHG?	Yes **UCMR4** **CCL5**	Three algal toxins were on the CCL3 and CCL4. The USEPA included 10 algal toxins in the UCMR4 (listed above). 4 algal toxins (cyanotoxins) are included in draft CCL5 which is under review. The list of cyanotoxins included, but is not limited to: anatoxin-a, cylindrospermopsin, MC, and saxitoxin, hence have a higher chance to be regulated in the next 10 years.
SUMMARY – SIGNIFICANT TO PUBLIC HEALTH IN GENERAL? *(Based on above answers))*	Yes	Algal toxins may occur in drinking water at significant concentrations during episodes of algal blooms. Three algal toxins were on the CCL3 and the CCL4, 10 algal toxins were added to the UCMR4 and 4 algal toxins are added to draft CCL5. Though rare, adverse health impacts to humans from drinking water have been reported.
OCCURRENCE		
Is scientific knowledge on CEC sources/formation well developed?	**Yes** **In Development**	Climate change can impact the freshwater and marine environment leading to algal blooms (USEPA, 2021d) and is widespread in temperate region (WRF, 2019). A study conducted on Florida's Karenia brevis red tide- a type of algal bloom found that algal toxins can travel in the air up to 4 miles inland from water source (CDC, 2021). Climate change poses an additional challenge in predicting changes in HAB frequency, intensity, and proliferation. Global warming altered precipitation patterns, and sea level rise, accompanied by changes in ocean and lake circulation, stratification, and upwelling, wind speed, and cyclone frequency and intensity, play increasingly important roles in modulating HAB dynamics. Hydrologic modifications and climate change enable HABs to reach larger magnitudes and persist longer when accompanied by excessive nutrient loading (Paerl et al. 2019). Factors that promote cyanobacterial bloom formation and persistence include (USEPA, 2019): • Extended periods of direct sunlight, • Elevated nutrient availability (especially phosphorus and nitrogen), • Elevated water temperature, • pH changes, • An increase in precipitation events, • Calm or stagnant water flow, and water column stability/lack of vertical mixing.

Question	Answer	Explanation and Comments
CEC presence reported in other water supplies? Are occurrence studies available?	Yes	In 2016, CDC launched One Health Harmful Algal Bloom System (OHHABS) to inform public about the algal blooms and its harmful effects in which 18 States reported 421 HAB events, 389 cases of human illness, and 413 cases of animal illness that occurred during 2016–2018. (Roberts et.al.2020). (https://www.cdc.gov/mmwr/volumes/69/wr/mm6950a2.htm) A report published (Henrie et.al.2017) provides detail information on the algal blooms occurring at various parts of United States and the formation trends and the efforts taken by the utilities in different states to control the algal blooms. In 2016, 19 states had public health advisories because of cyanotoxins (USGS, 2021). A recent study of MCs in Egypt reported levels in finished drinking water from 1.1 to 3.6 ug/L (Mohamed, 2015).
CEC present in SFPUC watersheds and/or surface waters? Are there complex issues involved in managing CEC ;e.g., point vs. non-point sources?	Yes	From 2018-2021, 26 monitoring stations in SFPUC source waters, treated and distribution system were monitored for cylindrospermopsin, anatoxin-a, saxitoxin. All data downloaded from StarLims from 2018 to date is included in the report electronically. This detailed monitoring was concluded at the beginning of 2020 and replaced with more focused monitoring of primarily total MCs (occasionally other toxins) at select locations. The occurrences and frequency of total MCs in East and West Bay Reservoirs are given in Tables 5-2, 5-3, and 5-4. MCs are commonly detected in Calaveras Reservoir during fall months with highest concentration observed at 23 µg/L on 11/5/2018. Total MCs were detected in San Antonio Reservoir particularly during summer months of 2019, with highest concentration observed at 0.8 µg/L. SVWTP TRW Effluent treated effluent samples were all non-detect in 2018-2021 for total MCs (<0.15 µg/L). The occurrence of total MCs in LCS was mainly observed in 2019 at 0.92 µg/L, whereas San Andreas Reservoir had highest concentration of total MC in 2019 at 4 µg/L. Pilarcitos Reservoir were non-detect except one sample at 0.5 µg/L in 2020. HTWTP Raw had detectable of total MCs in Dec 2018, Jan 2019, and May 2019 up to 0.5 µg/L, however the HTWTP treated effluents were all non-detect in 2018-2021 for total MCs (<0.15 µg/L).
Is the CEC a potential groundwater contaminant?	No	Algal toxins are expected only in surface waters where algal blooms can occur (require sunlight).

Question	Answer	Explanation and Comments
If the CEC is a potential groundwater contaminant, is it highly mobile in the subsurface? *Is* the CEC low-sorbing and resistant to microbial degradation?	**NA**	
Precursor present in SFPUC source waters? **(Including surface waters and groundwaters)**	**Yes**	Low levels of nutrients (derived from plants and animals), as well as low levels of blue-green algae, are naturally present in watersheds. Nutrients are precursors to algal blooms. Algal toxins are produced from algal blooms. The SFPUC watersheds are not impacted by high nutrient loads due to such activities as wastewater discharges, industrial pollution, agricultural runoff, or landscape irrigation runoff. However, warming climate and drought may coincide with algal blooms in the future. Based on the monitoring data, MCs are observed in some of SFPUC's reservoirs during fall and summer season such as Calaveras Reservoir, San Andreas Reservoir, San Antonio Reservoir, Lower Crystal Springs Reservoir and Pilarcitos Reservoir. The treatment strategies used between 2016 -2018 to reduce algae level were continued by using Hypolimnetic Oxygenation System (HOS) and use of hydrogen peroxide-based algaecide in Calaveras Reservoir.
Formed or added during current SFPUC treatment? **If so, describe whether the formation or addition of CEC can be controlled.**	**Possible**	Algal toxins are not produced during treatment, however, cells can be broken (lysed) by prechlorination, increasing the dissolved toxin fraction. Strategy is to discontinue prechlorination during significant cyanotoxin blooms. In addition, WTP recycle streams may need to be monitored to ensure toxins do not re- enter treatment process. SFPUC monitors WTP effluents biweekly for presence of MCs. The sample results are non- detect and the results are presented in Tables 5-2, 5-3, and 5-4.

Question	Answer	Explanation and Comments
Formed or added within SFPUC storage or distribution? **If so, describe whether the formation or addition of CEC can be controlled.**	**No**	Algal toxins are not produced during storage or distribution. The monitoring conducted during 2018 – 2020 at reservoirs and distribution system showed results as non-detect. There is speculation in the literature that cyanobacteria can proliferate in the distribution system – to date there is no evidence for this.
Detected in SFPUC drinking water?	**No**	Samples collected in 2018 -2021 at SVWTP TWR Effluent and HTWTP Post Effluent indicate that algal toxins do not pass through the treatment train and all the results in the drinking water to date are non-detect. SFPUC's treatment and multi-barrier approach are effective in removing algal toxins.
SUMMARY – OCCURRENCE IN SOURCE AND DRINKING WATER? (OR SIGNIFICANT POTENTIAL TO OCCUR) **(**Based on above answers)	**Yes in surface water No in drinking water**	MCs are commonly detected during fall and summer months in Calaveras Reservoir, San Andreas Reservoir, San Antonio Reservoir, Lower Crystal Springs Reservoir. The occurrence frequency is shown in Tables 5-2, 5-3, and 5-4. HTWTP and SVWTP influent/effluents are monitored for the presence of algal toxins when they are online. So far toxins have not been detected in the treated effluents.

TREATMENT

Question	Answer	Explanation and Comments
Is scientific knowledge on CEC treatment/removal well developed?	**Yes** **Basic Know-ledge**	Process operation should avoid cell rupture and toxin release. Hazardously high concentrations of dissolved cyanotoxins appear to occur less frequently. They are well removed by most types of activated carbon. Chlorination and ozonation are effective for the removal of many cyanotoxins at sufficiently high doses and contact times, but not very effective for saxitoxins. Potassium permanganate is effective for microcystins, whereas limited or no data are available at present for other toxins. Chlorine dioxide and chloramine are ineffective for removing cyanotoxins (WHO, 2017).
Likely to pass through current treatment for Hetch Hetchy Supply? Describe any complex issues involved with the treatment/removal of CEC.	**Yes** **But Not Present**	Tesla Water Treatment Facility provides treatment via primary disinfection using chlorine and UV treatment. There is no filtration. Therefore, if algal cells occurred in the source water, these would not be removed and cell- bound toxins may be released during disinfection. However, Hetch Hetchy Reservoir does not experience blue-green algal blooms, the source of algal toxins. No threat from algal toxins is posed to Hetch Hetchy water, Lake Eleanor, Lake Cherry due to low nutrients, low phytoplankton abundance and benign algal communities (SFPUC - AWSS, 2021). Free Chlorine would remove 80% of extracellular MCs. Monitoring was conducted at Tesla Portal and Alameda East from Feb 2018- Feb 2019 for MCs, anatoxin-a, cylindrospermopsin, and saxitoxin. All results were non-detect at these two locations.
Likely to pass through current treatment at SVWTP? Describe any complex issues involved with the treatment/removal of CEC.	**No**	SVWTP has a conventional filtration treatment process (i.e., coagulation, flocculation, sedimentation, and dual media filtration), primary disinfection with free chlorine, and adds ammonia to convert free chlorine to monochloramine. Thus, removal of algal cells by sedimentation/filtration and approximately 80% extracellular toxin removal by free chlorination, would be expected. The treated effluent at SVWTP is monitored when plant is online for MCs, anatoxin-a, saxitoxin, cylindrospermopsin from Jan 2018 to Feb 2020 and all results were non-detect. Total MCs were continued to be monitored from Jan 2018 to date and so far the results are non-detect.

Question	Answer	Explanation and Comments
Likely to pass through current treatment at HTWTP? Describe any complex issues involved with the treatment/removal of CEC.	No	HTWTP has a direct filtration treatment process (i.e., coagulation, flocculation and dual media filtration), preceded by pre-ozone oxidation, and followed by primary disinfection with free chlorine. Ammonia is added to convert free chlorine to monochloramine. Pre-ozonation may partially remove some algal toxins (e.g., microcystin but not saxitoxin), but conversely, has been found to lyse cyanobacteria (if present) which releases toxins (Fan, 2014). Ozone is still effective in removing intra and extracellular toxins. The treated effluent at HTWTP is monitored when plant is online for MCs, anatoxin-a, saxitoxin, cylindrospermopsin from April 2018 – March 2020. The results were non-detect. These toxins are still monitored on a routine basis. MC is monitored weekly, whereas others are monitored quarterly. MCs were monitored from Sept 2018 – March 2020 and all were below detection limits. Total MCs are continued to be monitored to date and the results have been non-detect.
Likely to pass through current treatment for groundwater? Describe any complex issues involved with the treatment/removal of CEC.	No	Algal toxins are not expected to occur in groundwater.
SUMMARY – LIKELY TO PASS (NOT REMOVED BY) CURRENT TREATMENT? *(Based on above answers)*	No	Filtration at SVWTP and HTWTP should provide removal of algal cells and free chlorination should reduce extracellular toxins by approximately 80%. The unfiltered Hetch Hetchy system will not remove algae, however, blue-green algae (and associated cyanotoxins) are not present in Hetch Hetchy supply.

CEC PRIORITIZATION – CURRENT ASSESSMENT	
Instructions	This section prioritizes the CEC based upon the information developed in the above Diagnostic Questions as well as in the background information. For top priorities (high and medium priorities), develop monitoring and/or mitigation as appropriate. For low priorities, maintain current measures- source water protection, track regulatory developments, health/technical studies and reevaluate priority when needed.
Could CEC occur in SFPUC drinking water at levels of possible health significance? *(Based on above Diagnostic Questions)*	**NO** Based on monitoring conducted by SFPUC, it appears that the vulnerability of SFPUC water supplies to algal toxins is low to medium. Algal toxins could occur in SFPUC untreated local source water at levels of possible health significance during significant algal blooms. No algal toxins were detected to date in any treated drinking water.
CEC Prioritization for SFPUC High, Medium, or Low. Provide explanation. *(A high number of "Yes" answers to the Diagnostic Questions indicates a higher priority, and "No" or very few "Yes" answers indicates a lower priority.)*	**MEDIUM** Though rare, adverse health impacts to humans from algal toxins in drinking waterassociated with severe algal blooms have been reported elsewhere (though not for SFPUC). Algae types and levels and algal toxin concentrations could change over time due to climate change or other environmental factors.

Implemented Actions Indicate the progress and results of any action items, above, such as implemented in previous cycles of CEC review. Evaluate whether changes to the action plan are required.	• SFPUC conducted algal toxin investigations in 2007 and 2010 and prepared Algae Monitoring and Mitigation Plan (SFPUC, 2011), updated by SFPUC (2019). • Improved monitoring of algae per Algae Monitoring and Mitigation Plans. • SFPUC conducted monitoring of algal toxins as a part of UCMR4 at 26 locations (reservoirs, distribution system and treated drinking water) from 2018 -2020. Select reservoirs, influent and effluent at WTPs when online are currently being monitored. • Operated HOS on Calaveras and San Antonio Reservoirs. • Applied hydrogen peroxide-based algaecide in Calaveras Reservoir. • Adjusted SVWTP operations (no pre-oxidation) during algal blooms associated with cyanotoxins and closely monitored reservoir, WTP influent and effluent. Closely coordinated with other Divisions during algal blooms. • Developed in-house analytical capabilities at WQD Millbrae Laboratory to measure cyanotoxins. • Monitored regulatory developments, technical, and scientific literature.

Recommended Actions Does the situation merit investing additional resources or has the information gathered so far fulfilled due diligence? Actions could include monitoring and other measures (specified by source water, if necessary).	• Inspection and maintenance of the line diffusers of Calaveras and San Antonio Reservoirs, modified HOS system operations, use of algaecide. • SVWTP mitigation measures for algal toxins through modification of plant operations include: (a) optimization of coagulant and flocculant dose, (b) suspension of pre-chlorination, (c) addition of powdered activated carbon (PAC) (when available), (d) oxidation with free chlorine, (e) change of source water, and (f) adjustment of adit depth in source water reservoir. • Continue monitoring the watershed raw water quality at the sampling locations- Upper and Lower Crystal Springs Reservoir, San Andreas Reservoir, Pilarcitos Reservoir, and HTWTP Influent as per the frequency stated in the Peninsula Watershed Sanitary Survey. • Protect watershed raw quality from construction activities, fires etc. per the recommendations provided in the sanitary surveys. The Peninsula Watershed Sanitary survey recommends following the limnology Standard Operating Procedures stated in Algae Monitoring and Mitigation Plan Update. • Follow the updated Algae Monitoring and Mitigation Plan Update- 2019 for Peninsula Reservoirs. The plan recommends installation of HOS system in future at LCS and Pilarcitos Reservoir if the algal bloom issue persists, and use of algaecide. • HTWTP receives water from San Andreas Reservoir which does not exhibit algal bloom issues. In an event of change in source water quality the plan recommend: increased monitoring, adjust adit depth in source water reservoir, optimizing coagulation and filter performance, pre-oxidizing with ozone and hydrogen peroxide. • Maintain/enhance analytical capabilities for algal toxins at WQD Millbrae Laboratory. • Monitor algal toxins with minimum detection levels listed by Cal. OEEHA (2021) • Monitor algal toxins listed in draft CCL5 after its final review. • Track information, peer-reviewed publications, and any federal and state regulatory developments.

This evaluation was prepared based on available information (peer-reviewed literature and occurrence data) with the purpose of prioritizing work and informing the public on unregulated CECs. This evaluation will be updated every 6 years or when significant new research or occurrence data on CECs become available that may warrant changing priority and recommendations.

Water Quality Division, SFPUC Monitoring 2016 – 2021

Contaminants of Emerging Concern (CEC) in Drinking Water

Algal Toxins

The Water Quality Division (WQD) has been monitoring algal toxins in all the reservoirs. Total MCs are analyzed by the Millbrae Laboratory using the Cyanotoxin Automated Analysis System (CAAS) manufactured by Eurofins Abraxis (2019). The algal toxins can be analyzed using EPA method 546 – Enzyme-Linked Immunosorbent Assay (ELISA). The CAAS can analyze contaminants such as cyanotoxins, pesticides, herbicides etc. The full 2018-2021 monitoring data from StarLIMS are attached to the report electronically. Below are the Figures 5-1 and 5-2 of (a) Total MC in East and West Bay Reservoirs, and (b) in drinking waters. There were no detects in drinking waters. As seen from the figures, the Calaveras Reservoir periodically shows an increase in Total MC levels above the USEPA Health Advisory limits for drinking water particularly during the Fall season as pointed in 2019 CEC report.

From 2018-2020, 26 monitoring stations in SFPUC source waters, treated and distribution system were monitored for MCs, cylindrospermopsin, anatoxin-a, saxitoxin as a part of UCMR4. All toxins were non-detect. Cylindrospermopsin, anantoxin-a, saxitoxin still continue to be monitored at select locations.

The frequency of algal toxins monitoring, and maximum detected values can be found in Table 5-2. From the table it can be seen that the Calaveras Reservoir had maximum concentration of MC – RR and MC - LA at 10 feet in July 2018 and February 2018 respectively, whereas maximum concentration of MC - LR was found at the surface in November 2018. San Antonio Reservoir had maximum concentration of MC -RR, and MC -LR at the surface on June 17th, 2019. The SVWTP TWR Eff had only one instance of detected MC – LF in Feb 2019 [Note: Per Millbrae Lab, the result is false positive. No independent validation was available at that time for the analytical methods developed in house. The Lab participated in proficiency studies and now the data compare well with sub-lab data]. LCS Reservoir had max concentrations of MC- LA in April 2019. The San Andreas Reservoir had max concentration of MC- LA at the surface water in March 2019 and HTWTP Raw had max concentration of MC-LA and LF in March 2019. From the data it is evident that the elevated concentrations of algal toxins mainly take place in spring/summer and in Fall. The occurrence frequency is summarized in Tables 5-3 and 5-4.

No Cyanotoxins Detected in SFPUC Drinking Water

HTWTP and SVWTP influent/effluents are monitored for the presence of algal toxins when they are online. So far toxins have not been detected in the treated effluents.

The results are summarized in Tables 5-3 and 5-4.

Figure 5-1(a). Algal Toxin Levels in East Bay Reservoirs (2018-2021)

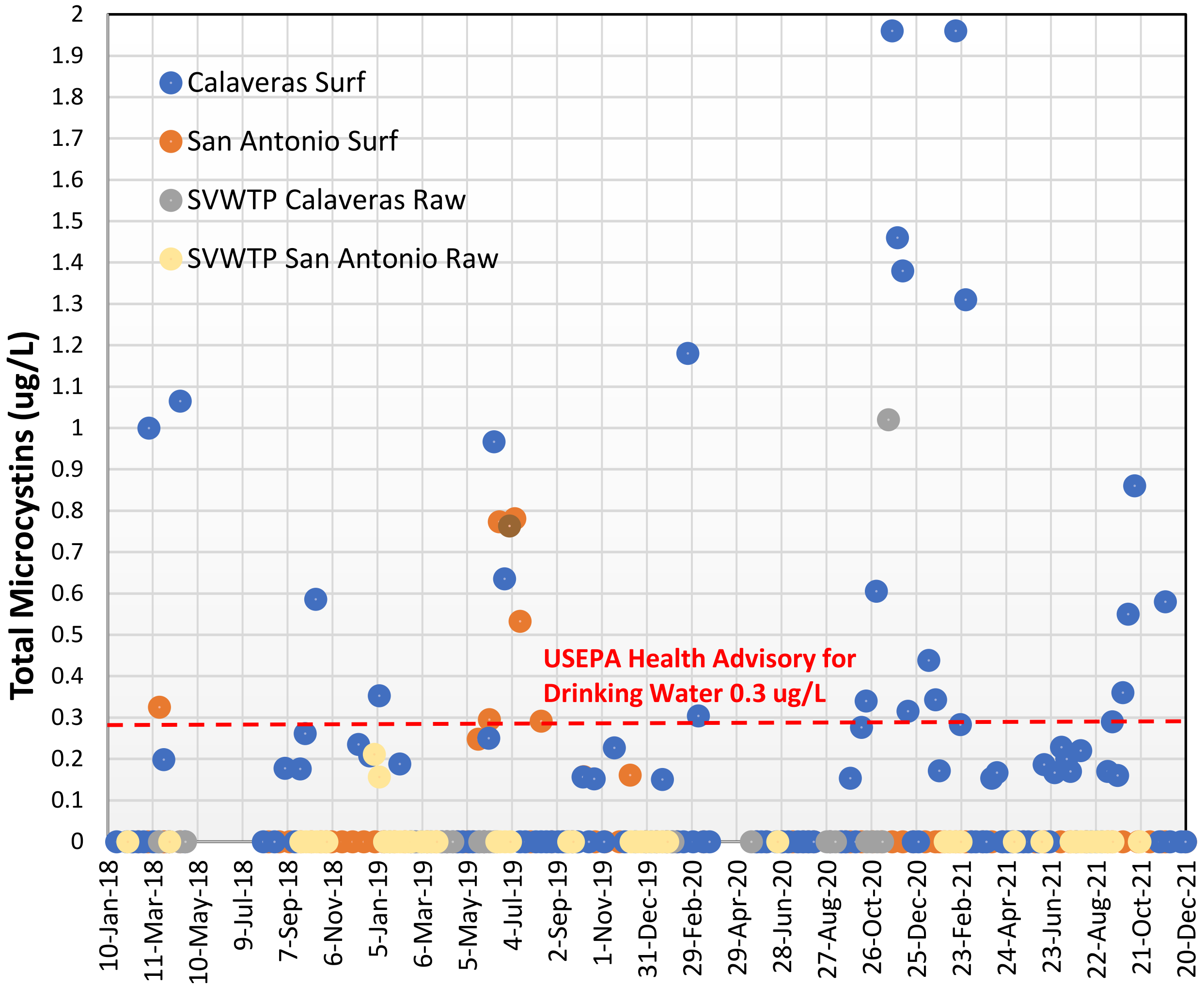


Figure 5-1(b). Algal Toxin Levels in SVWTP Eff TWR Drinking Water (2018-2021)

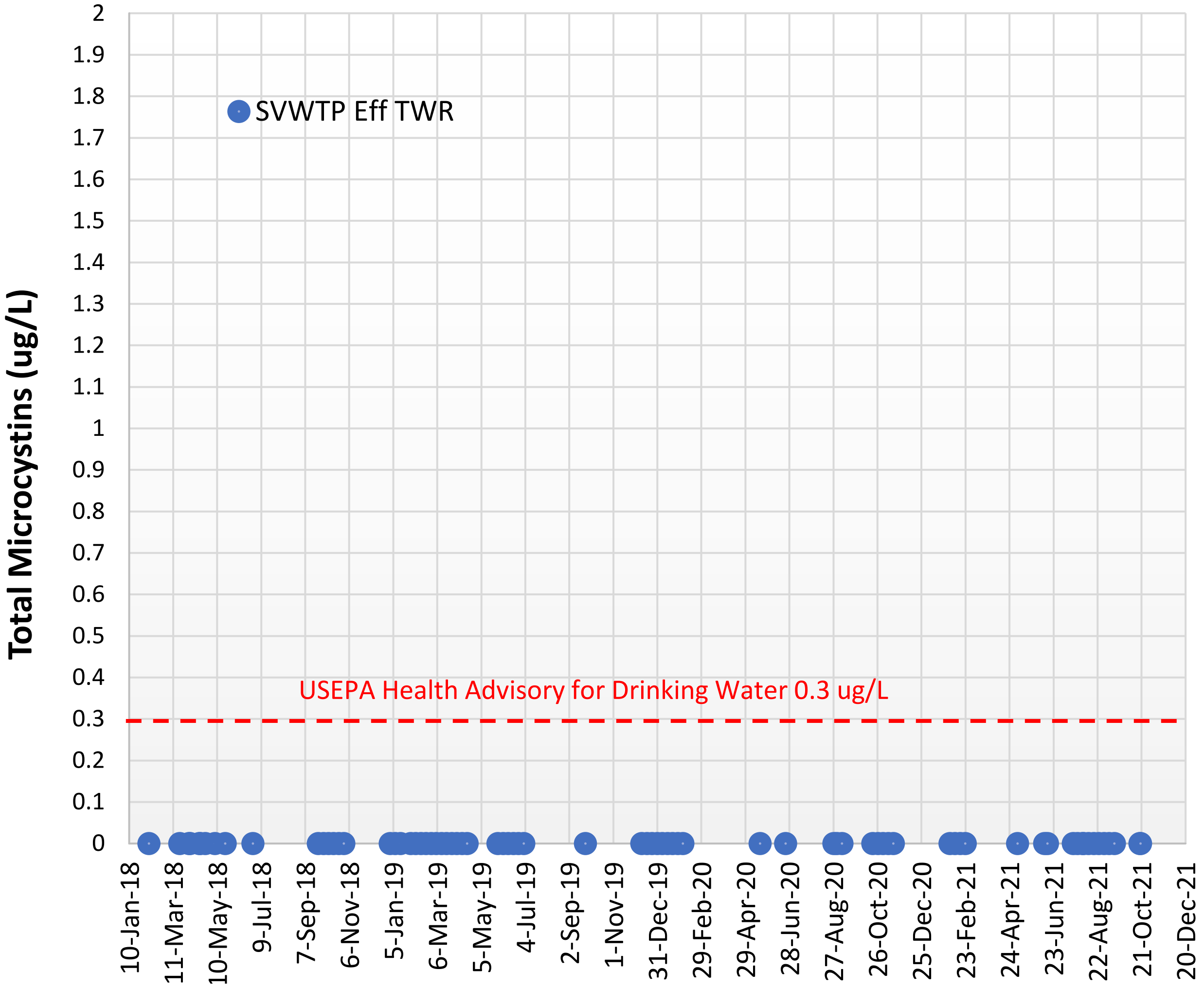


Figure 5-2(a). Algal Toxin Levels in West Bay Reservoirs (2018-2021)

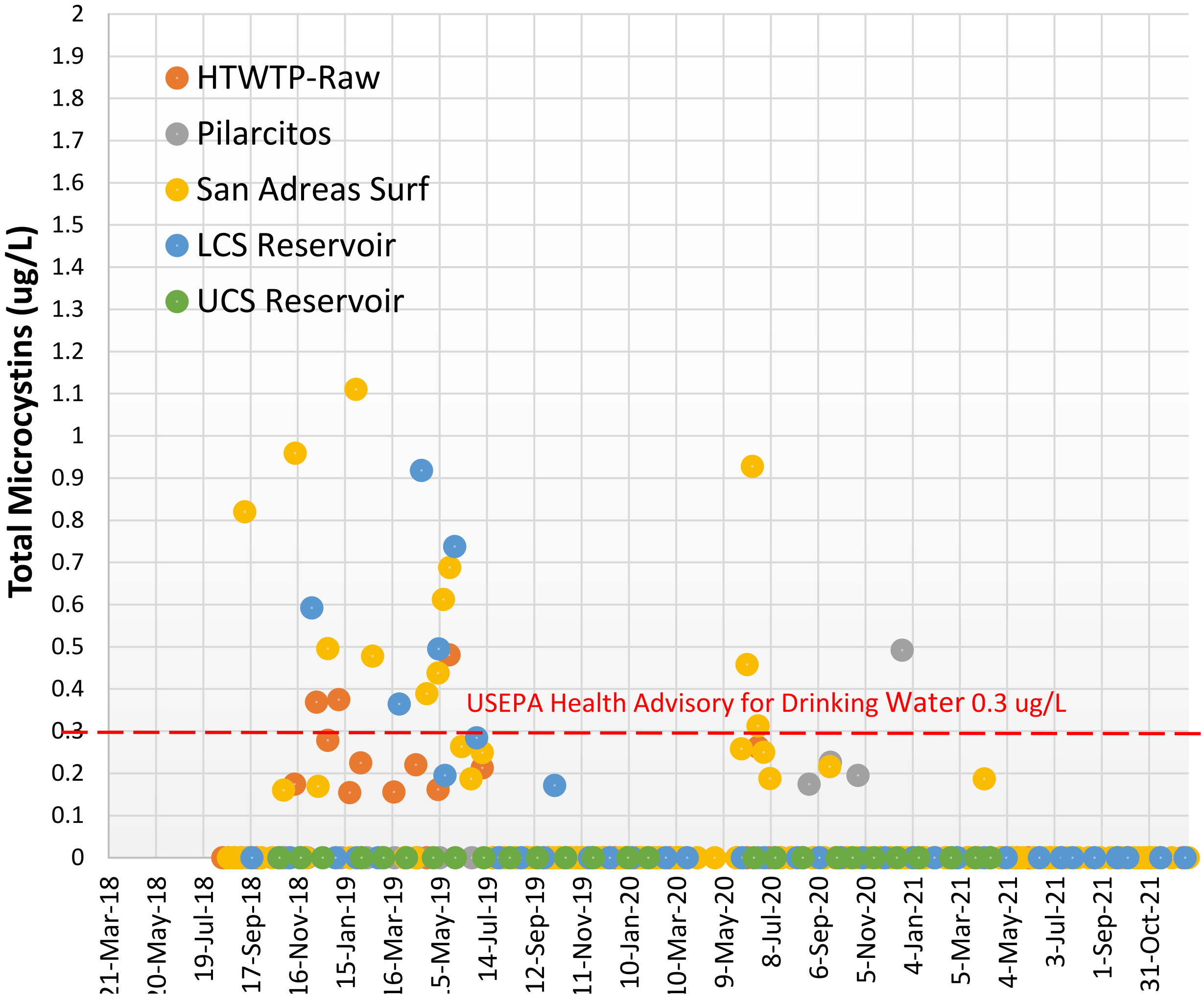
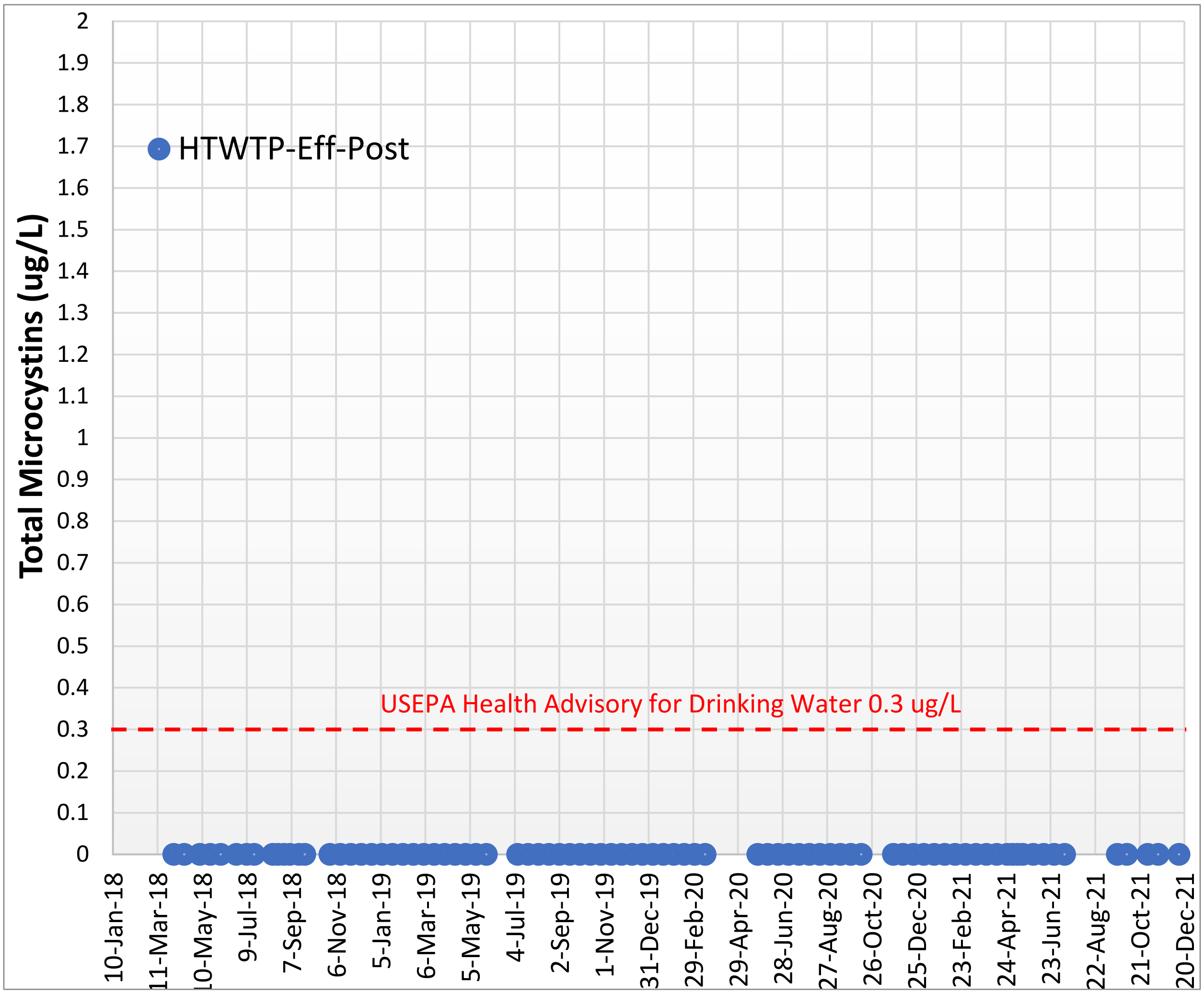


Figure 5-2(b). Algal Toxin Levels in HTWTP Eff Post Drinking Water (2018-2021)



The SVWTP treatment process train includes chemical addition, coagulation, taste and odor control with powdered activated carbon, mechanical flocculation, sedimentation with plate settlers, dual-media filtration, disinfection, and a 17.5-million-gallon treated water reservoir. Sodium hypochlorite is used as the primary disinfectant and chloramine is the secondary disinfectant. Sodium hydroxide is added to filtered water at the plant clearwell or between the chlorine contact tank and treated water reservoir to raise pH for corrosion control. The plant effluent is also fluoridated (2020 Watershed Sanitary Survey Update for the Alameda Watershed, Final report, 2021).

Preliminary algal toxin sampling was conducted at major SFRWS source water reservoirs and treatment plants in 2007 and 2010. Most measurements in raw waters were low or non-detect. This preliminary sampling was not designed to coincide with a major algal bloom and can be considered a “dry run”. SFPUC did not detect toxins in finished drinking waters.

From 2010 to 2015, phytoplankton levels (mainly blue-green algae) at Calaveras Reservoir increased approximately tenfold. This increase in phytoplankton levels could be related to drought and warmer temperaturesand/or due to an ongoing dam improvement project at Calaveras Reservoir requiring low water levels. SFPUC conducted 12 months of algal toxin monitoring at Calaveras Reservoir (August 2015 to August 2016) with subsequent follow-up monitoring to assess toxin occurrence and treatability at SVWTP. Monitoring included four toxins, including: microcystins, cylindrospermopsin, anatoxin-a, and saxitoxin (Olson et.al., 2016).

Initially, in 2015 the goals and desired outcomes were to evaluate the feasibility of algal toxin kits, increase the SFPUC database for algal toxins, and prepare a response plan for WTPs in case of cyanotoxin occurrence. In addition, customers may have questions regarding algal toxins and this evaluation and supporting data will help support communications with customers. SFPUC will be better prepared to respond in case of future algal blooms and concerns about algal toxins.

Table 5-2. Summary of Monitoring for Algal Toxins in SFPUC Water System from 2018 -2021 (Includes UCMR4 Monitoring Results from 2018-2020)

Location	Max Concentration (µg/L)								
	Microcystin-RR	Microcystin-YR	Microcystin-LA	Microcystin-LY	Microcystin-LR	Microcystin-LF	Anatoxin-a	Cylindro-spermopsin	Saxitoxin
Tesla Portal	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(5)
Alameda East	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(11)	(11)	(11)	(11)	(11)	(11)	(19)	(16)	(5)
Calaveras Res	0.189 (at 10 feet)	<0.5	5.36 (at 10 feet)	<1	3.35 (at surface)	<1	<0.01	<0.5	<1
(Data Points)	(154)	(154)	(155)	(154)	(154)	(146)	(154)	(151)	(99)
San Antonio Res	0.8 (at surface)	<0.5	<0.25	<1	0.87 (at surface)	<1	<0.01	<0.5	<1
(Data Points)	(136)	(136)	(136)	(136)	(136)	(130)	(136)	(131)	(99)
SVWTP Raw Calaveras	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(29)	(29)	(29)	(29)	(29)	(27)	(29)	(28)	(12)
SVWTP Raw San Antonio	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(43)	(43)	(43)	(43)	(43)	(41)	(43)	(43)	(17)
SVWTP EFF	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	N/A
(Data Points)	(2)	(2)	(2)	(2)	(2)	(1)	(2)	(2)	(0)

Location	**Max Concentration (µg/L)**								
	Microcystin-RR	**Microcystin-YR**	**Microcystin-LA**	**Microcystin-LY**	**Microcystin-LR**	**Microcystin-LF**	**Anatoxin-a**	**Cylindro-spermopsin**	**Saxitoxin**
SVWTP TWR EFF	<0.05	<0.5	<0.25	<1	<0.25	1.73	<0.01	<0.5	<1
(Data Points)	(55)	(55)	(55)	(55)	(55)	(48)	(60)	(56)	(24)
Irv Portal Meter 1	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(5)
Irv Potal Meter 2	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(12)	(12)	(12)	(12)	(12)	(12)	(13)	(10)	(5)
LCS Reservoir	<0.05	<0.5	3.53 (at surface)	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(23)	(23)	(23)	(23)	(23)	(20)	(25)	(24)	(37)
UCS Res North	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(16)	(16)	(16)	(16)	(16)	(16)	(16)	(14)	(29)
San Andreas Res	<0.05	<0.5	2.07 (at surface)	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(59)	(59)	(59)	(59)	(59)	(54)	(59)	(51)	(107)
Pilarcitos Res	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(17)	(17)	(17)	(17)	(17)	(14)	(17)	(15)	(27)

Location	Max Concentration (µg/L)								
	Microcystin-RR	**Microcystin-YR**	**Microcystin-LA**	**Microcystin-LY**	**Microcystin-LR**	**Microcystin-LF**	**Anatoxin-a**	**Cylindro-spermopsin**	**Saxitoxin**
HTWTP Raw	<0.05	<0.5	0.76	<1	<0.25	2.37	<0.01	<0.5	<1
(Data Points)	(48)	(48)	(48)	(48)	(48)	(42)	(47)	(47)	(76)
HTWTP Post	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(36)	(36)	(36)	(36)	(36)	(30)	(44)	(44)	(52)
SA2 Baden	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(12)	(12)	(12)	(12)	(12)	(12)	(20)	(16)	(5)
Sunset Line Baden	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(12)	(12)	(12)	(12)	(12)	(12)	(20)	(16)	(5)
Sunset Line-Casey	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(5)
Cry Spr Line#2 Casey	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(5)
Cry Spr Line#2 Baden	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(5)
UMO2	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(5)

Location	Max Concentration (µg/L)								
	Microcystin-RR	**Microcystin-YR**	**Microcystin-LA**	**Microcystin-LY**	**Microcystin-LR**	**Microcystin-LF**	**Anatoxin-a**	**Cylindro-spermopsin**	**Saxitoxin**
Sutro Res	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(5)
Sunset Res Out#2	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(4)
College Hill	<0.05	<0.5	<0.25	<1	<0.25	<1	<0.01	<0.5	<1
(Data Points)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(12)	(5)

*Per Millbrae Laboratory, the result is false positive. No independent validation was available at that time for the analytical methods developed in-house. The lab participated in proficiency studies and now they compare well with sub lab data.

Table 5-3. Summary of Total Microcystins Monitoring Results at Surface Samples in East Bay Reservoirs from 2018-2021 (Includes UCMR4 Monitoring Results from 2018-2020)

Reservoir	Year	# Data points (n)	>0.3 µg/L (n)	Max (µg/L)
Calaveras Reservoir	2018	28	9	23
	2019	38	3	0.97
	2020	38	10	4.11
	2021	50	15	6.03
San Antonio Reservoir	2018	18	1	0.33
	2019	29	4	0.78
	2020	21	0	<0.15
	2021	30	0	<0.15
SVWTP Raw Cal	2018	5	0	<0.15
	2019	13	0	<0.15
	2020	12	1	1.02
	2021			
SVWTP Raw San Antonio	2018	8	0	<0.15
	2019	23	0	<0.15
	2020	5	0	<0.15
	2021	19	0	<0.15
SVWTP TWR Eff	2018	17	0	<0.15
	2019	26	0	<0.15
	2020	15	0	<0.15
	2021	20	0	<0.15

Table 5-4. Summary of Total Microcystins Monitoring Results at Surface Samples in West Bay Reservoirs from 2018-2021 (Includes UCMR4 Monitoring Results from 2018-2020)

Reservoir	Year	# Data points (n)	>0.3 µg/L (n)	Max (µg/L)
UCS Reservoir	2018	3	0	<0.15
	2019	10	0	<0.15
	2020	9	0	<0.15
	2021	4	0	<0.15
LCS Reservoir	2018	5	1	0.6
	2019	16	4	0.92
	2020	11	0	<0.15
	2021	13	0	<0.15
San Andreas Reservoir	2018	12	3	0.96
	2019	37	7	4.24
	2020	37	3	0.93
	2021	34	0	<0.15
Pilarcitos Reservoir	2018	3	0	<0.15
	2019	11	0	<0.15
	2020	11	1	0.5
	2021	4	0	<0.15
HTWTP Raw	2018	11	1	0.37
	2019	24	2	0.48
	2020	20	0	0.26
	2021	22	0	<0.15
HTWTP EFF Post	2018	19	0	<0.15
	2019	24	0	<0.15
	2020	20	0	<0.15
	2021	22	0	<0.15

SFPUC Treatment and Multi-barrier Approach is Effective

The treatment is effective in removing algal toxins and monitoring results indicate no presence of algal toxins in finished drinking water.

The Harry Tracy Water Treatment Plant (HTWTP) is a direct filtration treatment plant comprised of primary disinfection and pre-oxidation with ozonation, coagulation, flocculation, filtration, and disinfection that treats water supplied from Crystal Springs Reservoir and San Andreas Reservoir before it is delivered to customers on the Peninsula and the City distribution system (SFPUC - AMMP, 2019).

Filter clogging algae such as diatoms have historically been the primary concern within the Peninsula system. Although elevated populations of diatoms in San Andreas Reservoir have led to shortened filter runs at HTWTP in the past, major modifications to the media and underdrains of all ten filters were completed in 2009, and five new and identical filters were brought online in 2015. Although there have not been any severe algal blooms since the filters were upgraded, HTWTP has been able to maintain normal water production while experiencing moderate algal blooms (SFPUC - AMMP, 2019).

The Toxin monitoring and response plan developed in 2018 (SFPUC, 2018) remains in effect for East Bay reservoirs. A conceptual engineering report for the addition of ozone treatment at SVWTP has been completed and has proceeded to the design phase. Ozone treatment in conjunction with the activated carbon system will combat taste and odor problems at SVWTP. Presence of ozone treatment prior to filtration at HTWTP provides removal of intracellular algal toxin if released during cell lysis due to oxidation process.

The reservoir treatment strategies to reduce algae level were continued by using Hypolimnetic Oxygenation System (HOS) and use of hydrogen peroxide-based algaecide in Calaveras Reservoir and San Antonio Reservoir (SFPUC - AMMP, 2019).

The Algae Monitoring and Mitigation Plan updated in June 2019 characterizes the historic limnologic profile of the system reservoirs, identifies lake management measures applicable to each reservoir, provides a monitoring plan for each reservoir, identifies response levels for key parameters, and summarizes potential health effects of algal toxins in drinking water (SFPUC, 2019).

Recommendations from SFPUC Recent Documents:

- Follow the updated Algae Monitoring and Mitigation Plan (AAMP) Update, SFPUC - 2019.
- No threat from algal toxins is posed to Hetch Hetchy water, Lake Eleanor, Lake Cherry due to low nutrients, low phytoplankton abundance and benign algal communities, hence no recommendation beyond monthly limnology monitoring of Hetch Hetchy and quarterly limnology monitoring of upcountry reservoirs – Lake Eleanor, Lake Cherry, and Priest Reservoir (SFPUC - AWSS, 2021).
- Continue the algae toxin monitoring program for Calaveras Reservoir, San Antonio Reservoir, SVWTP influent and finished water from SVWTP TWR effluent for MCs, cylindrospermopsin, saxitoxin at the frequency stated in 2020 Alameda Watershed Sanitary Survey (SFPUC – AWSS, 2021).
- Inspection and maintenance of the line diffusers of Calaveras and San Antonio Reservoirs is recommended, modified HOS system operations - maintain DO > 7 mg/L in the hypolimnion, if required the HOS can be operated intermittently depending on the DO levels between March 15th and December 15th of each year. At other times, HOS operations should be initiated if routine hypolimnetic DO readings fall below 5 mg/L, and the HOS should be shut down if DO conditions exceed 9 mg/L.
- Use of algaecide.
- Calaveras and San Antonio Reservoirs operations: (a) withdrawing water from deeper portions of the reservoir, (b) blending with Hetch Hetchy water and (c) isolating source water.
- SVWTP mitigation measures for algal toxins: (a) optimization of coagulant dose and flocculant aid dose, (b) suspension of pre-chlorination to avoid lysing of cells in the event of large blooms, (c) addition of powdered activated carbon (PAC) (when needed), (d) disinfection with free chlorine (preferably at pH<8), (e) change of source water, and (f) adjustment of adit depth in source water reservoir (SFPUC- AMMP, 2019).
- Continue monitoring the watershed raw water quality at the sampling locations- Upper and Lower Crystal Springs Reservoir, San Andreas Reservoir, Pilarcitos Reservoir, and HTWTP influent as per the frequency stated in the Peninsula Watershed Sanitary Survey (SFPUC – PWSS, 2020).

Recommendations from this Review

- Monitor for toxins using Cal OEHHA (2021) Interim Notification Levels or lower detection levels for some toxins to match interim NL. See Table 5-5 below. Interim NL are <u>lower</u> than current SFPUC detection levels for: mycrocystins, cylindrospermopsins, and saxitoxins.

Table 5-5. Comparison Between Cal. OEHHA (2021) Interim Notification Levels for Algal Toxins and Analytical Detection Levels in SFPUC StarLIMS

Algal Toxin	OEHHA Interim Notification Level (ug/L)	Current SFPUC Analytical Detection Level (ug/L)
Microcystins	0.03	0.15
Cylindrospermopsin	0.3	0.5
Anatoxin-a	4	0.01
Saxitoxins	0.6	1

Water Quality Division, Technical Review 2016 – 2021

Contaminants of Emerging Concern (CEC)

Algal Toxins

The nutrient over enrichment and excessive production of organic matter at the base of the food web, termed eutrophication, has led to undesirable biogeochemical and ecological consequences. The most obvious and troublesome is the overgrowth of noxious phytoplankton (i.e., “blooms”). The connection between excess nutrient inputs and Harmful Algal Blooms (HABs) has been broadly recognized in European and North American waters impacted by large-scale agriculture, industrialization, and urbanization. This troubling trend is now rapidly expanding in developing regions of Asia, Central and South America, Africa, Australia−New Zealand, and the Pacific Basin (Paerl et.al. 2018).

Microcystin (MC) and its congener (MCs) are naturally occurring cyclic peptides produced by strains of various species of cyanobacteria. One of the most common MCs, and the one most studied toxicologically, is MC-LR. MC-producing cyanobacteria are found primarily in freshwater environments, with a wide geographic and ecological distribution. As a result, MCs are the most commonly reported cyanobacterial toxins worldwide. Drinking-water is the most likely route of exposure to MCs. Recreational activities in lakes with cyanobacterial blooms may also be a relevant exposure pathway, potentially to high concentrations of MCs. Limited data suggest that MCs may also accumulate in some food items. Country- or region-specific assessments should consider whether recreation or food (e.g. fish eaten with viscera or shellfish from bloom-ridden water bodies) may significantly contribute to exposure (WHO, 2020).

Blue-green algae are commonly present in lakes and reservoirs in at least low levels. Composition and countchange seasonally as a function of water temperature, nutrient levels, and other factors (USGS, 2008).

Cyanobacterial blooms (when the algae biomass increases rapidly) can result in increased levels of cyanotoxins and aesthetic degradation of the water body (WRF, 2010). Blooms form in warm, slow-moving water that is rich in nutrients (such as from fertilizer runoff or septic tank overflows) and can occur at any time, but most often in late summer or early fall (CDC, 2010). SFPUC experience indicates occurrence in middle spring and early fall.

Occurrence and Health/Aesthetic Effects

Algal blooms caused by certain environmental conditions can produce toxins which can have harmful effect on human health, animals, aquatic life, recreational activities including swimming, commercial and recreational fishing (USEPA, 2021a). The algal toxins can impose economic impact causing increase in drinking water treatment cost, loss of revenue from recreational and tourism activities. Toledo, Ohio's 2014 algal toxin contamination even resulted in an estimated economic loss of $65 Million (Yeager et.al, 2018). Additionally, there will be an economic impact on population due to harmful effects on human health caused by consumption of seafood contaminated by algal toxins (Kouakou et.al 2019), skin contact with water containing cyanotoxins, inhaling or ingesting water containing cyanotoxin during swimming or recreational activities, and drinking water contaminated with algal toxins. Two categories of illness (digestive and respiratory) were considered for health costs. For digestive illness, costs were $86, $1,015, and $12,605, respectively, for mild, moderate, and severe cases. For respiratory illness, costs were $86, $1,235, and $14,600, respectively (Kouakou et.al 2019).

Cyanobacteria have often been associated with taste and odor problems, and therefore taste and odor are potential indicators of the presence of cyanobacteria. However, taste and odor issues are not solely caused by cyanobacteria(USEPA, 2012) and toxins can be present without the presence of taste and odor. The taste-and-odor compounds geosmin and MIB cause earthy/musty tastes and odors and are detectable by humans at concentrations between 5-10 ng/L. These compounds may be detectable in the environment before potential cyanobacterial producers are detected. The producer may be a relatively small component of the phytoplankton community. Taste-and-odor episodes caused by cyanobacteria have occurred even when cyanobacteria are not at detectable levels in the water column (USGS, 2008).

Some cyanobacteria cause taste and odor problems by producing compounds such as geosmin and 2-methylisoborneol (MIB) (AWWA, WRF, 2016).

Factors that promote cyanobacterial bloom formation and persistence include (USEPA, 2019):

- Extended periods of direct sunlight,
- Elevated nutrient availability (especially phosphorus and nitrogen),
- Elevated water temperature,
- pH changes,
- An increase in precipitation events,
- Calm or stagnant water flow, and water column stability/lack of vertical mixing.

Although bloom conditions in much of the U.S. are more favorable during the late summer, the interrelationship of these factors causes large seasonal and year-to-year fluctuations in the cyanobacteria levels. Some toxin-producing strains can occur early in the summer season while others are only found during late summer (USEPA, 2019).

The source of algal toxins is understood to be blue-green algal blooms that most often occur in late summer or early fall in warm, slow-moving water that is rich in nutrients and organic matter (Paerl, 2013). Watersheds with strong agricultural influences are the most impacted (Beaver, 2014). Microcystins and anatoxin-a are the most commonly detected algal toxins in California (SWRCB, 2019).

Climate change poses an additional challenge in predicting changes in HAB frequency, intensity, and proliferation. Global warming altered precipitation patterns, and sea level rise, accompanied by changes in ocean and lake circulation, stratification, and upwelling, wind speed, and cyclone frequency and intensity, play increasingly important roles in modulating HAB dynamics. Hydrologic modifications and climate change enable HABs to reach larger magnitudes and persist longer when accompanied by excessive nutrient loading (Paerl et al. 2018).

The two main types of toxins are (ADWG, 2021):

- Cyclic peptides (microcystins and nodularin). MCs cause damage to the liver and are possibly carcinogenic. Nodularin has an identical mode of action to MC in animals and is considered to present at least the same risk to human health as MC.
- Alkaloids (neurotoxins and cylindrospermopsin). Neurotoxins produced by cyanobacteria include anatoxin a, anatoxin a-s and the saxitoxins.

More than 80 MCs are identified to date, but only few occur frequently and in high concentrations. MC-LR is the most frequently occurring and most toxic MC congener. It is the only one for which enough toxicological data are available to derive a provisional guideline value. Frequently occurring cyanobacterial genera that may contain are MCs are Microcystis, Planktothrix and Dolichospermum (previously Anabaena) (WHO, 2017, EPA 2021e).

Table 5-6. Toxins Produced by Cyanobacteria (AWWA, WRF 2016)

Cyanobacteria Genus	Cyanotoxins Produced	MIB or Geosmin Producer
Microcystis	Microcystin	No
Anabaena	Anatoxin-a and microcystin	Geosmin
Aphanizomenon	Microcystin,anatoxin-a, and cylindrospermopsin	Geosmin
Cylindrospermopsis	Cylindrospermopsin	Anecdotal— MIB
Planktothrix	Microcystin	Geosmin
Psuedoanabeana	Microcystin and anatoxin-a	MIB and geosmin

Potential health concerns arise from exposure to the toxins through ingestion of drinking water, during recreation, through showering and potentially through consumption of algal food supplement tablets. Repeated or chronic exposure is the primary concern of the cyanotoxins; in some cases, however, acute toxicity is more important. Human fatalities have occurred through use of inadequately treated water containing high cyanotoxin levels for renal dialysis. Dermal exposure may lead to irritation of the skin and mucous membranes and possibly to allergic reactions (WHO 2017).

The harmful health effects of these cyanotoxins are well documented and may pose chronic or acute effect on liver, nervous and gastrointestinal system (AWWA, WRF, 2016). Types of cyanotoxins produced by blue-green algae include neurotoxins (affecting the nervous system), hepatotoxins (affecting the liver), and others (CDC, 2010). The most common exposures to algal toxins are from recreational activities but contaminated drinking water can be another route (drinking, inhalation while showering, etc). Health effects range from mild skin rash to serious illness or death (USEPA, 2012). Young children are more susceptible because they consume more water relative to their body weight (USEPA, 2015b).

The health effects are enumerated in Table 5-7.

Table 5-7. Health Effects of Toxins (AWWA, WRF 2016)

Toxin	Health Effects
Microcystin	Liver (possible carcinogen)
Anatoxin -a	Neurotoxin (nerve synapse)
Cylindrospermopsin	Liver and possibly kidney (genotoxic and carcinogen)
Saxitoxin	Neurotoxin (sodium channel blocker)

In a 2003 study published in AWWA Journal (AWWA 2007), 33 US water supplies were monitored for MC- LR. In raw waters, MC-LR levels ranged from ND to 5.65 µg/L. In treated waters, all levels were below the WHO guideline of 1 µg/L (i.e., a range of ND to 0.360 ug/L). A 2007 USEPA National Lakes Assessment of 1156 water bodies found that approximately 10% or 126 samples had MC concentrations greater than 1.0 µg/L (Beaver, 2014).

International occurrence studies have observed concentrations above the WHO guideline in treated drinking water. Althoughthe most common exposures to algal toxins occur during recreational activities in contaminated waters (USEPA, 2012), the risk associated with drinking water is not negligible.

Incident Report Map

The California SWRCB monitors the algal blooms in California and the information is available in the form of incident report map on their website on the lakes that have algal blooms. The incident report map can be accessed at https://mywaterquality.ca.gov/habs/where/freshwater_events.html

In 2016, CDC launched One Health Harmful Algal Bloom System (OHHABS) to inform public about the algal blooms and its harmful effects in which 18 States reported 421 harmful algal bloom events, 389 cases of human illness, and 413 cases of animal illness that occurred during 2016–2018. (Roberts et.al.2020). (https://www.cdc.gov/mmwr/volumes/69/wr/mm6950a2.htm)

A report published by the American Water Works Association (AWWA, 2016), “Cyanotoxins in US Drinking Water: Occurrence, Case Studies and State Approaches to Regulation”, provides detailed information on the algal blooms occurring at various parts of United States and the formation trends and the efforts taken by the utilities in different states to control the algal blooms.

US and International Regulations

From a regulatory perspective, USEPA has repeatedly included cyanotoxins in the final CCL4, and published two liquid chromatography–tandem mass spectrometry methods for cyanotoxin analysis, an important step towards regulating the algal toxins in the future. Cyanotoxins were not included in the first three UCMRs because cyanotoxin analytical methods were insufficient.

USEPA Health Advisories

The development of the new analytical methods, the listing of cyanotoxins on the final CCL4, the listing of total MCs, as well as six individual MCs (-LA, -LF, -LR, -LY, -RR, -RY), nodularin, cylindrospermopsin, and anatoxin-a in the final UCMR 4, all point to the probable development of maximum contaminant levels for MCs, cylindrospermopsin, anatoxin-a, and/or other cyanotoxins (Henrie et.al.2017).

In 2015, EPA developed Health Advisory for MC of 0.3 µg/L for bottle fed infants and pre-school children and, 1.6 µg/L for school-age children and adults, whereas Cylindrospermosin had Health Advisory of 0.7 µg/L for bottle fed infants and pre-school children and 3.0 µg/L for school-aged children and adults (USEPA, 2021a).

Four cyanotoxins - anatoxin-a, cylindrospermopsin, MCs, and saxitoxin are included in draft CCL5 (USEPA, 2021c).

California OEHHA Interim Notification Levels

In May 2021, the Office of Environmental Health Hazard Assessment (OEHHA) recommended an interim Notification Levels for saxitoxins – 0.6 µg/L, microcystins – 0.03 µg/L and cylindrospermosin – 0.3 µg/L, anatoxin-A of 4.0 µg/L in drinking waters until it completes its review based on recent toxicity study. Based on the study conducted, these four algal toxins are believed to cause -neurotoxicity (anatoxin-a and saxitoxin), spermatotoxicity (microcystin), and liver toxicity (cylindrospermosin) (California OEHHA, 2021).

Due to the growing concern over the presence of cyanotoxins in drinking water, the WHO published an addendum to its Guidelines for Drinking Water Quality in 1998, which included a guideline value for MC-LR, an acutely toxic cyanotoxin. The health-based guideline value for total (i.e., free plus cell-bound) concentration of MC-LR was set at 1 µg/L; however, the WHO emphasizes that the guideline value is only provisional, since it only pertains to MCLR, and since the toxicity data for other cyanotoxins are still being collected (WHO, 2017, Soltani et al. 2017). The provisional guideline value (GV) of 1 µg/L for 70-year lifetime consumption was retained in subsequent editions (WHO, 2017). The revised draft reaffirms the 70-year lifetime value of 1 µg/L and adds a short-term (about two weeks) GV of 10 µg/L (rounded from 12 µg/L). The recently proposed WHO guidelines are higher than the US and Canadian values. The major difference is that Canada and USEPA based their decisions on a 28-day study in rats, whereas WHO based its recommendation on a 90-day study in mice (Cotruvo, 2020).

Due to the potential for rapid scum formation at a cyanobacterial density of 100,000 cells per ml or 50 µg l-1 chlorophyll a (from scum-forming cyanobacterial taxa), intensification of surveillance and protective measures are appropriate at these levels. This guideline is for a moderate health alert in recreational waters (WHO,1999). WHO has published guideline values for cyanobacteria and chlorophyll-a in raw water that correspond to different alert levels (AWWA, 2007).

Australian drinking water authorities have set a guideline value of 1.3 µg/L for MCs, expressed as MCLR. New Zealand has developed Maximum Allowable Values (MAVs) for several cyanotoxins, including anatoxin and anatoxin-A, cylindrospermopsin, MCs, nodularin, and saxitoxins. The USEPA, on the other hand, has yet to set any firm, enforceable Maximum Contaminant Levels (MCLs) for cyanobacterial toxins, and has only added cyanobacteria and their toxins to its CCL, which prioritizes contaminants for setting MCLs. In Canada, a Maximum Acceptable Concentration (MAC) of 1.5 µg/L has been developed for cyanobacterial toxins expressed as MCLR. Canada’s guideline was derived using Tolerable Daily Intake (TDI) values, determined using No-observed Adverse Effect Levels (NOAEL), which are based on human or animal toxicity studies. Brazil has developed guidelines for three cyanobacterial toxins (MCs, saxitoxins, and cylindrospermopsin), with guideline values being set as 1.0 µg/L, 3.0 µg/L, and 15 µg/L, respectively. Several other countries still rely on the WHO provisional guideline of 1 µg/L MCLR (Soltani et al. 2017).

Drinking water standards for MC-LR similar to that of WHO have been set by other countries, including the Czech Republic, Singapore and Uruguay; Brazil, France and Spain, have also established drinking water standards of 1 µg/L, for all MCs. New Zealand has established provisional maximum acceptable values of 1 µg/L for MCs (as MC-LRequiv), 1 µg/L for cylindrospermopsin, 3 µg/L for saxitoxin (as equivalents), 6 µg/L for anatoxin-a, 1 µg/L for anatoxin-a(s), 2 µg/L for homoanatoxin-a and 1 µg/L for nodularin (Health Canada, 2021).

In the European Union, European Directives 1998/83/EC and 2013/397EU govern the drinking water legislation of the various member states, with the aim “to protect human health from the adverse effects of any contamination of water intended for human consumption by ensuring that it is wholesome and clean.” Despite the wide distribution of cyanotoxins in European bodies of water, the most recent EU Decision (2018/840) to update the substances of environmental concern for European Union does not specifically address cyanotoxins (Serra et.al. 2021).

A summary of international regulation on cyanotoxin is shown in Table 5-8.

Table 5-8. International Cyanotoxin Regulation Summary (AWWA, 2016)

	Microcystin[1] (µg/L)	**Cylindrospermopsin (µg/L)**	**Anatoxin-a (µg/L)**	**Nodularin (µg/L)**	**Saxitoxin (µg/L)**
Range	1 – 1.5	1 - 15	1 - 6	1	3
Number of countries with regulation or guidance [3]	16	2	2[2]	1	3

[1] Some of the guidance and regulation is for microcystin-LR, and others are for all microcystins. Countries include Australia, Brazil, Canada, Czech Republic, Denmark, France, Finland, Germany, Italy, Netherlands, New Zealand, Singapore, Spain, Turkey, Uruguay and South Africa.

[2] The Providence of Quebec, Canada limit is included, although it does not apply to all of Canada

[3] Excluding the US

TREATMENT

Treatment of Lakes, Reservoirs, and Ponds

Physical Approaches

Screens/barriers such oil screens, booms or curtains may be used to concentrate cyanoHABs that float on the surface, and subsequently remove them, or deflect them away from water intake points. The effectiveness of these barriers for removing cyanoHABs is difficult to quantify but they have been used to provide some level of protection for water supply intakes, e.g. in Lake Taihu, China during several *Microcystis* sp. Blooms. Ultrasonics high power ultrasound will destroy any organism in its power beam. It comes with relatively high energy costs. High frequency ultrasound can rupture the buoyancy regulating capacity of cyanobacteria but has very limited penetration through the water column. There is no evidence that low power, low frequency ultrasound works (Burford et al. 2019).

Chemical Approaches

A common practice for treating cyanobacterial blooms is through use of chemical treatment. A literature review conducted by Southern Nevada Water Authority points to the use of peroxide-based algaecide which provides immediate relief from algal blooms but leads to cell lysis causing toxins to release, which could have harmful effects on aquatic life. Hence, the author suggests controlling the blooms by strategizing nutrient control at watershed and using ozone application (Kibuye et.al. 2020).

Copper sulfate can be used in algae treatment. It breaks down algae, resulting in the release of algal toxins and odorous substances that decay over time. Hence, a withholding period is needed after copper sulfate has been used as an algicide, and it may be necessary to monitor copper residues, toxins, and odors during a follow-up period. Copper sulfate products should not be used to treat more than half of a lake or pond at one time, in order to avoid depletion of oxygen caused by decaying vegetation. One to two weeks should be allowed between copper sulfate treatments to allow water oxygen levels to recover. A limit of 2 mg/L has been established by Australian Drinking Water Guidelines based on health considerations and of 1 mg/L for aesthetic considerations for copper residues resulting from the use of copper sulfate (ADWG, 2021).

Mechanical Approaches

Use of mechanical and biological methods seem to be promising in controlling cyanobacterial blooms. Mechanical methods such as aeration and hypolimnetic oxygenation (HOS) has proved to provide long-term effect but could have limitation due to increase in water temperature impacting cold water habitat (Kibuye et.al.2021).

Biological Approaches

A range of bacterial, fungal and yeast products is under consideration as potential agents to control cyanoHABs, although their effectiveness requires verification. Some reviews suggest that there is little evidence of the effectiveness of these products. In accordance with a central tenant of microbial ecology, everything is everywhere and the environment selects, meaning that the microbes introduced via such products are likely already present within water bodies and the likelihood of those microbes proliferating and/or discouraging the growth of cyanoHABs will be a function of environmental conditions, not the introduction of the microbes (Kibuye et.al. 2021, Burford et al. 2019).

The most studied plant products that can potentially control cyanoHABs are barley and rice straw, with loosened, rotted straw being more effective than compact, fresh straw. There is some evidence that the polyphenol extracts released from straw, under the effect of sunlight, can produce hydrogen peroxide which can differentially suppress cyanoHABs, compared with eukaryotic algae. There is also some evidence to suggest that the straw supports the growth of fungi that secrete anti-microbial compounds that are active against cyanoHABs. There have been cases of suppression of all algal species, not just cyanoHABs, with barely straw, but success has been mixed. However, the method is relatively inexpensive and straightforward. It is most practical for use in small waterbodies. A range of other plant products have been tested, but studies are limited and much more work needs to be done before these may be applicable and cost effective at larger scales (Burford et al. 2019).

Fish introduction or removal can be used as a short-term method used to reduce nutrient concentrations, but do not replace the need for watershed nutrient reduction strategies. Removal of bottom-feeding, herbivorous fish can reduce resuspension of particles from the bottom and the associated nutrients. However, this may only be useful for shallow lakes and ponds where sediment derived nutrients are the largest source of nutrients to the system and where fish populations are very dense. Once these fish are removed, submerged aquatic plants can be established which can help reduce nutrient concentrations. Additionally, removal of fish species that feed on zooplankton can, in turn, increase zooplankton density and hence their grazing of primary producers, including cyanoHABs. However, this is not always effective because some zooplankton species will actively avoid eating cyanoHABs as they can be difficult to handle or digest, or in some cases they avoid cyanotoxins that may be produced. Alternatively, some fish may consume the cyanoHAB predators. Overall, although fish removal may be a useful short-term strategy, it is often not possible to achieve a stable, effective system in the longer term. Other factors of importance are insufficient fish removal or recovery of fish species that graze on zooplankton. Another method of potential cyanoHAB control involves the addition of filter-feeding fish which graze directly on algae and cyanobacteria. This method is suggested for highly productive lakes, e.g. subtropics and tropics, where zooplankton grazing is ineffective, in reducing bloom populations. Its success has been varied, however, possibly because the extra fish also produce a substantial nutrient load. Introduction of filter feeding mussels is another strategy to increase the grazing pressure on cyanobacteria (Burford et al. 2019).

Treatment of Algal Toxins at Water Treatment Plants

Conventional drinking water treatment (coagulation, flocculation, sedimentation, and filtration) is effective at removing algal cells and therefore algal toxins should be best confined within the cells (USEPA, 2015b). The best treatment approach is to remove the cells, intact and without damage, by sedimentation and filtration (WQRA, 2010). Chlorination or ozonation prior to filtration can cause cell lysis and release of cell-bound toxins (USEPA, 2015b; Fan, 2014).

For extracellular toxins (not cell-bound), free chlorine (post filtration) will remove > 80% of extracellular microcystins, but is ineffective for anatoxin-a (USEPA, 2015b). A study of 33 US water supplies indicated that existing water treatment processes were generally effective for microcystin removal (AWWA, 2007).

Treatment Effectiveness for the Removal of Cell-bound and Dissolved Cyanotoxins

Filtration and Oxidation

Water treatment processes can be highly effective in removing both cyanobacterial cells and MCs. As MCs almost always occur largely cell-bound, any drinking water treatment that removes particles i.e. soil, or riverbank filtration, flocculation and filtration or dissolved air filtration-controls them effectively if the process is optimized to target their removal. This also applies to the cell-bound fraction of other cyanotoxins. Process operation should avoid cell rupture and toxin release. Hazardously high concentrations of dissolved cyanotoxins appear to occur less frequently.

They are well removed by most types of activated carbon. Chlorination at pH <8 and ozonation are effective for the removal of many cyanotoxins at sufficiently high doses and contact times, but not very effective for saxitoxins. Potassium permanganate is effective for MCs, whereas limited or no data are available at present for other toxins. Chlorine dioxide and chloramine are ineffective for removing cyanotoxins (WHO, 2017). Pre-oxidation using ozone, pre-chlorination, permanganate can cause cell lysis releasing the toxins, hence a careful consideration needs to be given to the selection of oxidant, an appropriate dose, and a subsequent step to remove any dissolved toxins formed during the oxidation process. They are well removed by most types of activated carbon (WHO, 2017).

Complete removal of cyanotoxin could be a challenging process for conventional water treatment plants due to possibility of dissolved extracellular toxin passing through the treatment process. The potential regrowth of toxin-producing cyanobacteria in distribution pipelines and storage tanks also cannot be ruled out (Ponnusamy et.al. 2019).

Adsorption

Carbon is often used at WTPs to remove taste and odor (T&O) and other organic compounds, typically in the form of powdered activated carbon (PAC) and granular activated carbon (GAC). Research has demonstrated effective removal of microcystins using PAC or GAC, and more limited research on the removal of cylindrospermopsin, anatoxin-a, and saxitoxin has also exhibited promising results (USEPA 2016). PAC dosed after the initial oxidant exposure can be effective to sorb the released metabolite but requires sufficient exposure time and doses (Zamyadi et.al., 2021). Powdered activated carbon may be a more practical option for intermittent or emergency use, it is important to seek advice and carefully select the most appropriate type for toxin removal, as carbons vary significantly in performance for different compounds (ADWG, 2021).

Membranes

Although rare in the drinking water industry in fresh water applications, the “tighter”, high-pressure membranes, reverse osmosis (RO) and nanofiltration, are capable of removing extracellular cyanotoxins by a combination of size exclusion and charge effects, depending on the cyanotoxin molecule being removed (USEPA, 2016).

Biofiltration

Studies have demonstrated that biodegradation of a variety of cyanotoxins, including MCs, nodularin, cylindrospermopsin, and anatoxin-a can occur in some situations. The most effective way for water treatment plants to utilize biodegradation for cyanotoxins is likely by biological filtration processes, or biofiltration. Water treatment plants can consider if it is feasible to modify existing sand or GAC filters to make them biologically active and able to host microorganisms that are capable of degrading the cyanotoxins that are present in their source water (USEPA 2016).

Detection Methods

Cyanotoxin Monitoring

Cyanotoxin monitoring is most cost effective based on surveillance of source water for evidence of cyanobacterial blooms or bloom-forming potential (i.e. nutrient levels and phytoplankton species composition), with vigilance increased where such events occur. In contrast, monitoring finished water against target cyanotoxin concentrations is unsatisfactory for determining whether or not it is safe, because of the large variety of toxins (particularly of MCs), the lack of guideline values for all but one (i.e. MC-LR) against which to monitor and the lack of analytical standards for many. Analysis of cyanotoxins is particularly useful for validating and optimizing the efficacy of control measures such as riverbank filtration or treatment. A caveat in cyanotoxin analysis is the need for extraction of the cell-bound fraction from the cells; although this is easy to do, particularly for MCs, neglecting extraction from cells will lead to dramatic underestimation of concentration (WHO, 2017).

Analytical Methods

A range of commercially available immunoassay (ELISA) kits offer a rapid technique for screening and semi-quantitative measurement of toxins in cyanobacterial cell material and in water. Cyanobacteria are detected by light microscopy, identified using morphological characteristics, and counted per standard volume of water (ADWG, 2021). For drinking water, the EPA developed Method 544, a liquid chromatography/tandem mass spectrometry (LC/MS/MS) method for MCs and nodularin (combined intracellular and extracellular), Method

545, a LC-ESI/MS/MS method for the determination of cylindrospermopsin and anatoxin-a, and Method 546, an ADDA-ELISA method (USEPA 2019).

ELISA is Recommended for Total Microcystins Quantification

Antibodies isolated against a specific toxin or a specific group of toxins have been considered as the most promising screening method for cyanotoxins. The enzyme-linked immunosorbent assay (ELISA) is one of such methods that have been widely applied, due to its cost efficiency per sample, minimum sample processing and fast throughput. The USEPA has recommended ELISA for water treatment utilities as a primary analytical tool for the quantification of total MCs in raw and treated water (He et.al., 2017).

Microscopy Analysis

Microscopy analysis have been traditionally employed for the monitoring of cyanobacterial communities in waterbodies. Their use enables the taxonomic analysis of microorganisms present in a cyanobacterial bloom and the assessment of cyanobacterial relative abundance in a water ecosystem. The main disadvantage of this technique is the impossibility to distinguish between toxic and non-toxic cyanobacteria, not allowing the risk assessment of a bloom (Sanseverino et.al., 2017).

Physicochemical Methods

Physicochemical parameters including weather, nutrients availability or presence of photopigments can be used to evaluate the growth condition of phytoplankton in waterbodies (Sanseverino et.al., 2017).

Molecular-based Methods

Due to the high sensitivity of molecular based techniques, they enable the early warning of toxic cyanobacteria in water which can be detected a long time before the manifestation of cyanobacterial blooms, so representing a useful monitoring method. These molecular approaches include the Polymerase-Chain Reaction (PCR), the quantitative Real-time Polymerase Chain Reaction (qPCR) and the Desoxyribonucleic Acid (DNA) Microarray (DNA chips) (Sanseverino et.al., 2017).

On-line Probes

The use of spectral imaging of intracellular photosynthetic pigments for the detection of chlorophyll-containing algae and cyanobacteria has been recognized by fresh and marine water researchers for some time. Methods based on in-place monitoring of fluorescence of photosynthetic pigments have received support as a suitable tool for rapid estimation of cyanobacteria biomass at drinking WTP intakes. Chlorophyll-a measurements have long been used as a surrogate indicator of total phytoplankton values. Since cyanobacteria make up a portion of total phytoplankton, measurements of this pigment have also been utilized as a rough indicator of cyanobacteria density. Because of the limitations of chlorophyll-a as a diagnostic parameter for cyanobacteria, attention has been focused on phycocyanin for its standing as the most common photosynthetic accessory pigment to chlorophyll, and the most specific pigment present in cyanobacteria cells (Health Canada, 2021).

Phycocyanin fluorescence probe demonstrated its usefulness for monitoring cyanobacterial biovolume at the intake of a drinking WTP. Probe-measured phycocyanin fluorescence was significantly correlated with cyanobacterial biovolume, and values provided an appropriate warning of the potential for toxin-containing cells at the plant's intake. Two Quebec drinking WTPs known to be susceptible to blooms, further validated the success of phycocyanin probes for rapid assessment of the occurrence of cyanobacteria in drinking water sources. Since online methods for both pigments have shown individual success, it has been suggested that having both phycocyanin and chlorophyll-a probes in place in a drinking water intake would improve the accuracy of monitoring and management response for sources in which blooms from multiple types of phytoplankton are likely (Health Canada, 2021).

Adenosine triphosphate (ATP) analysis can provide new insight towards early detection and mitigation of cyanobacterial blooms. ATP is a molecule found in all living cells, integral to many metabolic processes such as storing and transferring of cells. Although ATP has been studied with respect to cyanobacteria, it has unrealized potential for rapid detection and optimized algaecide treatment of blooms. Luminescence-based ATP testing (using luciferase, an enzyme from fireflies) has become simple, quick to use (results within 5 min of sample collection) and inexpensive. While it has been deployed for distribution system monitoring, wastewater/reclaimed water characterization, biofiltration monitoring, and drinking water oxidation process assessment, its application in source water monitoring for detection and optimized treatment of cyanobacterial blooms warrants investigation. Furthermore, the recent availability of ATP online analyzers places this technology in a prime position for source and drinking water monitoring (Greenstein et.al. 2019).

Satellite Images

Satellite pictures of water bodies can be used for warning. Ohio EPA reviews satellite images to determine the algal blooms in drinking water and notifies water utility (AWWA, WRF, 2016).

A study was conducted using satellite images and the subset of UCMR4 quantitative response to determine the algal blooms at surface waters near drinking water intakes across United States. A subset of UCMR 4 qualitative responses in drinking water sources spanning March 2018 through November 2019 and corresponding satellite-derived cyanobacteria detect and non-detect measurements achieved an overall agreement of 94%. This demonstrates the utility of satellite imagery as a complement to ground-based measurements for assessing cyanobacterial occurrence at drinking water sources (Coffer et.al.2021).

RECOMMENDATIONS

USEPA Recommendations for PWS to Manage Cyanotoxins in Drinking Water.

USEPA recommends public drinking water systems (PWSs) to develop system-specific plans for evaluating their source waters for vulnerability to contamination by MCs and cylindrospermopsin. The recommendation provides a stepwise approach to PWSs to inform their decisions on whether and how to monitor and (or) treat for MCs and cylindrospermopsin and when and how to communicate with stakeholders.

The Stepwise Approach to Manage Cyanotoxins (USEPA 2015):

- Conduct a system-specific evaluation for vulnerability to blooms - evaluate source water characteristics, water quality parameters, source water assessment information, climate and weather information, land use, and nutrient levels.
- Prepare and observe potential blooms – seasonal variation, existing treatment evaluation, visual inspection and phytoplankton identification, bloom indicators such as presence of chlorophyll and phycocyanin, source water mitigation (intake relocation/ alternative source water).
- Determine whether cyanotoxins are present in the raw water and recommend communication and treatment activities if cyanotoxins are found in the raw water.
- Determine whether cyanotoxins are present in finished water and recommend communication and treatment activities if cyanotoxin are found; and
- Continue finished water monitoring, treatment, and communication activities if cyanotoxins are found in the finished water above acceptable levels.

The nutrient loads from sewage effluents and from watersheds, need to be controlled, as these are the main drivers causing algal blooms. The latter involves controlling erosion as well as the amount of manure and fertilizers spread in the watershed. Hydrological management actions such as water body mixing and flushing can render hydrophysical conditions less suitable for cyanobacteria and thus shift plankton species from cyanobacteria to others such as diatoms that are less relevant to human health. Drinking-water can usually be treated to acceptable levels by a well-run conventional treatment plant implementing coagulation, flocculation, filtration and chlorination; if this is not sufficient, ozonation and activated carbon filtration or addition of powdered activated carbon can be effective (WHO, 2017).

Need to Reduce Both Nitrogen and Phosphorus Input

Phosphorus (P) reductions have been traditionally prescribed exclusively for freshwater systems, while nitrogen (N) reductions were mainly stressed for brackish and coastal waters. However, because most systems are hydrologically interconnected, single nutrient (e.g., P only) reductions upstream may not necessarily reduce HAB impacts downstream. Reducing both N and P inputs is the only viable nutrient management solution for long-term control of HABs (Paerl et.al., 2018).

WHO Guidance on Multiple Barriers to Reduce Cyanotoxins

WHO provides guidance on multiple barriers to reduce cyanotoxin levels in water, including controlling nutrient loads from the watershed, managing water bodies, optimizing sites for drinking-water off-takes or recreation, applying drinking-water treatment to remove cyanobacteria and cyanotoxins, and providing information or warnings for recreational use of water bodies with blooms. This includes guidance on planning, managing, and documenting the measures used to mitigate cyanotoxin risks by developing a water safety plan (WHO, 2020).

Several literature reviews on algal bloom management fall along the same line as recommendations made by USEPA and WHO (listed above), suggesting monitoring water source, using alternate water source, optimizing treatment, communication to the respective stakeholders (Smith, 2019, Kibuye et.al. 2020).

USEPA is Required to Implement Strategy to Control HABs (Office of General Inspector USEPA, 2021)

The EPA does not have an agency wide strategy for addressing harmful algal blooms to reduce, mitigate, and control freshwater HABs. By creating an agency wide HAB strategy, the EPA can reduce HABs and their impacts on human health and the environment using the authorities and tools provided by the Clean Water and Safe Drinking Water Acts.

USEPA National Lakes Assessment

The EPA collects data about nutrient pollution and, in 2012, the EPA found in its National Lakes Assessment that about one in three lakes (about 33 percent) had excess nitrogen and two out of five lakes (40 percent) had excess phosphorus when assessed against regionally specific benchmarks determined by the EPA. In addition, the EPA estimated that about 15,000 water bodies were impaired by nutrients.

According to the EPA's 2012 National Lakes Assessment, 8.3 percent more lakes were in what the EPA defines as the "most disturbed condition," based on the density of cyanobacteria, than in the 2007 survey. The detection of microcystin, a cyanotoxin, also increased by 9.5 percent. Given these trends, the negative impacts of HABs and the risks of exposure to dangerous cyanotoxins will rise unless actions are taken to mitigate, respond to, and prevent freshwater HABs.

SDWA provides the EPA the authority to establish safe levels of contaminants in drinking water, or maximum contaminant levels. HAB events can occur in rivers, lakes, and reservoirs that serve as raw water sources for drinking water. While there is no federal mandate requiring comprehensive protection for these drinking water sources, drinking water utilities, the EPA, and states can engage in other efforts to protect them.

The Office of General Inspector USEPA 2021 Recommends (USEPA, 2021b):

1. To develop an agencywide strategic action plan, including milestones, to direct the EPA's efforts to maintain and enhance a national program to forecast, monitor, and respond to freshwater harmful algal blooms. This plan should incorporate strategies for:
    a. Identifying knowledge gaps.
    b. Closing identified knowledge gaps, particularly related to health risks from exposure to cyanotoxins in drinking water and during recreational activities.
    c. Monitoring and tracking harmful algal blooms.
    d. Enhancing the EPA's national leadership role in addressing freshwater algal blooms.
    e. Coordinating EPA activities internally and with states.
    f. Assessing the health risks from exposure to cyanotoxins in drinking water and during recreational activities and establishing additional criteria, standards, and advisories, as the scientific information allows.
2. Publish final numeric water quality criteria recommendations for nitrogen and phosphorus under the Clean Water Act for lakes and reservoirs and publish implementation materials to help states in adopting these criteria recommendations.

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6. Inorganics

This group refers principally to metals but can include other inorganic chemicals that may be of concern. The major source of trace (low-level) inorganics in drinking water is weathering of rocks (i.e., natural erosion), with additional potential sources from industrial discharges (e.g., electrical, defense, and mining facilities, drilling), atmospheric deposition into natural water bodies, electronics, ceramics, corrosion of pipelines, etc. (Kavcar et al., 2009; USEPA, 2009). Most water supplies contain trace amounts of inorganic compounds (MEC, 2017).

The following presents data and findings for: Boron, Chromium (VI), Cadmium, Cobalt, Germanium, Manganese, Molybdenum, Strontium, Vanadium, and Zinc.

MEDIUM PRIORITY FOR SFPUC

Significant levels of unregulated inorganics discussed here are not expected to occur in treated surface water due SFPUC's protected watersheds and manganese treatment.

Chromium (VI) and manganese occur in raw groundwater at levels of concern but are blended with surface water to reduce their levels to relatively low before serving to the customers. This new water source needs to be monitored and managed for these inorganics.

This section presents: (1) Screening Evaluation Table, (2) SFPUC Monitoring Review 2016-2021, and (3) Technical Review 2016-2021 of available scientific studies.

Table 6-1. Screening Evaluation Table for Inorganics

GENERAL INFORMATION ON CEC	
Instructions	This Screening Evaluation may be applied to a CEC group or an individual CEC. The purpose of this section of the Evaluation is to develop background information on the CEC or CEC group.
CEC Name	**Inorganics**
CEC Description Is CEC a group? If individual CEC, which group is CEC part of?	This group refers principally to metals and radionuclides but can include other inorganic chemicals that may be of concern. The major source of trace (low-level) inorganics in drinking water is chemical weathering of rocks (i.e., natural erosion), with additional potential sources from industrial discharges (e.g., electrical, defense, and mining facilities, drilling), atmospheric deposition into natural water bodies, electronics, ceramics, corrosion of pipelines,etc. (Kavcar et al., 2009; USEPA, 2009). Most water supplies contain trace amounts of inorganic compounds (MEC, 2017).
CEC Grouping What is the basis for grouping? *(Grouping factors are: common health effects, treatment, and analytical method, and/or compound co-occurrence)*	Inorganics is a group. The basis for the grouping is chemical class (e.g., metals) and common sources (e.g., industry or natural geology).
Examples and Indicators If group, what are notable examples? Are there possible indicator constituents? *(A suitable indicator occurs at quantifiable levels and may co-occur with other CEC, exhibit similar treatment and fate in environment)*	Examples of unregulated inorganics are below. Literature reviewed for this Screening Evaluation (see Supporting Information below) does not describe potential indicators for inorganics. The USEPA regulates several inorganics using MCLs and groups these metals under “Inorganic Chemicals” (USEPA,2009). CEC (unregulated) inorganics (include Mn and Zn have secondary MCL). Cd is regulated but state is considering revision to MCL. • Boron (UCMR, CA Notification Level, Draft CCL5) • Cadmium (USEPA and State MCL) • Chromium (VI) (an MCL of 10 μg/L has, again, been proposed by SWRCB) • Cobalt (CCL4, UCMR3, Draft CCL5) • Germanium (CCL4, UCMR4) • Lithium (Draft CCL5 and UCMR5)

	• Manganese (SMCL, CA Notification Level, CCL4, UCMR4, Draft CCL5) • Molybdenum (CCL4, UCMR3) • Strontium (CCL3, UCMR3) • Tungsten (Draft CCL5) • Vanadium (CCL4, CA Notification Level, UCMR3, Draft CCL5) • Zinc (SMCL)
Health Advisories Does CEC have a USEPA Health Advisory (e.g., Drinking Water Equivalent Level [DWEL]) or California Notification Level?	The following metals have CA Notification Levels (SWRCB, 2021a): • Boron – 1 mg/L • Manganese – 0.5 mg/L • Vanadium – 0.05 mg/L Please see Table 6-2 in monitoring review.
Regulatory Development Status Is CEC on USEPA Candidate Contaminant List (CCL), Unregulated Contaminant Monitoring Rule (UCMR) list, or California Public Health Goal (PHG) list?	Cr (VI) proposed California MCL of 10 µg/L was rescinded by SWRCB in 2017 after the court ruling. Hence, California does not have MCL for Cr (VI) yet, but the MCL for total Chromium is 50 µg/L, lower than USEPA's MCL at 100 µg/L. Regulations for Cr (VI) MCL is underway (SWRCB, 2021b). Recently the State has, again, proposed a Cr (VI) MCL of 10 µg/L (SWRCB, 2022). Boron, Cobalt, Lithium, Manganese, Tungsten, Vanadium are listed in draft CCL5 (USEPA, 2021b). Lithium is also listed in UCMR5 (USEPA, 2022). Cadmium is listed on the proposed priority for regulatory development by SWRCB. The current cadmium MCL and DLR are 5 µg/L and 1 µg/L, respectively. OEHHA has issued a PHG of 0.04 µg/L, based on kidney toxicity. U.S. EPA's MCLG for cadmium is 5 µg/L (SWRCB, 2022).

CONTEXT OF CEC EVALUATION AT SFPUC	
Instructions	The purpose of this section is to report SFPUC experience with the CEC or CEC Group, including occurrence data for each source water if available.
Purpose Why is evaluation undertaken? What is new about the issue that is considered 'emerging' (e.g., new chemical, new effect)?	Health studies continue to evolve and risk assessment may identify inorganics of concern that are not regulated in drinking water. Currently, several unregulated inorganics are on federal or state monitoring lists or have non-enforceable guidance levels.
Customer Interaction Widespread public concerns? Media coverage?	Currently there are no widespread public concerns or media coverage about unregulated inorganics in drinking water.
Expected Outcomes What are the likely benefits of the investigation to SFPUC and its customers?	Tracking occurrence and health studies of trace metals or other inorganics in drinking water will support improved understanding of the issue by SFPUC and should enhance communications and customer confidence.
Occurrence Data in US and SFPUC What occurrence information is available? Have detections, if any, been confirmed by follow-up sampling and/or QA/QC review?	Tables 6-3(a) and 6-3(b) in SFPUC monitoring review provide information on the occurrence data of inorganics in SFPUC surface water, groundwater, and drinking water. Inorganics monitored between 2016 – 2021 were Boron, Cr (VI), Cadmium, Cobalt, Germanium, Manganese, Molybdenum, Strontium, Vanadium, and Zinc.
Supporting Information List key references.	SWRCB, 2021b. Chromium-6 Drinking Water MCL. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/Chromium6.html SWRCB, 2022. Chromium 6 Drinking Water. Notice of Public Workshophttps://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/chromium6/notice_cr6wrkshp_040522.pdf

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DIAGNOSTIC QUESTIONS TO SUPPORT CEC PRIORITIZATION

Instructions	The purpose of the Diagnostic Questions is to determine whether the CEC or CEC group is significant to SFPUC drinking water and whether they merit further investigation and/or action. All answers require explanation except those clearly not applicable. The Diagnostic Questions are divided into Health, Occurrence, and Treatment sections. The more questions are answered with a “Yes”, the higher the probability that the CEC is a high priority or that a proactive approach should be taken.

HEALTH EFFECTS FROM SCIENTIFIC STUDIES

Question	**Answer**	**Explanation and Comments**
Is scientific knowledge on CEC health effects well developed?	**Yes**	For inorganics, the potential human health effects from long term exposure above the MCL are diverse and compound specific (USEPA, 2009). At low levels, (essential) metals in drinking water may provide a benefit with respect to dietary requirements (e.g., chromium, selenium) (Deveau, 2010). Please see Technical Review for discussion of health effects.
Based on current scientific understanding, does the CEC pose potential health risk at the levels typically found in drinking water in the US?	**No** **If Treated**	Concentrations of trace elements are more likely to be an issue in groundwater than in surface water, unless the area is impacted by mining. Metals reported to occur at concentrations above drinking-water benchmarks in untreated groundwater from some aquifers include manganese and the metalloid arsenic (arsenic is regulated) (USGS, 2019). Chromium (VI) is a developing concern and area of study.

Question	Answer	Explanation and Comments
Adverse health impacts observed in other drinking water systems? Are public health studies documenting human health impacts (disease or outbreaks) available?	**Yes**	One study of the impact of manganese in drinking water on school-age children IQ found that higher manganese was associated with lower IQ scores (medium manganese concentration in the study was 37 µg/L, with values ranging from 1 to 2,700 µg/L) (Bouchard, 2011). Adverse neurological effects of manganese have been reported (Brandhuber, 2022). The WRF Guidance for the treatment of manganese recommends that utilities set a target Mn concentration of 0.015 mg/L to avoid issues of precipitation and later mobilization in the distribution system (Brandhuber et al. 2013)
Existing regulations or guidelines outside of US (e.g.,WHO, EU)?	**Yes**	WHO has guidelines for metals as well as radionuclides (WHO, 2017). Per the European directives, the parametric values of the chemicals can be found at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020L2184 (EU, 2020). Some examples are Boron – 1.5 mg/L, Nickel – 20 µg/L, Manganese – 50 µg/L.
Existing US health advisories or CA notification levels?	**Yes**	See "Health Advisories" section above. Please see Table 6-2 in monitoring review.
Likely US regulation in the next 10 years? Is CEC on a regulatory development list, such as CCL? Is there a pending regulation or California PHG?	**Possible**	In 2013, the USEPA made a preliminary determination to regulate strontium and removed this chemical from the group of potential candidates for the CCL4; however no final regulatory determination has been released to date. Several metals have been listed in CCL5.
SUMMARY – SIGNIFICANT TO PUBLIC HEALTH IN GENERAL? *(Based on above answers)*	**Yes**	When present at elevated concentrations, some inorganics can be significant to public health e.g. Manganese, Chromium (VI), Strontium, Germanium.

OCCURRENCE

Question	Answer	Explanation and Comments
Is scientific knowledge on CEC sources/formation well developed?	**Yes**	Sources of trace metal inorganics are natural erosion and industrial wastes (Kavcar et al., 2009; USEPA, 2009, MEC, 2017).
CEC presence reported in other water supplies? Are occurrence studies available?	**Yes**	Inorganics can enter watersheds via air deposition from power plant air emissions and other sources. Throughout the country, air deposition is a common cause of mercury accumulation in fish tissue (mercury is regulated). As part of the National Water Quality Program (NWQP), groundwater quality is being characterized in 20 of the Nation's 68 Principal Aquifers. These 20 aquifers supply most of the groundwater used in the United States—they account for more than 75% of the groundwater for public supply and 85% of the groundwater for domestic supply. Among the aquifers, from 3 to 50% of samples contained at least one inorganic constituent that exceeded a benchmark. Those constituents were primarily the trace elements arsenic, fluoride, manganese, and strontium. At least one radioactive constituent, which also have geologic sources, exceeded a human-health benchmark in a small percentage of samples up to 12% in most of the aquifers studied (USGS, 2021a). Wildfires have been observed to increase levels of regulated and unregulated metals in down watershed surface waters for several months after the event (Smith, 2011). Concentrations of hundreds of mg/L have been observed, far in excess of guideline values, not at SFPUC. A wildfire impacting the watershed could result in temporarily increased levels of unregulated metals in SPFUC source waters.
CEC present in SFPUC watersheds and/or source waters? Are there complex issues involved in managing the CEC; e.g., point vs. non-point sources?	**Yes** **Only Trace Levels**	Monitoring of SFPUC surface waters indicateslow concentrations of several unregulated inorganics, which are naturallypresent in the environment and levels will vary based on local geology. Elevated metals concentrations are not a water quality problem for SFPUC surface water as watersheds are not affected by wastewater discharges, industrial pollution, or agricultural runoff. East Bay Reservoirs were monitored for the presence of Zinc and Mn during Santa Clara Unit fire in Aug-Sep 2020. Zn was below USEPA DWEL and SMCL, whereas there were 9 occurrences of Mn above SMCL. Overall levels after the fire were within range for surface water.

Question	Answer	Explanation and Comments
Is the CEC a potential groundwater contaminant?	**Yes**	Please see above – CEC presence in other water supplies. Boron, Cadmium, Cobalt, Molybdenum, Strontium, vanadium and zinc were below available health guidelines. Elevated concentrations of Chromium (VI) and Manganese are observed in Regional and City Wells that require blending.
If the CEC is a potential groundwater contaminant, is it highly mobile in the subsurface? *Is* the CEC low-sorbing and resistant to microbial degradation?	**Yes/No**	Mobility of trace metals and inorganic ions varies depending on soil chemistry and ion properties. Trace metals present in water and groundwater occur as ions (e.g., SeO_3^{2-} and CrO_4^{2-}) which can sorb to charged soil surfaces. Because soil particles are predominantly negatively charged, positively charged metal ions and complexes are more likely to sorb and therefore be less mobile (USEPA, 1992). Concentrations of trace elements are more likely to be a problem in groundwater than in surface water, unless the area is impacted by mining. Change in geochemical conditions, such as pH and redox, due to slow movement of groundwater along a flowpath from recharge to discharge can affect the release of metals into the groundwater (USGS, 2019).
Precursor present in SFPUC source waters? *(Including surface waters and groundwaters)*	**No**	Generally, there are no "precursors" for inorganics. Interaction with aquifers for groundwater.
Formed or added during current SFPUC treatment? If so, describe whether the formation or addition of CEC can be controlled.	**No**	Metals are impurities of treatment chemicals. At trace levels, metals will be introduced. SFPUC's Chemical Quality Control Program confirms that these impurities are at very low, acceptable levels by conducting tests on chemical deliveries. Available evidence from monitoring indicates inorganics reviewed here are not added during treatment at SFPUC.
Formed or added within SFPUC storage or distribution? If so, describe whether the formation or addition of CEC can be controlled.	**No**	In the same manner that lead and copper may occur in distribution and tap water from corrosion of pipelines, unregulated trace metals could also potentially be added during storage or distribution from pipe corrosion. Available evidence from monitoring indicates inorganics reviewed here are not added within SFPUC storage or distribution. Corrosion control treatment is optimized in SFPUC distribution pipes.

Question	Answer	Explanation and Comments
Detected in SFPUC drinking water?	**Yes/No** **Only Trace Levels or Not Detected**	Based on conducted monitoring, all results for Boron, Cadmium, Chromium (VI), Manganese, Molybdenum, Strontium, Vanadium, and Zinc were below health guideline values for drinking water.
SUMMARY – OCCURRENCE IN SOURCE AND DRINKING WATER? *(OR SIGNIFICANT POTENTIAL TO OCCUR)* *(Based on above answers)*	**Yes - Source Water** **No - Drinking water**	No guideline values were available for Cobalt and Germanium, but all results were below method detection limits. Source waters contain only traces of inorganics except for seasonally varying levels of manganese in East Bay and Peninsula sources. Groundwater contains levels of Cr (VI) and manganese that require treatment at the well or blending with source water. No concerns for other inorganics discussed here and in drinking water (see above).
TREATMENT		
Is scientific knowledge on CEC treatment/removal well developed?	**Yes**	Trace metals can be removed from drinking water using adsorbents (Naeem etal., 2007). There is also removal during oxidation and conventional treatment. Removal of Cr (VI), manganese, and strontium is well researched (WRF, Najm, 2016).
Likely to pass through current treatment for Hetch HetchySupply? Describe any complex issues involved with the treatment/ removal of CEC.	**Yes** **But not Present**	Tesla Water Treatment Facility provides treatment via primary disinfection using UV treatment and chlorine (no conventional filtration).The treatment does not target metals. Very low levels (trace or not detected) were observed in Hetch Hetchy supply.
Likely to pass through current treatment at SVWTP? Describe any complex issues involved with the treatment/removal of CEC.	**No for Mn** **Yes for Other** **But Not Present**	SVWTP has a conventional treatment process (i.e., coagulation, flocculation, sedimentation, and deep bed anthracite/ sand filtration), primary disinfection with free chlorine, followed by chloramine. Treatment removes manganese. Treatment does not target other inorganics but may remove some during conventional treatment. Inorganics monitored in SVWTP drinking water during 2016-2021 were well below the USEPA DWEL/CA NL/CA MCL/CA SMCL.

Question	**Answer**	**Explanation and Comments**
Likely to pass through current treatment at HTWTP? Describe any complex issues involved with the treatment/removal of CEC.	**No for Mn** **Yes for Other But Not Present**	HTWTP has a direct filtration treatment process (i.e., coagulation and deep bed anthracite/sand filtration), preceded by pre-ozone oxidation, and followed by primary disinfection with free chlorine. Ammonia is added to convert free chlorine to chloramine. Treatment does not target other inorganics but may remove some during filtration. Treatment removes manganese. Inorganics monitored in HTWTP drinking water during 2016-2021 were well below the USEPA DWEL/CA NL/CA MCL/CA SMCL.
Likely to pass through current treatment for groundwater? Describe any complex issues involved with the treatment/removal of CEC.	**Yes for Mn and Cr (VI)**	Groundwater treatment will include chlorination and other chemical addition steps with no filtration. For some wells, iron and manganese treatment is planned and this may also reduce concentrations of other trace inorganics.
SUMMARY – LIKELY TO PASS (NOT REMOVED BY) CURRENT TREATMENT? *(Based on above answers)*	**No Source Water** **Yes Groundwater**	SFPUC treatment removes manganese. Groundwater treatment will have to be installed for regional wells and blended with treated source water in San Francisco.
CEC PRIORITIZATION – CURRENT ASSESSMENT		
Instructions	This section prioritizes the CEC based upon the information developed in the above Diagnostic Questions as well as in the background information. For top priorities (high and medium priorities), monitoring and/or mitigation measures should be developed if feasible and justified. For low priorities, the CEC will not warrant action items beyond continued source protection and tracking of new information.	
Could CEC occur in SFPUC drinking water at levels of possible health significance? *(Based on above Diagnostic Questions)*	**POSSIBLE** To date evaluated inorganics did not occur at levels of concern in SFPUC treated drinking water based on monitoring conducted by SFPUC. Chromium (VI) and manganese are present in groundwater and could occur at levels of concern if not treated and blended.	

CEC Prioritization for SFPUC	**MEDIUM PRIORITY FOR SFPUC**
High, Medium, or Low. Provide explanation. *(A high number of "Yes" answers to the Diagnostic Questions indicates a higher priority, and "No" or very few "Yes" answers indicates a lower priority.)*	Significant levels of unregulated inorganics discussed here are not expected to occur in treated surface water due to SFPUC's protected watersheds and manganese treatment. Cr (VI) and Mn occur in groundwater at levels of concern. This new water source needs to be monitored and managed for these inorganics.
Previously Implemented Actions Indicate the progress and results of any action items, above, such as implemented in previous cycles of CEC review. Evaluate whether changes to the action plan are required.	• Between 2016 – 2021 SFPUC conducted comprehensive monitoring for Cr (VI) and Mn system-wide. This is an on-going program associated with start-up of groundwater wells. • Maintained source water protection. • Continued Chemical Quality Control Program. • Performed UCMR4 mandatory monitoring for germanium and manganese, 2018- 2020. Results presented in 2019 CEC update report.
Recommended Actions Does the situation merit investing additional resources or has the information gathered so far fulfilled due diligence? Actions could include monitoring and other measures (specified by source water, if necessary).	• Continue groundwater monitoring for Cr (VI) and Mn. • Continue blended water monitoring for Cr (VI) and Mn in San Francisco. • Evaluate/implement treatment for Cr (VI) and Mn in Regional Wells. • Continue the Chemical Quality Control Program (October 2010) at water treatment plants to minimize impurities in treatment chemicals (e.g. metals). • Monitor inorganics listed in UCMR5 and draft CCL5 (Lithium). • Continue to maintain source water protection and optimized multibarrier water treatment and distribution system operation. • Track information on any Federal and State regulatory developments, especially for Cr (VI) in groundwater.

This evaluation was prepared based on available information (peer-reviewed literature and occurrence data) with the purpose of prioritizing work and informing the public on unregulated CECs. This evaluation will be updated every 6 years or when significant new research or occurrence data on CECs become available that may warrant changing priority and recommendations.

Water Quality Division, Monitoring Review 2016 – 2021

Contaminants of Emerging Concern (CEC) in Drinking Water

Inorganics

SFPUC has been monitoring inorganics listed in previous Federal lists UCMR3 and UCMR4, as well as CCL3 and CCL4, and chromium (VI) due to concerns about this metal and MCL proposed (since rescinded and currently under revision) by the State of California. The list of inorganics is presented in Table 6-2, including Federal and California MCL, SMCL, PHG, and guidance values DWEL, HBSL, NL.

UCMR5 includes lithium that has not been previously monitored. Draft CCL5 includes cobalt, lithium, manganese, tungsten and vanadium.

Table 6-2. Inorganics Listed by USEPA and State of California: (MCL, SMCL, PHG), Drinking Water Guideline Values (DWEL, HBSL, NL), Monitoring UCMR3, UCMR4, UCMR5, CCL3, CCL4, Draft CCL5

Inorganic	USEPA			CA STATE			USGS	Comments
	MCL	SMCL	DWEL	MCL	CA NL	PHG	HBSL	
	mg/L							
Boron			7		1		5	Draft CCL5
Cadmium	0.005		0.02	0.005		0.00004		Regulated
Chromium (VI)				0.01*		0.00002	0.02	CA MCL Pending
Cobalt								CCL4, UCMR3, Draft CCL5
Germanium								CCL4, UCMR4
Lithium							0.01	Draft CCL5 and UCMR5
Manganese		0.05	1.6		0.5		0.3	UCMR4 and Draft CCL5
Molybdenum			0.2				0.03	CCL4, UCMR3
Nickel			0.7	0.1		0.012		Not reviewed as CEC
Strontium			20				4	CCL3, UCMR3
Tungsten								Draft CCL5
Vanadium					0.05			CCL4, UCMR3, Draft CCL5
White Phosphorus			0.0005					Not reviewed as CEC
Zinc		5	10				2	Not reviewed as CEC

*CA MCL of 0.01 mg/L was rescinded in 2017 (recently reproposed – March 2022)
SMCL – Secondary Maximum Contaminant Level

The following monitoring programs were utilized to monitor inorganics:

- Annual Title 22 monitoring system-wide: boron, cadmium, chromium (VI), cobalt, manganese, molybdenum, strontium, vanadium, zinc,
- Regional and City groundwater wells: boron, cadmium, chromium (VI), manganese, strontium, vanadium, zinc,
- Blended drinking water in San Francisco, primarily in Sunset South and North Reservoir Outlets, Sutro Reservoir outlet, and other City locations, to evaluate concentrations after blending of groundwater with surface water: boron, chromium (VI), manganese, zinc,
- UCMR4 drinking water: germanium, manganese,
- Operations support for surface water treatment, Tesla Raw, SVWTP and HTWTP influent and effluent: manganese,
- Special sampling by WQD for various purposes: boron, cadmium, chromium (VI), cobalt, manganese, molybdenum, strontium, vanadium, zinc.

Table 6-3(a) presents the summary statistics for inorganics in groundwater and drinking water for SFPUC system in the most recent monitoring time frame 2016 – 2021. Tables 6-4 – 6-13 contain all inorganics data for this evaluation and can be consulted regarding specific location and variability in time.

Concentrations of Inorganics in SFPUC Drinking Water, 2016 – 2021

Based on conducted monitoring, all results for boron, cadmium, chromium (VI), manganese, molybdenum, strontium, vanadium and zinc were below published USEPA and State of California health guideline values for drinking water. No guideline values were available for cobalt and germanium but all results for these two inorganics were below method detection limits.

Blending of groundwater and surface water in San Francisco was effective in controlling concentrations of chromium (VI) below proposed California MCL of 10 μg/L in drinking water. The San Francisco Groundwater (SFGW) operations plan targets a blend Cr (VI) concentration of 4 μg/L.

Groundwater is not served directly to customers without blending/treatment. Concentrations of chromium (VI) and manganese in groundwater require blending in the City. Continuing monitoring for these metals is recommended at locations and frequencies provided in Tables 6-6 and 6-9. Chromium (VI) is monitored at Sunset and Sutro Reservoirs, which receive blended groundwater. The results are posted at Groundwater | SFPUC.

Table 6-3(b) presents the summary statistics for inorganics in surface water for SFPUC system in the most recent monitoring time frame 2016 – 2021, as well as special surface water sampling after East Bay Fire. This is provided for information only. Manganese and zinc concentrations after the fire ranged within the range for surface water.

Table 6-3(a). Summary Statistics of Inorganics Monitoring in SFPUC Groundwater and Drinking Water, 2016 -2021

	USEPA				CA State			Groundwater				Drinking Water				Number of Results in Drinking Water > Guidelines
	MCL	SMCL	DWEL	HBSL	MCL	NL	PHG	n	50	90	Max	n	50	90	Max	
									Percentile				Percentile			
Inorganic	µg/L							#	µg/L			#	µg/L			
Boron			7000			1000		47	52	481	649	25	26	117	203	None (Table 6-4)
Cadmium	5		20		5		0.04	108	<0.5	<0.5	<0.5	117	<0.5	<0.5	<0.5	None (Table 6-5)
Cr (VI)					10		0.02	462	**14**	**25**	35	766	0.14	0.56	1.51	None* (Table 6-6)
Cobalt								5	<1	<1	<1	18	<1	<1	<1	None (Table 6-7)
Germanium								Not Sampled				55	<0.3	<0.3	<0.3	None (Table 6-8)
Lithium				10				Not Sampled				Not Sampled				
Manganese		50	1,600	300		500		267	2	**25**	452	1247	2	4	50	None (Table 6-9)
Molybdenum			200					5	<1	<1	2.22	9	<1	<1	1.03	None (Table 6-10)
Strontium			20,000	4,000				106	218	996	1690	34	25	203	242	None (Table 6-11)
Tungsten								Not Sampled				Not Sampled				
Vanadium						50		37	5	7	7	21	<1	<1	<1	None (Table 6-12)
Zinc		5,000	10,000					81	3	18	31	118	<2	<2	9	None (Table 6-13)

HBSL - USGS/USEPA Nonregulatory Health Based Screening level

* Excluding CA PHG for Cr(VI)

Table 6-3(b). Summary Statistics of Inorganics Monitoring in SFPUC Surface Water and Special after East Bay Fire, 2016 -2021

	Surface Water				Special East Bay Fire Surface Water			
	n	50 Percentile	90 Percentile	Max	n	50 Percentile	90 Percentile	Max
Inorganic	#	µg/L			#	µg/L		
Boron	86	16	787	1740	Not Sampled			
Cadmium	88	<0.5	<0.5	<0.5	Not Sampled			
Cr (VI)	85	0.035	0.12	0.21	Not Sampled			
Cobalt	15	<1	<1	1.99	Not Sampled			
Germanium	Not Sampled				Not Sampled			
Lithium	Not Sampled				Not Sampled			
Manganese	792	6	18	477	71	9	66	260
Molybdenum	14	<1	1.22	1.5	Not Sampled			
Strontium	79	58	392	623	Not Sampled			
Tungsten	Not Sampled				Not Sampled			
Vanadium	35	<1	2.3	7	Not Sampled			
Zinc	57	<2	2.4	6	71	<0.37	1.4	7

Table 6-4. Boron SFPUC Monitoring Results, 2016-2021

Rasprojectno_(Project_ID)	ClSampNo	Date	Boron, B µg/L
Surface Water Hetch Hetchy			
T22_ANNUAL_RUNS	HHR	2016-06-15	9.91
T22_ANNUAL_RUNS	HHR	2017-06-19	<5
T22_ANNUAL_RUNS	HHR	2018-06-18	<5
T22_ANNUAL_RUNS	HHR	2019-06-18	9.64
T22_ANNUAL_RUNS	HHR	2020-06-16	<5
T22_ANNUAL_RUNS	HHR	2021-07-14	<7
T22_ANNUAL_RUNS	CHERRY_RES	2016-06-13	<5
T22_ANNUAL_RUNS	CHERRY_RES	2017-06-26	<5
T22_ANNUAL_RUNS	CHERRY_RES	2018-06-18	<5
T22_ANNUAL_RUNS	CHERRY_RES	2019-06-18	5.93
T22_ANNUAL_RUNS	CHERRY_RES	2020-06-17	<5
T22_ANNUAL_RUNS	CHERRY_RES	2021-07-01	<7
T22_ANNUAL_RUNS	CHERRY_CREEK	2016-06-14	<5
T22_ANNUAL_RUNS	CHERRY_CREEK	2017-06-26	<5
T22_ANNUAL_RUNS	CHERRY_CREEK	2018-06-18	<5
T22_ANNUAL_RUNS	CHERRY_CREEK	2019-06-19	6.2
T22_ANNUAL_RUNS	CHERRY_CREEK	2020-06-24	<5
T22_ANNUAL_RUNS	CHERRY_CREEK	2021-07-07	<7
T22_ANNUAL_RUNS	MOC_RES	2016-06-15	11.7
T22_ANNUAL_RUNS	MOC_RES	2017-07-19	<5
T22_ANNUAL_RUNS	MOC_RES	2019-06-18	7.99
T22_ANNUAL_RUNS	MOC_RES	2020-06-15	6
T22_ANNUAL_RUNS	MOC_RES	2021-07-14	<7
T22_ANNUAL_RUNS	MOC_TAILRACE	2017-06-20	6.46
T22_ANNUAL_RUNS	MOC_TAILRACE	2018-06-18	5.2
T22_ANNUAL_RUNS	LK_ELEANOR	2016-06-13	<5
T22_ANNUAL_RUNS	LK_ELEANOR	2017-06-26	<5
T22_ANNUAL_RUNS	LK_ELEANOR	2018-06-18	<5
T22_ANNUAL_RUNS	LK_ELEANOR	2019-06-18	5.83
T22_ANNUAL_RUNS	LK_ELEANOR	2020-06-22	<5
T22_ANNUAL_RUNS	LK_ELEANOR	2021-07-01	<7
T22_ANNUAL_RUNS	EI_RES	2016-06-14	6.98
T22_ANNUAL_RUNS	EI_RES	2017-06-19	<5
T22_ANNUAL_RUNS	EI_RES	2018-06-19	<5
T22_ANNUAL_RUNS	EI_RES	2019-06-19	7.3
T22_ANNUAL_RUNS	EI_RES	2020-06-23	6.74
T22_ANNUAL_RUNS	EI_RES	2021-07-14	<7

Rasprojectno_(Project_ID)	ClSampNo	Date	Boron, B µg/L
EAST BAY SURFACE WATER			
WQ_ENG_SPECIAL	ALAMEDA_CR_P_F3E	2016-06-15	926
WQ_ENG_SPECIAL	ALAMEDA_CR_P_F3E	2017-06-19	1740
WQ_ENG_SPECIAL	ALAMEDA_CR_P_F3E	2018-03-19	838
WQ_ENG_SPECIAL	ALAMEDA_CR_P_F3E	2018-04-12	873
WQ_ENG_SPECIAL	ALAMEDA_CR_P_F3E	2018-04-26	820
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2018-06-18	507
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2018-06-18	867
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2019-05-02	1490
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2019-06-17	625
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2020-07-01	652
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2020-07-01	1060
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2021-03-03	754
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2021-03-03	846
T22_ANNUAL_RUNS	CAL_SURF	2016-06-15	111
T22_ANNUAL_RUNS	CAL_SURF	2017-06-19	77.7
T22_ANNUAL_RUNS	CAL_SURF	2018-06-19	113
T22_ANNUAL_RUNS	CAL_SURF	2019-06-17	81.9
T22_ANNUAL_RUNS	CAL_SURF	2020-07-20	105
T22_ANNUAL_RUNS	CAL_SURF	2021-06-28	114
T22_ANNUAL_RUNS	SANT_SURF	2016-06-15	131
T22_ANNUAL_RUNS	SANT_SURF	2017-06-19	138
T22_ANNUAL_RUNS	SANT_SURF	2018-06-18	481
T22_ANNUAL_RUNS	SANT_SURF	2019-06-17	126
T22_ANNUAL_RUNS	SANT_SURF	2020-06-24	113
T22_ANNUAL_RUNS	SANT_SURF	2021-06-11	121
WEST BAY SURFACE WATER			
T22_ANNUAL_RUNS	LCS_SURF	2016-06-14	39.1
T22_ANNUAL_RUNS	LCS_SURF	2017-06-19	38.8
T22_ANNUAL_RUNS	LCS_SURF	2018-06-18	34.5
T22_ANNUAL_RUNS	LCS_SURF	2019-06-17	33.7
T22_ANNUAL_RUNS	LCS_SURF	2020-07-28	38.5
T22_ANNUAL_RUNS	LCS_SURF	2021-06-14	30.6
T22_ANNUAL_RUNS	PIL_SURF	2016-06-14	19.1
T22_ANNUAL_RUNS	PIL_SURF	2017-06-19	10.6
T22_ANNUAL_RUNS	PIL_SURF	2018-06-18	12.2
T22_ANNUAL_RUNS	PIL_SURF	2019-06-17	14.3
T22_ANNUAL_RUNS	PIL_SURF	2020-07-21	10.8
T22_ANNUAL_RUNS	PIL_SURF	2021-06-22	14.1
T22_ANNUAL_RUNS	STONE_DAM_SURF	2016-06-14	21.2
T22_ANNUAL_RUNS	STONE_DAM_SURF	2017-06-19	17.7

Rasprojectno_(Project_ID)	ClSampNo	Date	Boron, B µg/L
T22_ANNUAL_RUNS	STONE_DAM_SURF	2018-06-18	18.3
T22_ANNUAL_RUNS	STONE_DAM_SURF	2019-06-17	19.5
T22_ANNUAL_RUNS	STONE_DAM_SURF	2020-07-21	14.6
T22_ANNUAL_RUNS	STONE_DAM_SURF	2021-06-29	18.4
T22_ANNUAL_RUNS	SA_SURF	2016-06-14	32.7
T22_ANNUAL_RUNS	SA_SURF	2017-06-19	32.5
T22_ANNUAL_RUNS	SA_SURF	2018-06-18	41.3
T22_ANNUAL_RUNS	SA_SURF	2019-06-17	36.1
T22_ANNUAL_RUNS	SA_SURF	2020-06-15	31.7
T22_ANNUAL_RUNS	SA_SURF	2021-06-16	30.2
GROUNDWATER SF CITY			
T22_ANNUAL_RUNS	LK_MERCED_S	2017-06-19	58.7
T22_ANNUAL_RUNS	LK_MERCED_S	2019-06-17	61.4
T22_ANNUAL_RUNS	LK_MERCED_S	2020-07-14	51.7
T22_ANNUAL_RUNS	SF_ZOO_WELL_3	2016-06-14	39.6
T22_ANNUAL_RUNS	SF_ZOO_WELL_4	2017-06-19	43.2
T22_ANNUAL_RUNS	SF_ZOO_WELL_5	2020-06-17	34.6
SFGW_HISTORICAL	SFGW-LMW	2017-06-14	25.1
SFGW_7WEEK	SFGW-SSW	2018-04-19	28.6
SFGW_RUNS	SFGW-LMW	2020-07-14	18.5
SFGW_RUNS	SFGW-SSW	2020-07-14	20.1
SFGW_RUNS	SFGW-GCW	2020-07-15	37.6
SFGW_RUNS	SFGW-WSW	2020-07-15	40.9
SFGW_1ST-YR	SFGW-NLW	2020-07-16	53.9
SFGW_1ST-YR	SFGW-SWW	2020-07-20	56.6
GROUNDWATER PENINSULA			
GW_EVAL	Forest Hill Station	2016-09-13	146
GSR_PARTNER	GSR-SMW	2016-02-17	96
GSR_PRE-COMP	GSR-HBW	2019-06-24	24.3
GSR_PRE-COMP	GSR-PDWLGWLGW	2019-06-24	16.9
GSR_PRE-COMP	GSR-SBW	2019-06-24	22.6
GSR_PRE-COMP	GSR-MSW	2019-06-25	20.4
GSR_PRE-COMP	GSR-MYW	2019-06-25	29.2
GSR_PRE-COMP	GSR-SDW	2019-06-25	52
GSR_PRE-COMP	GSR-BSW	2019-06-26	21.5
GSR_PRE-COMP	GSR-CBW	2019-06-26	28.9
GSR_PRE-COMP	GSR-FSW	2019-06-26	23.2
GSR_1ST-YR	GSR-HBW	2020-07-07	21.8
GSR_1ST-YR	GSR-PDW	2020-07-07	9.67
GSR_1ST-YR	GSR-CBW	2020-07-08	26.2
GSR_1ST-YR	GSR-FSW	2020-07-08	20.4

Rasprojectno_(Project_ID)	ClSampNo	Date	Boron, B µg/L
GSR_1ST-YR	GSR-MYW	2020-07-08	26.5
GROUNDWATER EAST BAY			
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2016-06-14	393
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2017-06-19	565
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2018-06-18	400
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2019-06-26	394
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2020-06-16	414
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2016-06-14	457
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2017-06-19	580
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2018-06-18	490
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2019-06-17	447
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2020-06-16	488
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2021-06-23	476
T22_ANNUAL_RUNS	SUNOL_FILTER	2016-06-14	649
T22_ANNUAL_RUNS	SUNOL_FILTER	2017-06-19	112
T22_ANNUAL_RUNS	SUNOL_FILTER	2018-06-18	441
T22_ANNUAL_RUNS	SUNOL_FILTER	2019-06-17	451
T22_ANNUAL_RUNS	SUNOL_FILTER	2020-06-17	375
T22_ANNUAL_RUNS	SUNOL_FILTER	2021-06-23	403
DRINKING WATER			
T22_ANNUAL_RUNS	ALAMEDA_EAST	2016-06-14	21.9
T22_ANNUAL_RUNS	ALAMEDA_EAST	2017-06-19	11.3
T22_ANNUAL_RUNS	ALAMEDA_EAST	2018-06-18	14.9
T22_ANNUAL_RUNS	ALAMEDA_EAST	2019-06-17	17.4
T22_ANNUAL_RUNS	ALAMEDA_EAST	2021-06-22	26.8
T22_ANNUAL_RUNS	SVWTP_EFF	2016-06-14	123
T22_ANNUAL_RUNS	SVWTP_EFF	2017-06-19	203
T22_ANNUAL_RUNS	SVWTP_EFF	2018-06-28	104
T22_ANNUAL_RUNS	SVWTP_EFF	2019-06-17	107
T22_ANNUAL_RUNS	SVWTP_TWR_EFF	2021-06-15	123
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2016-06-21	41.8
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2017-06-19	35.2
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2018-06-18	35
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2019-07-02	34.8
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2021-06-16	32.1
T22_ANNUAL_RUNS	CS#2_BADEN	2016-06-14	21.7
T22_ANNUAL_RUNS	CS#2_BADEN	2019-06-17	26.4
T22_ANNUAL_RUNS	EI_TK	2016-06-14	8.9
T22_ANNUAL_RUNS	EI_TK	2018-06-19	<5
T22_ANNUAL_RUNS	MOC_TK	2016-06-15	12.5
T22_ANNUAL_RUNS	MOC_TK	2018-06-18	<5

Rasprojectno_(Project_ID)	ClSampNo	Date	Boron, B µg/L
T22_ANNUAL_RUNS	OSH_TK	2016-06-15	14.6
T22_ANNUAL_RUNS	OSH_TK	2018-06-19	5.59
SFGW_RUNS	SSO#1_N	2020-07-09	17.1
SFGW_RUNS	SSO#2_S	2020-07-09	17

Table 6-5. Cadmium SFPUC Monitoring Results, 2016-2021

Rasprojectno_(Project_ID)	ClSampNo	Date	Cadmium µg/L
SURFACE WATER HETCH HETCHY			
WQ_MOCCASIN_SPECIAL	OSH_BKPK_WELL	2-Mar-16	<0.5
WQ_MOCCASIN_SPECIAL	OSH_BKPK_WELL	23-Mar-16	<0.5
T22_ANNUAL_RUNS	CHERRY_RES	13-Jun-16	<0.5
T22_ANNUAL_RUNS	LK_ELEANOR	13-Jun-16	<0.5
T22_ANNUAL_RUNS	CHERRY_CREEK	14-Jun-16	<0.5
T22_ANNUAL_RUNS	EI_RES	14-Jun-16	<0.5
T22_ANNUAL_RUNS	HHR	15-Jun-16	<0.5
T22_ANNUAL_RUNS	MOC_RES	15-Jun-16	<0.5
WQ_ENG_SPECIAL	SP1 MtnTnl@PriestRes	12-Jan-17	<0.5
WQ_ENG_SPECIAL	SP4 MtnTnl@EarlyInt	12-Jan-17	<0.5
T22_ANNUAL_RUNS	EI_RES	19-Jun-17	<0.5
T22_ANNUAL_RUNS	HHR	19-Jun-17	<0.5
T22_ANNUAL_RUNS	MOC_TAILRACE	20-Jun-17	<0.5
T22_ANNUAL_RUNS	CHERRY_CREEK	26-Jun-17	<0.5
T22_ANNUAL_RUNS	CHERRY_RES	26-Jun-17	<0.5
T22_ANNUAL_RUNS	LK_ELEANOR	26-Jun-17	<0.5
T22_ANNUAL_RUNS	MOC_RES	19-Jul-17	<0.5
T22_ANNUAL_RUNS	CHERRY_CREEK	18-Jun-18	<0.5
T22_ANNUAL_RUNS	CHERRY_RES	18-Jun-18	<0.5
T22_ANNUAL_RUNS	HHR	18-Jun-18	<0.5
T22_ANNUAL_RUNS	LK_ELEANOR	18-Jun-18	<0.5
T22_ANNUAL_RUNS	MOC_TAILRACE	18-Jun-18	<0.5
T22_ANNUAL_RUNS	EI_RES	19-Jun-18	<0.5
WQ_ENG_SPECIAL	LLOYD LAKE	28-Jun-18	<0.01
T22_ANNUAL_RUNS	CHERRY_RES	18-Jun-19	<0.5
T22_ANNUAL_RUNS	HHR	18-Jun-19	<0.5
T22_ANNUAL_RUNS	LK_ELEANOR	18-Jun-19	<0.5
T22_ANNUAL_RUNS	MOC_RES	18-Jun-19	<0.5
T22_ANNUAL_RUNS	CHERRY_CREEK	19-Jun-19	<0.5
T22_ANNUAL_RUNS	EI_RES	19-Jun-19	<0.5
T22_ANNUAL_RUNS	MOC_RES	15-Jun-20	<0.5
T22_ANNUAL_RUNS	HHR	16-Jun-20	<0.5
T22_ANNUAL_RUNS	CHERRY_RES	17-Jun-20	<0.5
T22_ANNUAL_RUNS	LK_ELEANOR	22-Jun-20	<0.5
T22_ANNUAL_RUNS	EI_RES	23-Jun-20	<0.5
T22_ANNUAL_RUNS	CHERRY_CREEK	24-Jun-20	<0.5
T22_ANNUAL_RUNS	CHERRY_RES	1-Jul-21	<0.5
T22_ANNUAL_RUNS	LK_ELEANOR	1-Jul-21	<0.5

Rasprojectno_(Project_ID)	ClSampNo	Date	Cadmium µg/L
T22_ANNUAL_RUNS	CHERRY_CREEK	7-Jul-21	<0.5
T22_ANNUAL_RUNS	EI_RES	14-Jul-21	<0.5
T22_ANNUAL_RUNS	HHR	14-Jul-21	<0.5
T22_ANNUAL_RUNS	MOC_RES	14-Jul-21	<0.5
EAST BAY SURFACE WATER			
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	15-Jun-16	<0.5
T22_ANNUAL_RUNS	CAL_SURF	15-Jun-16	<0.5
T22_ANNUAL_RUNS	SANT_SURF	15-Jun-16	<0.5
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	19-Jun-17	<0.5
T22_ANNUAL_RUNS	CAL_SURF	19-Jun-17	<0.5
T22_ANNUAL_RUNS	SANT_SURF	19-Jun-17	<0.5
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	18-Jun-18	<0.5
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	18-Jun-18	<0.5
T22_ANNUAL_RUNS	CAL_SURF	18-Jun-18	<0.5
T22_ANNUAL_RUNS	SANT_SURF	18-Jun-18	<0.5
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2-May-19	<0.5
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	17-Jun-19	<0.5
T22_ANNUAL_RUNS	CAL_SURF	17-Jun-19	<0.5
T22_ANNUAL_RUNS	SANT_SURF	17-Jun-19	<0.5
T22_ANNUAL_RUNS	SANT_SURF	24-Jun-20	<0.5
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	1-Jul-20	<0.5
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	1-Jul-20	<0.5
T22_ANNUAL_RUNS	CAL_SURF	20-Jul-20	<0.5
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	3-Mar-21	<0.5
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	3-Mar-21	<0.5
T22_ANNUAL_RUNS	SANT_SURF	11-Jun-21	<0.5
T22_ANNUAL_RUNS	CAL_SURF	28-Jun-21	<0.5
WEST BAY SURFACE WATER			
T22_ANNUAL_RUNS	LCS_SURF	14-Jun-16	<0.5
T22_ANNUAL_RUNS	PIL_SURF	14-Jun-16	<0.5
T22_ANNUAL_RUNS	SA_SURF	14-Jun-16	<0.5
T22_ANNUAL_RUNS	STONE_DAM_SURF	14-Jun-16	<0.5
T22_ANNUAL_RUNS	LCS_SURF	19-Jun-17	<0.5
T22_ANNUAL_RUNS	PIL_SURF	19-Jun-17	<0.5
T22_ANNUAL_RUNS	SA_SURF	19-Jun-17	<0.5
T22_ANNUAL_RUNS	STONE_DAM_SURF	19-Jun-17	<0.5
T22_ANNUAL_RUNS	LCS_SURF	18-Jun-18	<0.5
T22_ANNUAL_RUNS	PIL_SURF	18-Jun-18	<0.5
T22_ANNUAL_RUNS	SA_SURF	18-Jun-18	<0.5
T22_ANNUAL_RUNS	STONE_DAM_SURF	18-Jun-18	<0.5
T22_ANNUAL_RUNS	LCS_SURF	17-Jun-19	<0.5

Rasprojectno_(Project_ID)	ClSampNo	Date	Cadmium µg/L
T22_ANNUAL_RUNS	PIL_SURF	17-Jun-19	<0.5
T22_ANNUAL_RUNS	SA_SURF	17-Jun-19	<0.5
T22_ANNUAL_RUNS	STONE_DAM_SURF	17-Jun-19	<0.5
T22_ANNUAL_RUNS	SA_SURF	15-Jun-20	<0.5
T22_ANNUAL_RUNS	PIL_SURF	21-Jul-20	<0.5
T22_ANNUAL_RUNS	STONE_DAM_SURF	21-Jul-20	<0.5
T22_ANNUAL_RUNS	LCS_SURF	28-Jul-20	<0.5
T22_ANNUAL_RUNS	LCS_SURF	14-Jun-21	<0.5
T22_ANNUAL_RUNS	SA_SURF	16-Jun-21	<0.5
T22_ANNUAL_RUNS	PIL_SURF	22-Jun-21	<0.5
T22_ANNUAL_RUNS	STONE_DAM_SURF	29-Jun-21	<0.5
SURFACE WATER SF CITY			
T22_ANNUAL_RUNS	LK_MERCED_S	20-Jun-16	<0.5
T22_ANNUAL_RUNS	LK_MERCED_S	19-Jun-17	<0.5
T22_ANNUAL_RUNS	LK_MERCED_S	14-Jul-20	<0.5
GROUNDWATER SF CITY			
T22_ANNUAL_RUNS	SF_ZOO_WELL_5	14-Jun-16	<0.5
SFGW_HISTORICAL	SFGW-LMW	14-Jun-17	<0.5
T22_ANNUAL_RUNS	SF_ZOO_WELL_5	19-Jun-17	<0.5
SFGW_1ST-YR	SFGW-LMW	11-Jan-18	<0.5
SFGW_1ST-YR	SFGW-GCW	6-Mar-18	<0.5
SFGW_1ST-YR	SFGW-SSW	6-Mar-18	<0.5
SFGW_1ST-YR	SFGW-WSW	8-Mar-18	<0.5
SFGW_HISTORICAL	SFGW-LMW	17-Apr-18	<0.5
SFGW_1ST-YR	SFGW-GCW	12-Jun-18	<0.5
SFGW_1ST-YR	SFGW-SSW	12-Jun-18	<0.5
SFGW_1ST-YR	SFGW-WSW	12-Jun-18	<0.5
SFGW_1ST-YR	SFGW-LMW	17-Jul-18	<0.5
SFGW_1ST-YR	SFGW-GCW	18-Sep-18	<0.5
SFGW_1ST-YR	SFGW-SSW	18-Sep-18	<0.5
SFGW_1ST-YR	SFGW-WSW	18-Sep-18	<0.5
SFGW_OPS	SFGW - WSW	4-Oct-18	<0.5
SFGW_1ST-YR	SFGW-LMW	17-Oct-18	<0.5
SFGW_1ST-YR	SFGW-GCW	11-Dec-18	<0.5
SFGW_1ST-YR	SFGW-SSW	11-Dec-18	<0.5
SFGW_1ST-YR	SFGW-WSW	11-Dec-18	<0.5
SFGW_WRD	SFGW-SSW	16-May-19	<0.5
SFGW_RUNS	SFGW-GCW	17-Jun-19	<0.5
SFGW_RUNS	SFGW-LMW	17-Jun-19	<0.5
SFGW_RUNS	SFGW-SSW	17-Jun-19	<0.5
SFGW_RUNS	SFGW-WSW	17-Jun-19	<0.5

Rasprojectno_(Project_ID)	ClSampNo	Date	Cadmium µg/L
T22_ANNUAL_RUNS	SF_ZOO_WELL_5	17-Jun-20	<0.5
SFGW_RUNS	SFGW-LMW	14-Jul-20	<0.5
SFGW_RUNS	SFGW-SSW	14-Jul-20	<0.5
SFGW_RUNS	SFGW-GCW	15-Jul-20	<0.5
SFGW_RUNS	SFGW-WSW	15-Jul-20	<0.5
SFGW_1ST-YR	SFGW-NLW	16-Jul-20	<0.5
SFGW_1ST-YR	SFGW-SWW	20-Jul-20	<0.5
SFGW_1ST-YR	SFGW-NLW	20-Oct-20	<0.5
SFGW_1ST-YR	SFGW-SWW	20-Oct-20	<0.5
SFGW_1ST-YR	SFGW-NLW	12-Jan-21	<0.5
SFGW_1ST-YR	SFGW-SWW	12-Jan-21	<0.5
SFGW_1ST-YR	SFGW-NLW	13-Apr-21	<0.5
SFGW_1ST-YR	SFGW-SWW	13-Apr-21	<0.5
SFGW_RUNS	SFGW-LMW	13-Jul-21	<0.5
SFGW_RUNS	SFGW-SSW	13-Jul-21	<0.5
SFGW_RUNS	SFGW-WSW	13-Jul-21	<0.5
SFGW_RUNS	SFGW-GCW	20-Jul-21	<0.5
SFGW_RUNS	SFGW-NLW	20-Jul-21	<0.5
SFGW_RUNS	SFGW-SWW	20-Jul-21	<0.5
GROUNDWATER PENINSULA			
GSR_PARTNER	GSR-SMW	17-Feb-16	<0.5
GSR_PRE-COMP	GSR-HBW	24-Jun-19	<0.5
GSR_PRE-COMP	GSR-PDWLGWLGW	24-Jun-19	<0.5
GSR_PRE-COMP	GSR-SBW	24-Jun-19	<0.5
GSR_PRE-COMP	GSR-MSW	25-Jun-19	<0.5
GSR_PRE-COMP	GSR-MYW	25-Jun-19	<0.5
GSR_PRE-COMP	GSR-SDW	25-Jun-19	<0.5
GSR_PRE-COMP	GSR-BSW	26-Jun-19	<0.5
GSR_PRE-COMP	GSR-CBW	26-Jun-19	<0.5
GSR_PRE-COMP	GSR-FSW	26-Jun-19	<0.5
GSR_1ST-YR	GSR-HBW	7-Jul-20	<0.5
GSR_1ST-YR	GSR-PDW	7-Jul-20	<0.5
GSR_1ST-YR	GSR-CBW	8-Jul-20	<0.5
GSR_1ST-YR	GSR-FSW	8-Jul-20	<0.5
GSR_1ST-YR	GSR-MYW	8-Jul-20	<0.5
GSR_HISTORICAL	GSR-SDW	5-Aug-20	<0.5
GSR_PARTNER	GSR-BFW	12-Aug-20	<0.5
GSR_PARTNER	GSR-LPW	26-Aug-20	<0.5
GSR_1ST-YR	GSR-CBW	21-Oct-20	<0.5
GSR_1ST-YR	GSR-FSW	21-Oct-20	<0.5
GSR_1ST-YR	GSR-PDW	21-Oct-20	<0.5

Rasprojectno_(Project_ID)	ClSampNo	Date	Cadmium µg/L
GSR_1ST-YR	GSR-HBW	22-Oct-20	<0.5
GSR_1ST-YR	GSR-MYW	22-Oct-20	<0.5
GSR_1ST-YR	GSR-HBW	6-Jan-21	<0.5
GSR_1ST-YR	GSR-MYW	6-Jan-21	<0.5
GSR_1ST-YR	GSR-PDW	7-Jan-21	<0.5
GSR_1ST-YR	GSR-CBW	13-Jan-21	<0.5
GSR_1ST-YR	GSR-FSW	13-Jan-21	<0.5
GSR_1ST-YR	GSR-BSW	7-Apr-21	<0.5
GSR_1ST-YR	GSR-CBW	7-Apr-21	<0.5
GSR_1ST-YR	GSR-FSW	7-Apr-21	<0.5
GSR_1ST-YR	GSR-PDW	7-Apr-21	<0.5
GSR_1ST-YR	GSR-HBW	8-Apr-21	<0.5
GSR_1ST-YR	GSR-MYW	8-Apr-21	<0.5
GSR_RUNS	GSR-MYW	7-Jul-21	<0.5
GSR_RUNS	GSR-HBW	8-Jul-21	<0.5
GSR_RUNS	GSR-PDW	8-Jul-21	<0.5
GSR_1ST-YR	GSR-BSW	14-Jul-21	<0.5
GSR_RUNS	GSR-CBW	14-Jul-21	<0.5
GSR_RUNS	GSR-FSW	14-Jul-21	<0.5
GSR_1ST-YR	GSR-SBW	18-Aug-21	<0.5
GSR_1ST-YR	GSR-BSW	6-Oct-21	<0.5
GSR_1ST-YR	GSR-SBW	4-Nov-21	<0.5
GSR_1ST-YR	GSR-MSW	16-Dec-21	<0.5
GROUNDWATER EAST BAY			
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	14-Jun-16	<0.5
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	14-Jun-16	<0.5
T22_ANNUAL_RUNS	SUNOL_FILTER	14-Jun-16	<0.5
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	19-Jun-17	<0.5
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	19-Jun-17	<0.5
T22_ANNUAL_RUNS	SUNOL_FILTER	19-Jun-17	<0.5
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	18-Jun-18	<0.5
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	18-Jun-18	<0.5
T22_ANNUAL_RUNS	SUNOL_FILTER	18-Jun-18	<0.5
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	17-Jun-19	<0.5
T22_ANNUAL_RUNS	SUNOL_FILTER	17-Jun-19	<0.5
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	26-Jun-19	<0.5
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	16-Jun-20	<0.5
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	16-Jun-20	<0.5
T22_ANNUAL_RUNS	SUNOL_FILTER	17-Jun-20	<0.5
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	23-Jun-21	<0.5
T22_ANNUAL_RUNS	SUNOL_FILTER	23-Jun-21	<0.5

Rasprojectno_(Project_ID)	ClSampNo	Date	Cadmium µg/L
DRINKING WATER			
T22_ANNUAL_RUNS	ALAMEDA_EAST	14-Jun-16	<0.5
T22_ANNUAL_RUNS	CS#2_BADEN	14-Jun-16	<0.5
T22_ANNUAL_RUNS	EI_TK	14-Jun-16	<0.5
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	14-Jun-16	<0.5
T22_ANNUAL_RUNS	SVWTP_EFF	14-Jun-16	<0.5
T22_ANNUAL_RUNS	MOC_TK	15-Jun-16	<0.5
T22_ANNUAL_RUNS	OSH_TK	15-Jun-16	<0.5
T22_ANNUAL_RUNS	HTWTP_EFF_POST	21-Jun-16	<0.5
DS_GW_CCM	CHS#03	22-Aug-16	<0.5
DS_GW_CCM	CS#2_BADEN	22-Aug-16	<0.5
DS_GW_CCM	HPS	22-Aug-16	<0.5
DS_GW_CCM	LS	22-Aug-16	<0.5
DS_GW_CCM	MCS#02	22-Aug-16	<0.5
DS_GW_CCM	MMS#02	22-Aug-16	<0.5
DS_GW_CCM	PHS	22-Aug-16	<0.5
DS_GW_CCM	SA#2_BADEN	22-Aug-16	<0.5
DS_GW_CCM	SA#3_BADEN	22-Aug-16	<0.5
DS_GW_CCM	SHS#01	22-Aug-16	<0.5
DS_GW_CCM	SS#05	22-Aug-16	<0.5
DS_GW_CCM	SSL_BADEN	22-Aug-16	<0.5
DS_GW_CCM	SSO#1_N	22-Aug-16	<0.5
DS_GW_CCM	SSO#2_S	22-Aug-16	<0.5
DS_GW_CCM	SUMS	22-Aug-16	<0.5
DS_GW_CCM	SUTS#06	22-Aug-16	<0.5
DS_GW_CCM	UMS#04	22-Aug-16	<0.5
DS_GW_CCM	CHS#03	19-Sep-16	<0.5
DS_GW_CCM	CS#2_BADEN	19-Sep-16	<0.5
DS_GW_CCM	HPS	19-Sep-16	<0.5
DS_GW_CCM	LS	19-Sep-16	<0.5
DS_GW_CCM	MCS#02	19-Sep-16	<0.5
DS_GW_CCM	MMS#02	19-Sep-16	<0.5
DS_GW_CCM	PHS	19-Sep-16	<0.5
DS_GW_CCM	SA#2_BADEN	19-Sep-16	<0.5
DS_GW_CCM	SA#3_BADEN	19-Sep-16	<0.5
DS_GW_CCM	SHS#01	19-Sep-16	<0.5
DS_GW_CCM	SS#05	19-Sep-16	<0.5
DS_GW_CCM	SSL_BADEN	19-Sep-16	<0.5
DS_GW_CCM	SSO#1_N	19-Sep-16	<0.5
DS_GW_CCM	SSO#2_S	19-Sep-16	<0.5
DS_GW_CCM	SUMS	19-Sep-16	<0.5

Rasprojectno_(Project_ID)	ClSampNo	Date	Cadmium µg/L
DS_GW_CCM	SUTS#06	19-Sep-16	<0.5
DS_GW_CCM	UMS#04	19-Sep-16	<0.5
DS_GW_CCM	CHS#03	17-Oct-16	<0.5
DS_GW_CCM	CS#2_BADEN	17-Oct-16	<0.5
DS_GW_CCM	HPS	17-Oct-16	<0.5
DS_GW_CCM	LS	17-Oct-16	<0.5
DS_GW_CCM	MCS#02	17-Oct-16	<0.5
DS_GW_CCM	MMS#02	17-Oct-16	<0.5
DS_GW_CCM	PHS	17-Oct-16	<0.5
DS_GW_CCM	SA#2_BADEN	17-Oct-16	<0.5
DS_GW_CCM	SA#3_BADEN	17-Oct-16	<0.5
DS_GW_CCM	SHS#01	17-Oct-16	<0.5
DS_GW_CCM	SS#05	17-Oct-16	<0.5
DS_GW_CCM	SSL_BADEN	17-Oct-16	<0.5
DS_GW_CCM	SSO#1_N	17-Oct-16	<0.5
DS_GW_CCM	SSO#2_S	17-Oct-16	<0.5
DS_GW_CCM	SUMS	17-Oct-16	<0.5
DS_GW_CCM	SUTS#06	17-Oct-16	<0.5
DS_GW_CCM	UMS#04	17-Oct-16	<0.5
DS_GW_CCM	CHS#03	27-Feb-17	<0.5
DS_GW_CCM	CS#2_BADEN	27-Feb-17	<0.5
DS_GW_CCM	HPS	27-Feb-17	<0.5
DS_GW_CCM	LS	27-Feb-17	<0.5
DS_GW_CCM	MCS#02	27-Feb-17	<0.5
DS_GW_CCM	MMS#02	27-Feb-17	<0.5
DS_GW_CCM	PHS	27-Feb-17	<0.5
DS_GW_CCM	SA#2_BADEN	27-Feb-17	<0.5
DS_GW_CCM	SA#3_BADEN	27-Feb-17	<0.5
DS_GW_CCM	SHS#01	27-Feb-17	<0.5
DS_GW_CCM	SS#05	27-Feb-17	<0.5
DS_GW_CCM	SSL_BADEN	27-Feb-17	<0.5
DS_GW_CCM	SSO#1_N	27-Feb-17	<0.5
DS_GW_CCM	SSO#2_S	27-Feb-17	<0.5
DS_GW_CCM	SUMS	27-Feb-17	<0.5
DS_GW_CCM	SUTS#06	27-Feb-17	<0.5
DS_GW_CCM	UMS#04	27-Feb-17	<0.5
T22_ANNUAL_RUNS	ALAMEDA_EAST	19-Jun-17	<0.5
T22_ANNUAL_RUNS	CS#2_BADEN	19-Jun-17	<0.5
T22_ANNUAL_RUNS	EI_TK	19-Jun-17	<0.5
T22_ANNUAL_RUNS	HTWTP_EFF_POST	19-Jun-17	<0.5
T22_ANNUAL_RUNS	OSH_TK	19-Jun-17	<0.5

Rasprojectno_(Project_ID)	ClSampNo	Date	Cadmium µg/L
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	19-Jun-17	<0.5
T22_ANNUAL_RUNS	SVWTP_EFF	19-Jun-17	<0.5
T22_ANNUAL_RUNS	MOC_TK	20-Jun-17	<0.5
T22_ANNUAL_RUNS	ALAMEDA_EAST	18-Jun-18	<0.5
T22_ANNUAL_RUNS	CS#2_BADEN	18-Jun-18	<0.5
T22_ANNUAL_RUNS	EI_TK	19-Jun-18	<0.5
T22_ANNUAL_RUNS	HTWTP_EFF_POST	18-Jun-18	<0.5
T22_ANNUAL_RUNS	MOC_TK	18-Jun-18	<0.5
T22_ANNUAL_RUNS	OSH_TK	19-Jun-18	<0.5
T22_ANNUAL_RUNS	SVWTP_EFF	28-Jun-18	<0.5
T22_ANNUAL_RUNS	ALAMEDA_EAST	17-Jun-19	<0.5
SFGW_RUNS	SSO#1_N	17-Jun-19	<0.5
T22_ANNUAL_RUNS	SVWTP_EFF	17-Jun-19	<0.5
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2-Jul-19	<0.5
WQ_ENG_SPECIAL	SS#01	27-Feb-20	<0.5
WQ_ENG_SPECIAL	SS#03	27-Feb-20	<0.5
WQ_ENG_SPECIAL	SS#04	27-Feb-20	<0.5
WQ_ENG_SPECIAL	SS#05	27-Feb-20	<0.5
WQ_ENG_SPECIAL	SS#06	27-Feb-20	<0.5
WQ_ENG_SPECIAL	SS#07	27-Feb-20	<0.5
WQ_ENG_SPECIAL	SS#08	27-Feb-20	<0.5
WQ_ENG_SPECIAL	SS#09	27-Feb-20	<0.5
WQ_ENG_SPECIAL	SS#10	27-Feb-20	<0.5
WQ_ENG_SPECIAL	SS#11	27-Feb-20	<0.5
T22_ANNUAL_RUNS	ALAMEDA_EAST	15-Jun-20	<0.5
T22_ANNUAL_RUNS	HTWTP_EFF_POST	15-Jun-20	<0.5
T22_ANNUAL_RUNS	MOC_TK	15-Jun-20	<0.5
T22_ANNUAL_RUNS	CS#2_BADEN	16-Jun-20	<0.5
T22_ANNUAL_RUNS	OSH_TK	16-Jun-20	<0.5
T22_ANNUAL_RUNS	EI_TK	23-Jun-20	<0.5
T22_ANNUAL_RUNS	SVWTP_EFF	24-Jun-20	<0.5
SFGW_RUNS	SSO#1_N	9-Jul-20	<0.5
SFGW_RUNS	SSO#2_S	9-Jul-20	<0.5
T22_ANNUAL_RUNS	SVWTP_TWR_EFF	15-Jun-21	<0.5
T22_ANNUAL_RUNS	HTWTP_EFF_POST	16-Jun-21	<0.5
T22_ANNUAL_RUNS	ALAMEDA_EAST	22-Jun-21	<0.5

Table 6-6. Chromium (VI) Title 22 and Special Groundwater SFPUC Monitoring Results, 2016-2021

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SURFACE WATER HETCH HETCHY			
T22_ANNUAL_RUNS	HHR	2016-06-15	<0.02
T22_ANNUAL_RUNS	HHR	2017-06-19	<0.02
T22_ANNUAL_RUNS	HHR	2018-06-18	<0.02
T22_ANNUAL_RUNS	HHR	2019-06-18	<0.02
T22_ANNUAL_RUNS	HHR	2020-06-16	<0.02
T22_ANNUAL_RUNS	HHR	2021-07-26	<0.02
T22_ANNUAL_RUNS	LK_ELEANOR	2016-06-13	<0.02
T22_ANNUAL_RUNS	LK_ELEANOR	2017-06-26	<0.02
T22_ANNUAL_RUNS	LK_ELEANOR	2018-06-18	<0.02
T22_ANNUAL_RUNS	LK_ELEANOR	2019-06-18	<0.02
T22_ANNUAL_RUNS	LK_ELEANOR	2020-06-22	<0.02
T22_ANNUAL_RUNS	LK_ELEANOR	2021-07-01	<0.02
T22_ANNUAL_RUNS	CHERRY_RES	2016-06-13	<0.02
T22_ANNUAL_RUNS	CHERRY_RES	2017-06-26	0.025
T22_ANNUAL_RUNS	CHERRY_RES	2018-06-18	<0.02
T22_ANNUAL_RUNS	CHERRY_RES	2019-06-18	<0.02
T22_ANNUAL_RUNS	CHERRY_RES	2020-06-17	<0.02
T22_ANNUAL_RUNS	CHERRY_RES	2021-07-01	<0.02
T22_ANNUAL_RUNS	CHERRY_CREEK	2016-06-14	<0.02
T22_ANNUAL_RUNS	CHERRY_CREEK	2017-06-26	0.021
T22_ANNUAL_RUNS	CHERRY_CREEK	2018-06-18	0.021
T22_ANNUAL_RUNS	CHERRY_CREEK	2019-07-09	<0.02
T22_ANNUAL_RUNS	CHERRY_CREEK	2020-06-24	<0.02
T22_ANNUAL_RUNS	CHERRY_CREEK	2021-07-07	<0.02
T22_ANNUAL_RUNS	EI_RES	2016-06-14	<0.02
T22_ANNUAL_RUNS	EI_RES	2017-06-19	<0.02
T22_ANNUAL_RUNS	EI_RES	2018-06-19	<0.02
T22_ANNUAL_RUNS	EI_RES	2019-06-19	<0.02
T22_ANNUAL_RUNS	EI_RES	2020-06-23	<0.02
T22_ANNUAL_RUNS	EI_RES	2021-07-14	<0.02
T22_ANNUAL_RUNS	MOC_RES	2016-06-15	<0.02
T22_ANNUAL_RUNS	MOC_RES	2017-07-19	0.022
T22_ANNUAL_RUNS	MOC_RES	2019-06-18	0.156
T22_ANNUAL_RUNS	MOC_RES	2020-06-15	<0.02
T22_ANNUAL_RUNS	MOC_RES	2021-07-14	<0.02
WQ_ENG_SPECIAL	SP1 MtnTnl@PriestRes	2017-01-12	0.051
WQ_ENG_SPECIAL	SP4 MtnTnl@EarlyInt	2017-01-12	0.02
T22_ANNUAL_RUNS	MOC_TAILRACE	2017-06-20	<0.02
T22_ANNUAL_RUNS	MOC_TAILRACE	2018-06-18	0.022

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
EAST BAY SURFACE WATER			
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2018-06-18	0.16
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2019-06-17	0.2
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2020-07-01	0.158
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2021-03-03	0.11
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2016-06-15	0.12
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2017-06-19	0.12
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2018-06-18	0.099
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2019-05-02	0.061
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2020-07-01	0.106
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2021-03-03	0.054
T22_ANNUAL_RUNS	CAL_SURF	2016-06-15	0.079
T22_ANNUAL_RUNS	CAL_SURF	2017-06-19	0.096
T22_ANNUAL_RUNS	CAL_SURF	2018-06-18	0.048
T22_ANNUAL_RUNS	CAL_SURF	2019-06-17	0.122
T22_ANNUAL_RUNS	CAL_SURF	2020-07-20	0.038
T22_ANNUAL_RUNS	CAL_SURF	2021-06-28	0.029
T22_ANNUAL_RUNS	SANT_SURF	2016-06-15	0.095
T22_ANNUAL_RUNS	SANT_SURF	2017-06-19	0.12
T22_ANNUAL_RUNS	SANT_SURF	2018-06-18	0.101
T22_ANNUAL_RUNS	SANT_SURF	2019-06-17	0.121
T22_ANNUAL_RUNS	SANT_SURF	2020-06-24	0.073
T22_ANNUAL_RUNS	SANT_SURF	2021-06-11	0.078
WEST BAY SURFACE WATER			
T22_ANNUAL_RUNS	LCS_SURF	2016-06-14	0.18
T22_ANNUAL_RUNS	LCS_SURF	2017-06-19	0.2
T22_ANNUAL_RUNS	LCS_SURF	2018-06-18	0.107
T22_ANNUAL_RUNS	LCS_SURF	2019-06-17	<0.02
T22_ANNUAL_RUNS	LCS_SURF	2020-07-28	0.079
T22_ANNUAL_RUNS	LCS_SURF	2021-06-14	0.049
T22_ANNUAL_RUNS	SA_SURF	2016-06-14	0.12
T22_ANNUAL_RUNS	SA_SURF	2017-06-19	0.21
T22_ANNUAL_RUNS	SA_SURF	2018-06-18	0.096
T22_ANNUAL_RUNS	SA_SURF	2019-06-17	0.132
T22_ANNUAL_RUNS	SA_SURF	2020-06-15	0.06
T22_ANNUAL_RUNS	SA_SURF	2021-06-16	0.072
T22_ANNUAL_RUNS	PIL_SURF	2016-06-14	0.063
T22_ANNUAL_RUNS	PIL_SURF	2017-06-19	0.087
T22_ANNUAL_RUNS	PIL_SURF	2018-06-18	0.051
T22_ANNUAL_RUNS	PIL_SURF	2019-06-17	0.079
T22_ANNUAL_RUNS	PIL_SURF	2020-07-21	0.042

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
T22_ANNUAL_RUNS	PIL_SURF	2021-06-22	0.034
T22_ANNUAL_RUNS	STONE_DAM_SURF	2016-06-14	0.035
T22_ANNUAL_RUNS	STONE_DAM_SURF	2017-06-19	0.061
T22_ANNUAL_RUNS	STONE_DAM_SURF	2018-06-18	0.032
T22_ANNUAL_RUNS	STONE_DAM_SURF	2019-06-17	0.051
T22_ANNUAL_RUNS	STONE_DAM_SURF	2020-07-21	0.036
T22_ANNUAL_RUNS	STONE_DAM_SURF	2021-06-29	<0.02
GROUNDWATER SF CITY			
T22_ANNUAL_RUNS	LK_MERCED_S	2016-06-20	0.041
T22_ANNUAL_RUNS	LK_MERCED_S	2017-06-19	0.076
T22_ANNUAL_RUNS	LK_MERCED_S	2020-07-14	2.52
T22_ANNUAL_RUNS	SF_ZOO_WELL_5	2020-06-17	6.65
SFGW_HISTORICAL	SFGW-LMW	2017-03-01	9.2
SFGW_HISTORICAL	SFGW-LMW	2017-03-01	9.15
SFGW_HISTORICAL	SFGW-LMW	2017-04-17	7.12
SFGW_HISTORICAL	SFGW-LMW	2017-04-18	7.16
SFGW_HISTORICAL	SFGW-LMW	2017-06-07	7.6
SFGW_HISTORICAL	SFGW-LMW	2017-06-08	7.2
SFGW_HISTORICAL	SFGW-LMW	2017-06-12	7.3
SFGW_HISTORICAL	SFGW-LMW	2017-06-13	7.4
SFGW_HISTORICAL	SFGW-LMW	2017-06-14	7.6
SFGW_HISTORICAL	SFGW-LMW	2017-06-27	7.5
SFGW_HISTORICAL	SFGW-LMW	2017-06-28	7.5
SFGW_HISTORICAL	SFGW-LMW	2017-06-29	7.5
SFGW_HISTORICAL	SFGW-LMW	2017-07-05	7.5
SFGW_HISTORICAL	SFGW-LMW	2017-07-06	7.6
SFGW_HISTORICAL	SFGW-LMW	2017-07-11	7.4
SFGW_HISTORICAL	SFGW-LMW	2017-07-12	7.4
SFGW_HISTORICAL	SFGW-LMW	2017-07-13	7.3
SFGW_HISTORICAL	SFGW-LMW	2017-10-18	7.61
SFGW_7DAY	SFGW-LMW	2017-10-24	7.75
SFGW_7DAY	SFGW-LMW	2017-10-26	7.9
SFGW_7DAY	SFGW-LMW	2017-10-30	7.8
SFGW_7DAY	SFGW-LMW	2017-10-31	6.71
SFGW_7DAY	SFGW-LMW	2017-11-16	7.36
SFGW_7DAY	SFGW-LMW	2017-12-18	7.59
SFGW_7DAY	SFGW-LMW	2017-12-20	7.54
SFGW_7WEEK	SFGW-LMW	2017-12-26	7.68
SFGW_1ST-YR	SFGW-LMW	2018-01-11	7.49
SFGW_7WEEK	SFGW-LMW	2018-01-16	7.34
SFGW_7WEEK	SFGW-LMW	2018-01-23	7.54

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_7DAY	SFGW-GCW	2018-01-24	21.2
SFGW_7DAY	SFGW-GCW	2018-01-25	21.2
SFGW_7DAY	SFGW-GCW	2018-01-29	21.2
SFGW_7DAY	SFGW-GCW	2018-01-30	20.8
SFGW_7WEEK	SFGW-LMW	2018-01-30	7.07
SFGW_7DAY	SFGW-GCW	2018-01-31	20.5
SFGW_7DAY	SFGW-GCW	2018-02-01	21
SFGW_7DAY	SFGW-GCW	2018-02-05	20.9
SFGW_7WEEK	SFGW-LMW	2018-02-06	7.19
SFGW_7DAY	SFGW-WSW	2018-02-06	24.8
SFGW_7DAY	SFGW-WSW	2018-02-07	24.5
SFGW_7DAY	SFGW-WSW	2018-02-08	24.2
SFGW_7DAY	SFGW-WSW	2018-02-12	23.6
SFGW_7WEEK	SFGW-GCW	2018-02-13	20.8
SFGW_7WEEK	SFGW-LMW	2018-02-13	7.2
SFGW_7DAY	SFGW-WSW	2018-02-13	24.4
SFGW_7DAY	SFGW-WSW	2018-02-14	24.3
SFGW_7DAY	SFGW-WSW	2018-02-15	23.9
SFGW_7WEEK	SFGW-GCW	2018-02-20	20.2
SFGW_7DAY	SFGW-SSW	2018-02-20	11.3
SFGW_7WEEK	SFGW-WSW	2018-02-20	24.2
SFGW_7DAY	SFGW-SSW	2018-02-21	9.86
SFGW_7DAY	SFGW-SSW	2018-02-22	9.76
SFGW_7DAY	SFGW-SSW	2018-02-26	10.5
SFGW_7DAY	SFGW-GCW	2018-02-27	21.4
SFGW_7DAY	SFGW-SSW	2018-02-27	10.2
SFGW_7DAY	SFGW-WSW	2018-02-27	25.1
SFGW_7DAY	SFGW-SSW	2018-02-28	10.6
SFGW_7DAY	SFGW-SSW	2018-03-01	10.2
SFGW_7WEEK	SFGW-GCW	2018-03-06	21.9
SFGW_1ST-YR	SFGW-GCW	2018-03-06	21.6
SFGW_7WEEK	SFGW-SSW	2018-03-06	10.5
SFGW_1ST-YR	SFGW-SSW	2018-03-06	10.4
SFGW_7WEEK	SFGW-WSW	2018-03-08	24.9
SFGW_1ST-YR	SFGW-WSW	2018-03-08	24.5
SFGW_7WEEK	SFGW-GCW	2018-03-13	21.4
SFGW_7WEEK	SFGW-SSW	2018-03-13	10.5
SFGW_7WEEK	SFGW-WSW	2018-03-13	24.3
SFGW_1ST-YR	SFGW-GCW	2018-03-20	21.8
SFGW_1ST-YR	SFGW-LMW	2018-03-20	7.26
SFGW_1ST-YR	SFGW-SSW	2018-03-20	11.1

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_1ST-YR	SFGW-WSW	2018-03-20	24.6
SFGW_7WEEK	SFGW-GCW	2018-03-27	20.5
SFGW_7WEEK	SFGW-SSW	2018-03-27	9.71
SFGW_7WEEK	SFGW-WSW	2018-03-27	23.2
SFGW_7WEEK	SFGW-SSW	2018-04-04	9.56
SFGW_7WEEK	SFGW-SSW	2018-04-10	10.3
SFGW_7WEEK	SFGW-WSW	2018-04-10	23.9
SFGW_7WEEK	SFGW-SSW	2018-04-17	19.4
SFGW_7WEEK	SFGW-SSW	2018-04-19	19.7
SFGW_7WEEK	SFGW-WSW	2018-04-19	22.7
SFGW_1ST-YR	SFGW-GCW	2018-04-24	21
SFGW_1ST-YR	SFGW-LMW	2018-04-24	6.67
SFGW_1ST-YR	SFGW-GCW	2018-05-15	19.5
SFGW_1ST-YR	SFGW-SSW	2018-05-15	18.3
SFGW_1ST-YR	SFGW-WSW	2018-05-15	21.7
SFGW_1ST-YR	SFGW-LMW	2018-05-16	7.25
SFGW_1ST-YR	SFGW-GCW	2018-06-12	20.1
SFGW_1ST-YR	SFGW-SSW	2018-06-12	18.8
SFGW_1ST-YR	SFGW-WSW	2018-06-12	23.4
SFGW_1ST-YR	SFGW-GCW	2018-07-17	21.8
SFGW_1ST-YR	SFGW-LMW	2018-07-17	7.57
SFGW_1ST-YR	SFGW-SSW	2018-07-17	19
SFGW_1ST-YR	SFGW-WSW	2018-07-17	23.6
SFGW_1ST-YR	SFGW-GCW	2018-09-18	21.2
SFGW_1ST-YR	SFGW-GCW	2018-09-18	21.2
SFGW_1ST-YR	SFGW-SSW	2018-09-18	14.5
SFGW_1ST-YR	SFGW-SSW	2018-09-18	16.1
SFGW_1ST-YR	SFGW-WSW	2018-09-18	23.7
SFGW_1ST-YR	SFGW-WSW	2018-09-18	24.4
SFGW_1ST-YR	SFGW-GCW	2018-10-17	20.8
SFGW_1ST-YR	SFGW-LMW	2018-10-17	6.1
SFGW_1ST-YR	SFGW-SSW	2018-10-17	17.4
SFGW_1ST-YR	SFGW-WSW	2018-10-17	18.4
SFGW_1ST-YR	SFGW-GCW	2018-11-20	21.1
SFGW_1ST-YR	SFGW-SSW	2018-11-20	17.9
SFGW_1ST-YR	SFGW-WSW	2018-11-20	24
SFGW_1ST-YR	SFGW-GCW	2018-12-11	20.5
SFGW_1ST-YR	SFGW-LMW	2018-12-11	7.16
SFGW_1ST-YR	SFGW-SSW	2018-12-11	18.3
SFGW_1ST-YR	SFGW-WSW	2018-12-11	22.7
SFGW_RUNS	SFGW-GCW	2019-01-15	16.3

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_RUNS	SFGW-LMW	2019-01-15	0.024
SFGW_RUNS	SFGW-SSW	2019-01-15	13.2
SFGW_RUNS	SFGW-WSW	2019-01-15	19.7
SFGW_WRD	SFGW-SSW	2019-03-19	17.2
SFGW_WRD	SFGW-SSW	2019-03-26	17.7
SFGW_WRD	SFGW-SSW	2019-04-01	10.9
SFGW_WRD	SFGW-SSW	2019-04-04	9.73
SFGW_WRD	SFGW-SSW	2019-04-08	9.6
SFGW_WRD	SFGW-SSW	2019-04-11	10.2
SFGW_WRD	SFGW-SSW	2019-04-15	15.4
SFGW_WRD	SFGW-SSW	2019-04-18	10.2
SFGW_WRD	SFGW-SSW	2019-04-22	10.2
SFGW_RUNS	SFGW-GCW	2019-04-25	20.9
SFGW_RUNS	SFGW-LMW	2019-04-25	7.51
SFGW_WRD	SFGW-SSW	2019-04-25	10
SFGW_RUNS	SFGW-SSW	2019-04-25	9.95
SFGW_RUNS	SFGW-WSW	2019-04-25	21.4
SFGW_WRD	SFGW-SSW	2019-04-29	11.6
SFGW_WRD	SFGW-SSW	2019-05-02	11.4
SFGW_WRD	SFGW-SSW	2019-05-13	11.9
SFGW_WRD	SFGW-SSW	2019-05-13	12.9
SFGW_WRD	SFGW-SSW	2019-05-13	11.9
SFGW_WRD	SFGW-SSW	2019-05-13	22.5
SFGW_WRD	SFGW-SSW	2019-05-13	17.3
SFGW_WRD	SFGW-SSW	2019-05-16	12.3
SFGW_WRD	SFGW-SSW	2019-05-16	11.8
SFGW_WRD	SFGW-SSW	2019-05-16	11.9
SFGW_WRD	SFGW-SSW	2019-05-16	24.4
SFGW_WRD	SFGW-SSW	2019-05-16	11.8
SFGW_RUNS	SFGW-GCW	2019-07-16	22.1
SFGW_RUNS	SFGW-LMW	2019-07-16	9.31
SFGW_RUNS	SFGW-SSW	2019-07-16	19.8
SFGW_RUNS	SFGW-WSW	2019-07-16	21.6
SFGW_RUNS	SFGW-GCW	2019-10-15	22
SFGW_RUNS	SFGW-LMW	2019-10-15	8.26
SFGW_RUNS	SFGW-SSW	2019-10-15	19.1
SFGW_RUNS	SFGW-WSW	2019-10-15	23.7
SFGW_RUNS	SFGW-GCW	2020-01-21	22
SFGW_RUNS	SFGW-LMW	2020-01-21	2.51
SFGW_RUNS	SFGW-WSW	2020-01-21	22.7
SFGW_RUNS	SFGW-SSW	2020-01-29	18.3

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_RUNS	SFGW-GCW	2020-04-21	21.2
SFGW_RUNS	SFGW-LMW	2020-04-21	7.67
SFGW_RUNS	SFGW-SSW	2020-04-21	18.6
SFGW_RUNS	SFGW-WSW	2020-04-21	22.9
SFGW_7DAY	SFGW-NLW	2020-07-13	17.7
SFGW_RUNS	SFGW-LMW	2020-07-14	7.54
SFGW_RUNS	SFGW-LMW	2020-07-14	7.67
SFGW_RUNS	SFGW-SSW	2020-07-14	20.1
SFGW_RUNS	SFGW-SSW	2020-07-14	20.3
SFGW_7DAY	SFGW-SWW	2020-07-14	13.4
SFGW_RUNS	SFGW-GCW	2020-07-15	21.5
SFGW_RUNS	SFGW-GCW	2020-07-15	21.5
SFGW_RUNS	SFGW-WSW	2020-07-15	23
SFGW_RUNS	SFGW-WSW	2020-07-15	22.9
SFGW_1ST-YR	SFGW-NLW	2020-07-16	19.5
SFGW_7DAY	SPECIAL	2020-07-15	13.6
SFGW_7DAY	SPECIAL	2020-07-15	18.7
SFGW_7DAY	SFGW-NLW	2020-07-20	19
SFGW_7DAY	SFGW-SWW	2020-07-20	14.4
SFGW_1ST-YR	SFGW-SWW	2020-07-20	14.5
SFGW_7DAY	SFGW-NLW	2020-07-21	19.5
SFGW_7DAY	SFGW-SWW	2020-07-21	14.4
SFGW_7DAY	SFGW-NLW	2020-07-22	19.2
SFGW_7DAY	SFGW-SWW	2020-07-23	14.1
SFGW_RUNS	SFGW-GCW	2020-10-20	20.6
SFGW_RUNS	SFGW-LMW	2020-10-20	7.54
SFGW_1ST-YR	SFGW-NLW	2020-10-20	16.8
SFGW_RUNS	SFGW-SSW	2020-10-20	17.4
SFGW_1ST-YR	SFGW-SWW	2020-10-20	13.5
SFGW_RUNS	SFGW-WSW	2020-10-20	22.2
SFGW_RUNS	SFGW-GCW	2021-01-12	20.3
SFGW_RUNS	SFGW-LMW	2021-01-12	6.91
SFGW_1ST-YR	SFGW-NLW	2021-01-12	13.8
SFGW_RUNS	SFGW-SSW	2021-01-12	17.1
SFGW_1ST-YR	SFGW-SWW	2021-01-12	9.85
SFGW_RUNS	SFGW-WSW	2021-01-12	20.8
SFGW_RUNS	SFGW-GCW	2021-04-13	22
SFGW_RUNS	SFGW-LMW	2021-04-13	7.79
SFGW_1ST-YR	SFGW-NLW	2021-04-13	16.5
SFGW_1ST-YR	SFGW-SWW	2021-04-13	14.2
SFGW_RUNS	SFGW-WSW	2021-04-13	23.3

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SFGW_RUNS	SFGW-SSW	2021-04-22	17
SFGW_RUNS	SFGW-LMW	2021-07-13	7.73
SFGW_RUNS	SFGW-SSW	2021-07-13	18
SFGW_RUNS	SFGW-WSW	2021-07-13	22.3
SFGW_RUNS	SFGW-GCW	2021-07-20	21
SFGW_RUNS	SFGW-NLW	2021-08-12	15.6
SFGW_RUNS	SFGW-SWW	2021-08-12	14.4
SFGW_RUNS	SFGW-GCW	2021-10-12	21
SFGW_RUNS	SFGW-LMW	2021-10-12	6.7
SFGW_RUNS	SFGW-NLW	2021-10-12	18
SFGW_RUNS	SFGW-SSW	2021-10-12	18
SFGW_RUNS	SFGW-SWW	2021-10-12	14
SFGW_RUNS	SFGW-WSW	2021-10-12	23
GROUNDWATER PENINSULA			
GSR_PARTNER	GSR-SMW	2016-02-17	<0.02
GSR_PARTNER	GSR-LPW	2018-07-25	<0.02
GSR_PARTNER	GSR-LPW	2018-07-25	<0.02
GSR_PARTNER	GSR-LPW	2018-07-25	<0.02
GSR_HISTORICAL	GSR-FHW	2018-08-01	<0.02
GSR_HISTORICAL	GSR-FHW	2018-08-01	<0.02
GSR_HISTORICAL	GSR-FHW	2018-08-01	<0.02
GSR_HISTORICAL	GSR-FHW	2018-08-02	<0.02
GSR_HISTORICAL	GSR-FHW	2018-08-02	<0.02
GSR_HISTORICAL	GSR-FHW	2018-08-02	<0.02
GSR_HISTORICAL	GSR-MSW	2018-08-29	19.3
GSR_HISTORICAL	GSR-MSW	2018-08-29	18.6
GSR_HISTORICAL	GSR-MSW	2018-08-29	17.1
GSR_HISTORICAL	GSR-TIW	2018-08-30	18.4
GSR_HISTORICAL	GSR-TIW	2018-08-30	17
GSR_HISTORICAL	GSR-TIW	2018-08-30	19.2
GSR_HISTORICAL	GSR-CBW	2018-09-05	14.6
GSR_HISTORICAL	GSR-CBW	2018-09-05	13.9
GSR_HISTORICAL	GSR-CBW	2018-09-05	13.8
GSR_HISTORICAL	GSR-CRW	2018-09-05	25.4
GSR_HISTORICAL	GSR-CRW	2018-09-05	25.7
GSR_HISTORICAL	GSR-CRW	2018-09-05	25.3
GSR_HISTORICAL	GSR-CBW	2018-09-06	14.3
GSR_HISTORICAL	GSR-CBW	2018-09-06	14.2
GSR_HISTORICAL	GSR-CBW	2018-09-06	14.3
GSR_HISTORICAL	GSR-CRW	2018-09-06	26.8
GSR_HISTORICAL	GSR-CRW	2018-09-06	25.4

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
GSR_HISTORICAL	GSR-CRW	2018-09-06	26.6
GSR_HISTORICAL	GSR-LGW	2018-09-12	14.4
GSR_HISTORICAL	GSR-LGW	2018-09-12	14.8
GSR_HISTORICAL	GSR-LGW	2018-09-12	14.2
GSR_HISTORICAL	GSR-SBW	2018-09-12	25.3
GSR_HISTORICAL	GSR-SBW	2018-09-12	25.3
GSR_HISTORICAL	GSR-SBW	2018-09-12	25.2
GSR_HISTORICAL	GSR-LGW	2018-09-13	13.4
GSR_HISTORICAL	GSR-LGW	2018-09-13	13.8
GSR_HISTORICAL	GSR-LGW	2018-09-13	13.7
GSR_HISTORICAL	GSR-SBW	2018-09-13	25.2
GSR_HISTORICAL	GSR-SBW	2018-09-13	24.6
GSR_HISTORICAL	GSR-SBW	2018-09-13	24.8
GSR_HISTORICAL	GSR-HBW	2018-09-19	30.3
GSR_HISTORICAL	GSR-HBW	2018-09-19	30.2
GSR_HISTORICAL	GSR-HBW	2018-09-19	30
GSR_HISTORICAL	GSR-SRW	2018-09-19	13.8
GSR_HISTORICAL	GSR-SRW	2018-09-19	13.4
GSR_HISTORICAL	GSR-SRW	2018-09-19	14.1
GSR_HISTORICAL	GSR-HBW	2018-09-20	29.9
GSR_HISTORICAL	GSR-HBW	2018-09-20	30.2
GSR_HISTORICAL	GSR-HBW	2018-09-20	29.8
GSR_HISTORICAL	GSR-SRW	2018-09-20	14
GSR_HISTORICAL	GSR-SRW	2018-09-20	13.2
GSR_HISTORICAL	GSR-SRW	2018-09-20	14.2
GSR_HISTORICAL	GSR-MYW	2018-09-26	6.4
GSR_HISTORICAL	GSR-MYW	2018-09-26	6.43
GSR_HISTORICAL	GSR-MYW	2018-09-26	6.58
GSR_HISTORICAL	GSR-MYW	2018-09-27	6.56
GSR_HISTORICAL	GSR-MYW	2018-09-27	6.58
GSR_HISTORICAL	GSR-MYW	2018-09-27	6.62
GSR_PARTNER	GSR-PPW	2018-10-03	13.2
GSR_PARTNER	GSR-PPW	2018-10-03	12.8
GSR_PARTNER	GSR-PPW	2018-10-03	13.4
GSR_PARTNER	GSR-PPW	2018-10-04	12
GSR_PARTNER	GSR-PPW	2018-10-04	<0.2
GSR_PARTNER	GSR-PPW	2018-10-04	11.8
GSR_PARTNER	GSR-BFW	2018-10-03	11.6
GSR_PARTNER	GSR-BFW	2018-10-03	11.5
GSR_PARTNER	GSR-BFW	2018-10-03	11.8
GSR_PARTNER	GSR-BFW	2018-10-04	11.5

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
GSR_PARTNER	GSR-BFW	2018-10-04	11.4
GSR_PARTNER	GSR-BFW	2018-10-04	11.3
GSR_PARTNER	GSR-BFW	2020-08-12	13
GSR_PRE-COMP	GSR-HBW	2019-06-24	31.6
GSR_PRE-COMP	GSR-PDWLGWLGW	2019-06-24	16.1
GSR_PRE-COMP	GSR-SBW	2019-06-24	12.3
GSR_PRE-COMP	GSR-MSW	2019-06-25	23.1
GSR_PRE-COMP	GSR-MYW	2019-06-25	6.69
GSR_PRE-COMP	GSR-SDW	2019-06-25	<0.02
GSR_PRE-COMP	GSR-BSW	2019-06-26	24.5
GSR_PRE-COMP	GSR-CBW	2019-06-26	17.8
GSR_PRE-COMP	GSR-FSW	2019-06-26	29.5
GSR_7DAY	GSR-FSCP	2020-01-15	0.765
GSR_7DAY	GSR-FSW	2020-01-15	29.4
GSR_7DAY	GSR-FSCP	2020-01-16	0.565
GSR_7DAY	GSR-FSW	2020-01-16	28.5
GSR_7DAY	GSR-FSCP	2020-01-27	0.622
GSR_7DAY	GSR-FSW	2020-01-27	29.7
GSR_7DAY	GSR-FSCP	2020-01-28	0.62
GSR_7DAY	GSR-FSW	2020-01-28	29.5
GSR_7DAY	GSR-FSCP	2020-01-29	0.468
GSR_7DAY	GSR-FSW	2020-01-29	28.2
GSR_7DAY	GSR-FSCP	2020-01-30	0.571
GSR_7DAY	GSR-FSW	2020-01-30	27.6
GSR_7DAY	GSR-CBW	2020-02-19	19.2
GSR_7DAY	GSR-FSCP	2020-02-19	0.493
GSR_7DAY	GSR-CBW	2020-02-20	18.7
GSR_7DAY	GSR-FSCP	2020-02-20	0.446
GSR_7DAY	GSR-CBW	2020-02-21	19.1
GSR_7DAY	GSR-FSCP	2020-02-21	0.508
GSR_7DAY	GSR-CBW	2020-02-22	18.5
GSR_7DAY	GSR-FSCP	2020-02-22	0.477
GSR_7DAY	GSR-CBW	2020-03-02	20.1
GSR_7DAY	GSR-FSCP	2020-03-02	1.17
GSR_7DAY	GSR-FSW	2020-03-02	31.1
GSR_7DAY	GSR-CBW	2020-03-03	20.8
GSR_7DAY	GSR-FSCP	2020-03-03	1.18
GSR_7DAY	GSR-FSW	2020-03-03	30.8
GSR_7DAY	GSR-CBW	2020-03-04	20.4
GSR_7DAY	GSR-FSCP	2020-03-04	0.931
GSR_7DAY	GSR-FSW	2020-03-04	30.8

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
GSR_7DAY	GSR-CBW	2020-03-05	20.6
GSR_7DAY	GSR-FSCP	2020-03-05	1.2
GSR_7DAY	GSR-FSW	2020-03-05	31
GSR_7DAY	GSR-HBCP	2020-03-09	1.23
GSR_7DAY	GSR-HBW	2020-03-09	34.4
GSR_7DAY	GSR-HBCP	2020-03-10	1.27
GSR_7DAY	GSR-HBW	2020-03-10	34.7
GSR_7DAY	GSR-HBCP	2020-05-11	1.18
GSR_7DAY	GSR-HBW	2020-05-11	29.6
GSR_7DAY	GSR-HBCP	2020-05-12	1.09
GSR_7DAY	GSR-HBW	2020-05-12	28.9
GSR_7DAY	GSR-HBCP	2020-05-13	1.02
GSR_7DAY	GSR-HBW	2020-05-13	29.2
GSR_7DAY	GSR-HBCP	2020-05-14	0.983
GSR_7DAY	GSR-HBW	2020-05-14	29.4
GSR_7DAY	GSR-MYW	2020-05-26	5.52
GSR_7DAY	GSR-MYCP	2020-06-01	0.114
GSR_7DAY	GSR-MYW	2020-06-01	3.15
GSR_7DAY	GSR-MYCP	2020-06-02	0.025
GSR_7DAY	GSR-MYW	2020-06-02	3.19
GSR_7DAY	GSR-MYCP	2020-06-03	0.11
GSR_7DAY	GSR-MYW	2020-06-03	6.5
GSR_7DAY	GSR-MYCP	2020-06-04	0.127
GSR_7DAY	GSR-MYW	2020-06-04	6.41
GSR_7DAY	GSR-MYCP	2020-06-05	0.106
GSR_7DAY	GSR-MYW	2020-06-05	5.16
GSR_7DAY	GSR-PDCP	2020-06-23	0.471
GSR_7DAY	GSR-PDWLGWLGW	2020-06-23	16.2
GSR_7DAY	GSR-PDCP	2020-06-24	0.449
GSR_7DAY	GSR-PDWLGWLGW	2020-06-24	14.2
GSR_7DAY	GSR-PDCP	2020-06-25	0.425
GSR_7DAY	GSR-PDWLGWLGW	2020-06-25	14.2
GSR_7DAY	GSR-PDCP	2020-06-26	0.376
GSR_7DAY	GSR-PDWLGWLGW	2020-06-26	14.5
GSR_1ST-YR	GSR-HBW	2020-07-07	30.4
GSR_1ST-YR	GSR-PDW	2020-07-07	14.8
GSR_1ST-YR	GSR-CBW	2020-07-08	18
GSR_1ST-YR	GSR-FSW	2020-07-08	26.9
GSR_1ST-YR	GSR-MYW	2020-07-08	5.55
GSR_HISTORICAL	GSR-SDW	2020-08-05	<0.02
GSR_PARTNER	GSR-LPW	2020-08-26	<0.02

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
GSR_1ST-YR	GSR-CBW	2020-10-21	18.5
GSR_1ST-YR	GSR-FSW	2020-10-21	26.1
GSR_1ST-YR	GSR-PDW	2020-10-21	14
GSR_1ST-YR	GSR-HBW	2020-10-22	28.8
GSR_1ST-YR	GSR-MYW	2020-10-22	5.26
GSR_1ST-YR	GSR-HBW	2021-01-06	24.9
GSR_1ST-YR	GSR-MYW	2021-01-06	4.42
GSR_1ST-YR	GSR-PDW	2021-01-07	12.4
GSR_1ST-YR	GSR-CBW	2021-01-13	18.4
GSR_1ST-YR	GSR-FSW	2021-01-13	23.8
GSR_7DAY	GSR-BSW	2021-03-02	23
GSR_7DAY	GSR-FSCP	2021-03-02	0.98
GSR_7DAY	GSR-BSW	2021-03-03	24
GSR_7DAY	GSR-CBW	2021-03-03	20
GSR_7DAY	GSR-FSCP	2021-03-03	1.7
GSR_7DAY	GSR-FSW	2021-03-03	30
GSR_7DAY	GSR-BSW	2021-03-04	24
GSR_7DAY	GSR-CBW	2021-03-04	20
GSR_7DAY	GSR-FSCP	2021-03-04	1.8
GSR_7DAY	GSR-FSW	2021-03-04	29
GSR_7DAY	GSR-BSW	2021-03-05	24
GSR_7DAY	GSR-CBW	2021-03-05	20
GSR_7DAY	GSR-FSCP	2021-03-05	1.9
GSR_7DAY	GSR-FSW	2021-03-05	29
GSR_7DAY	GSR-BSW	2021-03-06	24
GSR_7DAY	GSR-CBW	2021-03-06	20
GSR_7DAY	GSR-FSCP	2021-03-06	2.4
GSR_7DAY	GSR-FSW	2021-03-06	29
GSR_1ST-YR	GSR-BSW	2021-04-07	22.5
GSR_1ST-YR	GSR-CBW	2021-04-07	19.9
GSR_1ST-YR	GSR-FSW	2021-04-07	28.7
GSR_1ST-YR	GSR-PDW	2021-04-07	14.7
GSR_1ST-YR	GSR-HBW	2021-04-08	30.5
GSR_1ST-YR	GSR-MYW	2021-04-08	5.63
GSR_7WEEK	GSR-MYCP	2021-06-01	0.086
GSR_7WEEK	GSR-MYW	2021-06-01	5.97
GSR_7WEEK	GSR-MYCP	2021-06-09	0.069
GSR_7WEEK	GSR-MYW	2021-06-09	6.36
GSR_7WEEK	GSR-MYCP	2021-06-16	0.081
GSR_7WEEK	GSR-MYW	2021-06-16	6.94
GSR_7WEEK	GSR-BSW	2021-06-23	23.7

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
GSR_7WEEK	GSR-CBW	2021-06-23	22.1
GSR_7WEEK	GSR-FSCP	2021-06-23	3.09
GSR_7WEEK	GSR-FSW	2021-06-23	30.1
GSR_7WEEK	GSR-MYCP	2021-06-23	0.067
GSR_7WEEK	GSR-MYW	2021-06-23	7.04
GSR_7WEEK	GSR-BSW	2021-07-01	20.2
GSR_7WEEK	GSR-CBW	2021-07-01	18.8
GSR_7WEEK	GSR-FSCP	2021-07-01	1.83
GSR_7WEEK	GSR-FSW	2021-07-01	26.1
GSR_7WEEK	GSR-MYCP	2021-07-01	0.086
GSR_7WEEK	GSR-MYW	2021-07-01	6.35
GSR_7WEEK	GSR-MYCP	2021-07-07	0.134
GSR_7WEEK	GSR-MYW	2021-07-07	6.59
GSR_1ST-YR	GSR-BSW	2021-07-14	20.8
GSR_RUNS	GSR-HBW	2021-08-05	31.7
GSR_RUNS	GSR-PDW	2021-08-05	13.6
GSR_7WEEK	GSR-BSW	2021-08-12	22.2
GSR_7WEEK	GSR-CBW	2021-08-12	20.7
GSR_7WEEK	GSR-FSCP	2021-08-12	2.2
GSR_7WEEK	GSR-FSW	2021-08-12	27.8
GSR_7WEEK	GSR-BSW	2021-08-18	23.1
GSR_7WEEK	GSR-CBW	2021-08-18	20.9
GSR_7WEEK	GSR-FSCP	2021-08-18	2.4
GSR_7WEEK	GSR-FSW	2021-08-18	27.4
GSR_1ST-YR	GSR-SBW	2021-08-18	13.9
GSR_7WEEK	GSR-BSW	2021-08-26	22
GSR_7WEEK	GSR-CBW	2021-08-26	20
GSR_7WEEK	GSR-FSCP	2021-08-26	1.8
GSR_7WEEK	GSR-FSW	2021-08-26	28
GSR_7WEEK	GSR-BSW	2021-09-01	22
GSR_7WEEK	GSR-CBW	2021-09-01	20
GSR_7WEEK	GSR-FSCP	2021-09-01	1.5
GSR_7WEEK	GSR-FSW	2021-09-01	28
GSR_1ST-YR	GSR-BSW	2021-10-06	21
GSR_RUNS	GSR-CBW	2021-10-06	20
GSR_RUNS	GSR-FSW	2021-10-06	27
GSR_RUNS	GSR-PDW	2021-10-06	15
GSR_RUNS	GSR-HBW	2021-10-07	30
GSR_RUNS	GSR-MYW	2021-10-07	6.2
GSR_1ST-YR	GSR-SBW	2021-11-04	15.8
GSR_7DAY	GSR-MSW	2021-12-08	21.6

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
GSR_1ST-YR	GSR-MSW	2021-12-16	21.1
GROUNDWATER EAST BAY			
T22_ANNUAL_RUNS	SUNOL_FILTER	2016-06-14	0.23
T22_ANNUAL_RUNS	SUNOL_FILTER	2017-06-19	0.14
T22_ANNUAL_RUNS	SUNOL_FILTER	2018-06-18	0.244
T22_ANNUAL_RUNS	SUNOL_FILTER	2019-06-17	0.246
T22_ANNUAL_RUNS	SUNOL_FILTER	2020-06-17	0.236
T22_ANNUAL_RUNS	SUNOL_FILTER	2021-06-23	0.225
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2016-06-14	3.9
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2016-06-14	3.4
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2017-06-19	3.8
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2017-06-19	3.4
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2018-06-18	3.96
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2018-06-18	3.33
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2019-06-17	3.68
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2019-06-26	2.42
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2020-06-16	2.3
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2020-06-16	3.16
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2021-06-23	3.82
WQ_MOCCASIN_SPECIAL	OSH_BKPK_WELL	2016-03-02	<0.02
WQ_MOCCASIN_SPECIAL	OSH_BKPK_WELL	2016-03-23	<0.02
DRINKING WATER			
T22_ANNUAL_RUNS	EI_TK	2020-06-23	0.041
T22_ANNUAL_RUNS	MOC_TK	2020-06-15	<0.02
T22_ANNUAL_RUNS	OSH_TK	2020-06-16	<0.02
T22_ANNUAL_RUNS	ALAMEDA_EAST	2016-06-14	0.023
T22_ANNUAL_RUNS	ALAMEDA_EAST	2017-06-19	0.039
T22_ANNUAL_RUNS	ALAMEDA_EAST	2018-06-18	0.031
T22_ANNUAL_RUNS	ALAMEDA_EAST	2019-06-17	0.041
T22_ANNUAL_RUNS	ALAMEDA_EAST	2020-06-15	<0.02
T22_ANNUAL_RUNS	ALAMEDA_EAST	2021-06-22	<0.02
T22_ANNUAL_RUNS	SVWTP_EFF	2016-06-14	0.098
T22_ANNUAL_RUNS	SVWTP_EFF	2017-06-19	0.13
T22_ANNUAL_RUNS	SVWTP_EFF	2018-09-21	0.073
T22_ANNUAL_RUNS	SVWTP_EFF	2019-06-17	0.12
T22_ANNUAL_RUNS	SVWTP_EFF	2020-06-24	0.0623
T22_ANNUAL_RUNS	SVWTP_TWR_EFF	2021-06-15	0.064
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2016-06-21	0.11
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2017-06-19	0.19
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2018-06-18	0.1
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2019-07-02	0.186

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2020-06-15	0.06
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2021-06-16	0.057
T22_ANNUAL_RUNS	CS#2_BADEN	2016-06-14	0.034
T22_ANNUAL_RUNS	CS#2_BADEN	2020-06-16	<0.02
SFDS_RUNS	SSO#1_N	2017-04-23	0.094
SFDS_RUNS	SSO#1_N	2017-05-02	0.144
SFDS_RUNS	SSO#1_N	2017-05-09	0.0892
SFDS_RUNS	SSO#1_N	2017-05-16	0.14
SFDS_RUNS	SSO#1_N	2017-05-23	0.14
SFDS_RUNS	SSO#1_N	2017-05-30	0.15
SFDS_RUNS	SSO#1_N	2017-06-06	0.14
SFDS_RUNS	SSO#1_N	2017-06-13	0.16
SFDS_RUNS	SSO#1_N	2017-06-20	0.12
SFDS_RUNS	SSO#1_N	2017-06-27	0.09
SFGW_HISTORICAL	SSO#1_N	2017-06-28	0.095
SFGW_HISTORICAL	SSO#1_N	2017-06-29	0.1
SFDS_RUNS	SSO#1_N	2017-07-04	0.1
SFGW_HISTORICAL	SSO#1_N	2017-07-05	0.12
SFGW_HISTORICAL	SSO#1_N	2017-07-06	0.13
SFDS_RUNS	SSO#1_N	2017-07-11	0.084
SFGW_HISTORICAL	SSO#1_N	2017-07-12	0.1
SFGW_HISTORICAL	SSO#1_N	2017-07-13	0.086
SFDS_RUNS	SSO#1_N	2017-07-18	0.038
SFDS_RUNS	SSO#1_N	2017-07-25	0.075
SFDS_RUNS	SSO#1_N	2017-08-01	0.062
SFDS_RUNS	SSO#1_N	2017-08-08	0.088
SFDS_RUNS	SSO#1_N	2017-08-15	0.08
SFDS_RUNS	SSO#1_N	2017-08-22	0.093
SFDS_RUNS	SSO#1_N	2017-08-29	0.1
SFDS_RUNS	SSO#1_N	2017-09-05	0.0784
SFDS_RUNS	SSO#1_N	2017-09-12	0.0778
SFDS_RUNS	SSO#1_N	2017-09-19	0.0646
SFDS_RUNS	SSO#1_N	2017-09-26	0.082
SFDS_RUNS	SSO#1_N	2017-10-03	0.0981
SFDS_RUNS	SSO#1_N	2017-10-10	0.0418
SFDS_RUNS	SSO#1_N	2017-10-17	0.0453
SFDS_RUNS	SSO#1_N	2017-10-24	0.0746
SFGW_7DAY	SSO#1_N	2017-10-24	0.101
SFGW_7DAY	SSO#1_N	2017-10-26	0.0699
SFGW_7DAY	SSO#1_N	2017-10-30	0.0807
SFDS_RUNS	SSO#1_N	2017-10-31	0.0859

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFDS_RUNS	SSO#1_N	2017-11-07	0.101
SFDS_RUNS	SSO#1_N	2017-11-14	0.103
SFGW_7DAY	SSO#1_N	2017-11-16	0.104
SFDS_RUNS	SSO#1_N	2017-11-21	0.0913
SFDS_RUNS	SSO#1_N	2017-11-28	0.0877
SFDS_RUNS	SSO#1_N	2017-12-05	0.0684
SFDS_RUNS	SSO#1_N	2017-12-12	0.0623
SFGW_7DAY	SSO#1_N	2017-12-18	0.0595
SFDS_RUNS	SSO#1_N	2017-12-19	0.0732
SFGW_7DAY	SSO#1_N	2017-12-20	0.055
SFDS_RUNS	SSO#1_N	2017-12-26	0.0303
SFDS_RUNS	SSO#1_N	2018-01-02	0.0533
SFDS_RUNS	SSO#1_N	2018-01-09	0.0519
SFDS_RUNS	SSO#1_N	2018-01-16	0.0409
SFDS_RUNS	SSO#1_N	2018-01-23	0.0392
SFGW_7DAY	SSO#1_N	2018-01-24	0.0595
SFGW_7DAY	SSO#1_N	2018-01-25	0.22
SFGW_7DAY	SSO#1_N	2018-01-29	0.356
SFDS_RUNS	SSO#1_N	2018-01-30	0.445
SFGW_7DAY	SSO#1_N	2018-01-31	0.586
SFGW_7DAY	SSO#1_N	2018-02-01	0.773
SFGW_7DAY	SSO#1_N	2018-02-05	0.719
SFDS_RUNS	SSO#1_N	2018-02-06	0.706
SFGW_7DAY	SSO#1_N	2018-02-07	0.768
SFGW_7DAY	SSO#1_N	2018-02-08	0.821
SFGW_7DAY	SSO#1_N	2018-02-12	0.519
SFDS_RUNS	SSO#1_N	2018-02-13	0.579
SFGW_7DAY	SSO#1_N	2018-02-14	0.619
SFGW_7DAY	SSO#1_N	2018-02-15	0.652
SFDS_RUNS	SSO#1_N	2018-02-20	0.39
SFGW_7DAY	SSO#1_N	2018-02-21	0.42
SFGW_7DAY	SSO#1_N	2018-02-22	0.393
SFGW_7DAY	SSO#1_N	2018-02-26	0.293
SFDS_RUNS	SSO#1_N	2018-02-27	0.299
SFGW_7DAY	SSO#1_N	2018-02-28	0.334
SFGW_7DAY	SSO#1_N	2018-03-01	0.34
SFDS_RUNS	SSO#1_N	2018-03-06	0.673
SFDS_RUNS	SSO#1_N	2018-03-13	0.568
SFDS_RUNS	SSO#1_N	2018-03-20	0.311
SFDS_RUNS	SSO#1_N	2018-03-27	0.884
SFDS_RUNS	SSO#1_N	2018-04-03	0.48

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFDS_RUNS	SSO#1_N	2018-04-10	0.268
SFGW_HISTORICAL	SSO#1_N	2018-04-17	0.168
SFDS_RUNS	SSO#1_N	2018-04-17	0.172
SFDS_RUNS	SSO#1_N	2018-04-24	0.0981
SFDS_RUNS	SSO#1_N	2018-05-01	0.0645
SFDS_RUNS	SSO#1_N	2018-05-08	0.067
SFGW_1ST-YR	SSO#1_N	2018-05-15	0.066
SFDS_RUNS	SSO#1_N	2018-05-15	0.07
SFDS_RUNS	SSO#1_N	2018-05-22	0.068
SFDS_RUNS	SSO#1_N	2018-05-29	0.048
SFDS_RUNS	SSO#1_N	2018-06-05	0.071
SFDS_RUNS	SSO#1_N	2018-06-12	0.056
SFGW_1ST-YR	SSO#1_N	2018-06-18	0.035
SFDS_RUNS	SSO#1_N	2018-06-19	0.035
SFDS_RUNS	SSO#1_N	2018-06-26	0.035
SFDS_RUNS	SSO#1_N	2018-07-03	0.066
SFDS_RUNS	SSO#1_N	2018-07-10	0.05
SFDS_RUNS	SSO#1_N	2018-07-17	0.045
SFGW_OPS	SSO#1_N	2018-07-24	0.11
SFGW_OPS	SSO#1_N	2018-07-31	0.059
SFGW_OPS	SSO#1_N	2018-08-08	0.059
SFGW_OPS	SSO#1_N	2018-08-14	0.053
SFGW_OPS	SSO#1_N	2018-08-21	0.06
SFGW_1ST-YR	SSO#1_N	2018-08-21	0.056
SFGW_OPS	SSO#1_N	2018-08-28	0.033
SFGW_OPS	SSO#1_N	2018-09-04	0.051
SFGW_OPS	SSO#1_N	2018-09-11	0.159
SFGW_OPS	SSO#1_N	2018-09-18	0.19
SFGW_OPS	SSO#1_N	2018-09-25	0.122
SFGW_OPS	SSO#1_N	2018-10-02	0.147
SFGW_OPS	SSO#1_N	2018-10-09	0.062
SFGW_OPS	SSO#1_N	2018-10-16	0.07
SFGW_OPS	SSO#1_N	2018-10-23	0.05
SFGW_1ST-YR	SSO#1_N	2018-10-25	0.05
SFGW_OPS	SSO#1_N	2018-11-06	0.08
SFGW_OPS	SSO#1_N	2018-11-13	0.056
SFGW_1ST-YR	SSO#1_N	2018-11-20	0.141
SFGW_OPS	SSO#1_N	2018-11-20	0.15
SFGW_OPS	SSO#1_N	2018-11-27	0.11
SFGW_OPS	SSO#1_N	2018-12-04	0.419
SFGW_OPS	SSO#1_N	2018-12-11	0.925

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_1ST-YR	SSO#1_N	2018-12-11	0.918
SFGW_OPS	SSO#1_N	2018-12-18	0.907
SFGW_OPS	SSO#1_N	2018-12-26	0.899
SFGW_OPS	SSO#1_N	2019-01-02	0.207
SFGW_OPS	SSO#1_N	2019-01-08	0.074
SFGW_RUNS	SSO#1_N	2019-01-15	0.11
SFGW_OPS	SSO#1_N	2019-01-15	0.105
SFGW_OPS	SSO#1_N	2019-01-22	0.085
SFGW_OPS	SSO#1_N	2019-01-29	0.071
SFGW_OPS	SSO#1_N	2019-02-05	0.088
SFGW_OPS	SSO#1_N	2019-02-12	0.075
SFGW_OPS	SSO#1_N	2019-02-19	0.128
SFGW_RUNS	SSO#1_N	2019-02-20	0.109
SFGW_OPS	SSO#1_N	2019-03-01	0.104
SFGW_OPS	SSO#1_N	2019-03-05	0.101
SFGW_OPS	SSO#1_N	2019-03-12	0.093
SFGW_OPS	SSO#1_N	2019-03-19	0.125
SFGW_RUNS	SSO#1_N	2019-03-19	0.113
SFGW_OPS	SSO#1_N	2019-03-26	0.113
SFGW_OPS	SSO#1_N	2019-04-02	0.36
SFGW_OPS	SSO#1_N	2019-04-09	0.145
SFGW_OPS	SSO#1_N	2019-04-16	0.198
SFGW_RUNS	SSO#1_N	2019-04-16	0.138
SFGW_OPS	SSO#1_N	2019-04-23	0.105
SFGW_OPS	SSO#1_N	2019-04-30	0.128
SFGW_OPS	SSO#1_N	2019-05-07	0.085
SFGW_OPS	SSO#1_N	2019-05-14	0.117
SFGW_OPS	SSO#1_N	2019-05-21	0.091
SFGW_RUNS	SSO#1_N	2019-05-21	0.081
SFGW_OPS	SSO#1_N	2019-05-28	0.174
SFGW_OPS	SSO#1_N	2019-06-04	0.204
SFGW_OPS	SSO#1_N	2019-06-11	0.148
SFGW_OPS	SSO#1_N	2019-06-18	0.134
SFGW_RUNS	SSO#1_N	2019-06-21	0.154
SFGW_RUNS	SSO#1_N	2019-06-21	0.148
SFGW_OPS	SSO#1_N	2019-06-25	0.193
SFGW_OPS	SSO#1_N	2019-07-02	0.175
SFGW_OPS	SSO#1_N	2019-07-09	0.161
SFGW_RUNS	SSO#1_N	2019-07-16	0.132
SFGW_OPS	SSO#1_N	2019-07-16	0.122
SFGW_OPS	SSO#1_N	2019-07-23	0.205

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_OPS	SSO#1_N	2019-07-30	0.109
SFGW_OPS	SSO#1_N	2019-08-06	0.114
SFGW_OPS	SSO#1_N	2019-08-13	0.135
SFGW_OPS	SSO#1_N	2019-08-20	0.155
SFGW_RUNS	SSO#1_N	2019-08-21	0.16
SFGW_OPS	SSO#1_N	2019-08-27	0.23
SFGW_OPS	SSO#1_N	2019-09-03	0.138
SFGW_OPS	SSO#1_N	2019-09-10	0.178
SFGW_RUNS	SSO#1_N	2019-09-16	0.321
SFGW_OPS	SSO#1_N	2019-09-17	0.333
SFGW_OPS	SSO#1_N	2019-09-24	0.36
SFGW_OPS	SSO#1_N	2019-10-01	0.3
SFGW_OPS	SSO#1_N	2019-10-08	0.456
SFGW_RUNS	SSO#1_N	2019-10-15	0.36
SFGW_RUNS	SSO#1_N	2019-10-15	0.352
SFGW_OPS	SSO#1_N	2019-10-16	0.416
SFGW_OPS	SSO#1_N	2019-10-22	0.426
SFGW_OPS	SSO#1_N	2019-10-29	0.38
SFGW_OPS	SSO#1_N	2019-11-05	0.494
SFGW_OPS	SSO#1_N	2019-11-19	0.774
SFGW_OPS	SSO#1_N	2019-11-26	0.76
SFGW_RUNS	SSO#1_N	2019-11-27	0.911
SFGW_OPS	SSO#1_N	2019-12-03	0.732
SFGW_OPS	SSO#1_N	2019-12-11	0.557
SFGW_RUNS	SSO#1_N	2019-12-17	0.624
SFGW_OPS	SSO#1_N	2019-12-19	0.895
SFGW_OPS	SSO#1_N	2019-12-24	0.681
SFGW_OPS	SSO#1_N	2019-12-31	0.413
SFGW_OPS	SSO#1_N	2020-01-07	0.489
SFGW_OPS	SSO#1_N	2020-01-21	0.662
SFGW_RUNS	SSO#1_N	2020-01-21	0.661
SFGW_OPS	SSO#1_N	2020-01-24	0.482
SFGW_OPS	SSO#1_N	2020-01-28	0.242
SFGW_OPS	SSO#1_N	2020-02-04	0.145
SFGW_OPS	SSO#1_N	2020-02-11	0.084
SFGW_OPS	SSO#1_N	2020-02-18	0.07
SFGW_RUNS	SSO#1_N	2020-02-18	0.059
SFGW_OPS	SSO#1_N	2020-02-25	0.431
SFGW_OPS	SSO#1_N	2020-03-03	0.2
SFGW_OPS	SSO#1_N	2020-03-10	0.302
SFGW_RUNS	SSO#1_N	2020-03-17	0.183

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_OPS	SSO#1_N	2020-03-17	0.19
SFGW_OPS	SSO#1_N	2020-03-24	0.147
SFGW_OPS	SSO#1_N	2020-03-31	0.168
SFGW_OPS	SSO#1_N	2020-04-07	0.231
SFGW_OPS	SSO#1_N	2020-04-14	0.108
SFGW_RUNS	SSO#1_N	2020-04-21	0.183
SFGW_OPS	SSO#1_N	2020-04-21	0.173
SFGW_OPS	SSO#1_N	2020-04-28	0.24
SFGW_OPS	SSO#1_N	2020-05-05	0.321
SFGW_OPS	SSO#1_N	2020-05-12	0.42
SFGW_OPS	SSO#1_N	2020-05-19	0.535
SFGW_RUNS	SSO#1_N	2020-05-19	0.566
SFGW_OPS	SSO#1_N	2020-05-26	0.461
SFGW_OPS	SSO#1_N	2020-06-02	0.417
SFGW_OPS	SSO#1_N	2020-06-09	0.182
SFGW_OPS	SSO#1_N	2020-06-16	0.26
SFGW_RUNS	SSO#1_N	2020-06-17	0.113
SFGW_OPS	SSO#1_N	2020-06-23	0.126
SFGW_OPS	SSO#1_N	2020-06-30	0.14
SFGW_OPS	SSO#1_N	2020-07-07	0.121
SFGW_RUNS	SSO#1_N	2020-07-09	0.118
SFGW_RUNS	SSO#1_N	2020-07-09	0.118
SFGW_OPS	SSO#1_N	2020-07-14	0.102
SFGW_OPS	SSO#1_N	2020-07-21	0.085
SFGW_OPS	SSO#1_N	2020-07-28	0.096
SFGW_OPS	SSO#1_N	2020-08-04	0.22
SFGW_OPS	SSO#1_N	2020-08-11	0.24
SFGW_RUNS	SSO#1_N	2020-08-18	0.161
SFGW_OPS	SSO#1_N	2020-08-18	0.163
SFGW_OPS	SSO#1_N	2020-08-25	0.407
SFGW_OPS	SSO#1_N	2020-09-02	0.929
SFGW_OPS	SSO#1_N	2020-09-08	1.08
SFGW_RUNS	SSO#1_N	2020-09-15	1.26
SFGW_OPS	SSO#1_N	2020-09-15	1.26
SFGW_OPS	SSO#1_N	2020-09-22	1.2
SFGW_OPS	SSO#1_N	2020-09-29	1.43
SFGW_OPS	SSO#1_N	2020-10-06	1.25
SFGW_OPS	SSO#1_N	2020-10-13	1.51
SFGW_OPS	SSO#1_N	2020-10-20	0.786
SFGW_RUNS	SSO#1_N	2020-10-20	0.75
SFGW_OPS	SSO#1_N	2020-10-29	0.945

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_OPS	SSO#1_N	2020-11-03	0.78
SFGW_OPS	SSO#1_N	2020-11-10	1.12
SFGW_RUNS	SSO#1_N	2020-11-17	1.2
SFGW_OPS	SSO#1_N	2020-11-17	1.2
SFGW_OPS	SSO#1_N	2020-11-24	0.96
SFGW_OPS	SSO#1_N	2020-12-01	1.1
SFGW_OPS	SSO#1_N	2020-12-08	1
SFGW_RUNS	SSO#1_N	2020-12-15	0.871
SFGW_OPS	SSO#1_N	2020-12-17	0.87
SFGW_OPS	SSO#1_N	2020-12-22	1.1
SFGW_OPS	SSO#1_N	2020-12-29	0.805
SFGW_OPS	SSO#1_N	2021-01-05	1
SFGW_OPS	SSO#1_N	2021-01-12	0.756
SFGW_RUNS	SSO#1_N	2021-01-12	0.767
SFGW_OPS	SSO#1_N	2021-01-19	0.412
SFGW_OPS	SSO#1_N	2021-01-26	1.24
SFGW_OPS	SSO#1_N	2021-02-02	0.868
SFGW_OPS	SSO#1_N	2021-02-09	1.03
SFGW_RUNS	SSO#1_N	2021-02-09	1.02
SFGW_OPS	SSO#1_N	2021-02-16	0.918
SFGW_OPS	SSO#1_N	2021-02-23	0.31
SFGW_OPS	SSO#1_N	2021-03-02	0.29
SFGW_RUNS	SSO#1_N	2021-03-09	0.38
SFGW_OPS	SSO#1_N	2021-03-09	0.36
SFGW_OPS	SSO#1_N	2021-03-16	0.082
SFGW_OPS	SSO#1_N	2021-03-23	0.041
SFGW_OPS	SSO#1_N	2021-04-02	0.095
SFGW_OPS	SSO#1_N	2021-04-06	0.122
SFGW_RUNS	SSO#1_N	2021-04-13	0.269
SFGW_OPS	SSO#1_N	2021-04-13	0.233
SFGW_OPS	SSO#1_N	2021-04-20	0.494
SFGW_OPS	SSO#1_N	2021-04-27	0.615
SFGW_OPS	SSO#1_N	2021-05-04	0.44
SFGW_OPS	SSO#1_N	2021-05-11	0.56
SFGW_RUNS	SSO#1_N	2021-05-11	0.56
SFGW_OPS	SSO#1_N	2021-05-18	0.359
SFGW_OPS	SSO#1_N	2021-05-25	0.516
SFGW_OPS	SSO#1_N	2021-06-01	0.623
SFGW_RUNS	SSO#1_N	2021-06-08	0.466
SFGW_OPS	SSO#1_N	2021-06-08	0.46
SFGW_OPS	SSO#1_N	2021-06-15	0.573

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_OPS	SSO#1_N	2021-06-22	0.438
SFGW_OPS	SSO#1_N	2021-06-29	0.688
SFGW_OPS	SSO#1_N	2021-07-07	0.737
SFGW_RUNS	SSO#1_N	2021-07-13	0.616
SFGW_OPS	SSO#1_N	2021-07-13	0.618
SFGW_OPS	SSO#1_N	2021-07-21	0.669
SFGW_OPS	SSO#1_N	2021-07-27	0.532
SFGW_OPS	SSO#1_N	2021-08-03	0.53
SFGW_RUNS	SSO#1_N	2021-08-10	0.416
SFGW_OPS	SSO#1_N	2021-08-10	0.414
SFGW_OPS	SSO#1_N	2021-08-17	0.807
SFGW_OPS	SSO#1_N	2021-08-24	0.637
SFGW_OPS	SSO#1_N	2021-08-31	0.53
SFGW_OPS	SSO#1_N	2021-09-07	0.23
SFGW_OPS	SSO#1_N	2021-09-14	0.316
SFGW_RUNS	SSO#1_N	2021-09-14	0.352
SFGW_OPS	SSO#1_N	2021-09-21	0.321
SFGW_OPS	SSO#1_N	2021-09-28	0.22
SFGW_OPS	SSO#1_N	2021-10-05	0.35
SFGW_OPS	SSO#1_N	2021-10-12	0.22
SFGW_RUNS	SSO#1_N	2021-10-12	0.2
SFGW_OPS	SSO#1_N	2021-10-19	0.286
SFGW_OPS	SSO#1_N	2021-10-26	0.324
SFGW_OPS	SSO#1_N	2021-11-02	0.333
SFGW_RUNS	SSO#1_N	2021-11-09	0.414
SFGW_OPS	SSO#1_N	2021-11-09	0.415
SFGW_OPS	SSO#1_N	2021-11-16	0.28
SFGW_OPS	SSO#1_N	2021-11-23	0.474
SFGW_OPS	SSO#1_N	2021-11-30	0.332
SFGW_OPS	SSO#1_N	2021-12-07	0.449
SFGW_OPS	SSO#1_N	2021-12-15	0.507
SFGW_RUNS	SSO#1_N	2021-12-15	0.517
SFGW_OPS	SSO#1_N	2021-12-21	0.549
SFGW_OPS	SSO#1_N	2021-12-28	0.257
SFDS_RUNS	SSO#2_S	2017-04-23	0.0953
SFDS_RUNS	SSO#2_S	2017-06-06	0.15
SFDS_RUNS	SSO#2_S	2017-06-13	0.16
SFDS_RUNS	SSO#2_S	2017-06-20	0.12
SFDS_RUNS	SSO#2_S	2017-06-27	0.1
SFGW_HISTORICAL	SSO#2_S	2017-06-28	0.11
SFGW_HISTORICAL	SSO#2_S	2017-06-29	0.12

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFDS_RUNS	SSO#2_S	2017-07-04	0.12
SFGW_HISTORICAL	SSO#2_S	2017-07-05	0.14
SFGW_HISTORICAL	SSO#2_S	2017-07-06	0.14
SFDS_RUNS	SSO#2_S	2017-07-11	0.094
SFGW_HISTORICAL	SSO#2_S	2017-07-12	0.12
SFGW_HISTORICAL	SSO#2_S	2017-07-13	0.1
SFDS_RUNS	SSO#2_S	2017-07-18	0.066
SFDS_RUNS	SSO#2_S	2017-07-25	0.072
SFDS_RUNS	SSO#2_S	2017-08-01	0.1
SFDS_RUNS	SSO#2_S	2017-08-08	0.11
SFDS_RUNS	SSO#2_S	2017-08-15	0.1
SFDS_RUNS	SSO#2_S	2017-08-22	0.1
SFDS_RUNS	SSO#2_S	2017-08-29	0.086
SFDS_RUNS	SSO#2_S	2017-09-05	0.0904
SFDS_RUNS	SSO#2_S	2017-09-12	0.107
SFDS_RUNS	SSO#2_S	2017-09-19	0.0713
SFDS_RUNS	SSO#2_S	2017-09-26	0.0945
SFDS_RUNS	SSO#2_S	2017-10-03	0.0533
SFDS_RUNS	SSO#2_S	2017-10-10	0.0528
SFDS_RUNS	SSO#2_S	2017-10-17	0.0563
SFGW_7DAY	SSO#2_S	2017-10-24	0.0953
SFDS_RUNS	SSO#2_S	2017-10-24	0.0673
SFGW_7DAY	SSO#2_S	2017-10-26	0.0746
SFGW_7DAY	SSO#2_S	2017-10-30	0.0914
SFDS_RUNS	SSO#2_S	2017-10-31	0.0992
SFDS_RUNS	SSO#2_S	2017-11-07	0.108
SFDS_RUNS	SSO#2_S	2017-11-14	0.0958
SFGW_7DAY	SSO#2_S	2017-11-16	0.0925
SFDS_RUNS	SSO#2_S	2017-11-21	0.191
SFDS_RUNS	SSO#2_S	2017-11-28	0.208
SFDS_RUNS	SSO#2_S	2017-12-05	0.166
SFDS_RUNS	SSO#2_S	2017-12-12	0.134
SFGW_7DAY	SSO#2_S	2017-12-18	0.0559
SFDS_RUNS	SSO#2_S	2017-12-19	0.0696
SFGW_7DAY	SSO#2_S	2017-12-20	0.0679
SFDS_RUNS	SSO#2_S	2017-12-26	0.0373
SFDS_RUNS	SSO#2_S	2018-01-02	0.0562
SFDS_RUNS	SSO#2_S	2018-01-09	0.0667
SFDS_RUNS	SSO#2_S	2018-01-16	0.0506
SFDS_RUNS	SSO#2_S	2018-01-23	0.0415
SFGW_7DAY	SSO#2_S	2018-01-24	0.0525

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_7DAY	SSO#2_S	2018-01-25	0.224
SFGW_7DAY	SSO#2_S	2018-01-29	0.0844
SFDS_RUNS	SSO#2_S	2018-01-30	0.0671
SFGW_7DAY	SSO#2_S	2018-01-31	0.577
SFGW_7DAY	SSO#2_S	2018-02-01	0.065
SFGW_7DAY	SSO#2_S	2018-02-05	0.0917
SFDS_RUNS	SSO#2_S	2018-02-06	0.0903
SFGW_7DAY	SSO#2_S	2018-02-07	0.0871
SFGW_7DAY	SSO#2_S	2018-02-08	0.0864
SFGW_7DAY	SSO#2_S	2018-02-12	0.0763
SFDS_RUNS	SSO#2_S	2018-02-13	0.0736
SFGW_7DAY	SSO#2_S	2018-02-14	0.0764
SFGW_7DAY	SSO#2_S	2018-02-15	0.0851
SFDS_RUNS	SSO#2_S	2018-02-20	0.0789
SFGW_7DAY	SSO#2_S	2018-02-21	0.0806
SFGW_7DAY	SSO#2_S	2018-02-22	0.0876
SFGW_7DAY	SSO#2_S	2018-02-26	0.294
SFDS_RUNS	SSO#2_S	2018-02-27	0.289
SFGW_7DAY	SSO#2_S	2018-02-28	0.0839
SFGW_7DAY	SSO#2_S	2018-03-01	0.0905
SFDS_RUNS	SSO#2_S	2018-03-06	0.13
SFDS_RUNS	SSO#2_S	2018-03-13	0.127
SFDS_RUNS	SSO#2_S	2018-03-20	0.103
SFDS_RUNS	SSO#2_S	2018-03-27	0.355
SFDS_RUNS	SSO#2_S	2018-04-03	0.406
SFDS_RUNS	SSO#2_S	2018-04-10	0.258
SFDS_RUNS	SSO#2_S	2018-04-17	0.185
SFGW_HISTORICAL	SSO#2_S	2018-04-17	0.188
SFDS_RUNS	SSO#2_S	2018-04-24	0.125
SFDS_RUNS	SSO#2_S	2018-05-01	0.0836
SFDS_RUNS	SSO#2_S	2018-05-08	0.078
SFGW_1ST-YR	SSO#2_S	2018-05-15	0.078
SFDS_RUNS	SSO#2_S	2018-05-15	0.073
SFDS_RUNS	SSO#2_S	2018-05-22	0.072
SFDS_RUNS	SSO#2_S	2018-05-29	0.06
SFDS_RUNS	SSO#2_S	2018-06-05	0.074
SFDS_RUNS	SSO#2_S	2018-06-12	0.053
SFGW_1ST-YR	SSO#2_S	2018-06-18	0.032
SFDS_RUNS	SSO#2_S	2018-06-19	0.038
SFDS_RUNS	SSO#2_S	2018-06-26	0.038
SFDS_RUNS	SSO#2_S	2018-07-03	0.06

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFDS_RUNS	SSO#2_S	2018-07-10	0.065
SFDS_RUNS	SSO#2_S	2018-07-17	0.171
SFGW_OPS	SSO#2_S	2018-07-24	0.535
SFGW_OPS	SSO#2_S	2018-07-31	0.526
SFGW_OPS	SSO#2_S	2018-08-08	0.402
SFGW_OPS	SSO#2_S	2018-08-14	0.217
SFGW_OPS	SSO#2_S	2018-08-21	0.158
SFGW_1ST-YR	SSO#2_S	2018-08-21	0.166
SFGW_OPS	SSO#2_S	2018-08-28	0.173
SFGW_OPS	SSO#2_S	2018-09-04	0.166
SFGW_OPS	SSO#2_S	2018-09-11	0.172
SFGW_OPS	SSO#2_S	2018-09-18	0.438
SFGW_OPS	SSO#2_S	2018-09-25	0.47
SFGW_OPS	SSO#2_S	2018-10-02	0.146
SFGW_OPS	SSO#2_S	2018-10-09	0.063
SFGW_OPS	SSO#2_S	2018-10-16	0.061
SFGW_OPS	SSO#2_S	2018-10-23	0.042
SFGW_OPS	SSO#2_S	2019-08-20	0.126
SFGW_RUNS	SSO#2_S	2019-08-21	0.121
SFGW_OPS	SSO#2_S	2019-08-27	0.188
SFGW_OPS	SSO#2_S	2019-09-03	0.123
SFGW_OPS	SSO#2_S	2019-09-10	0.248
SFGW_RUNS	SSO#2_S	2019-09-16	0.323
SFGW_OPS	SSO#2_S	2019-09-17	0.358
SFGW_OPS	SSO#2_S	2019-09-24	0.369
SFGW_OPS	SSO#2_S	2019-10-01	0.428
SFGW_OPS	SSO#2_S	2019-10-08	0.335
SFGW_RUNS	SSO#2_S	2019-10-15	0.211
SFGW_RUNS	SSO#2_S	2019-10-15	0.21
SFGW_OPS	SSO#2_S	2019-10-16	0.266
SFGW_OPS	SSO#2_S	2019-10-22	0.161
SFGW_OPS	SSO#2_S	2019-10-29	0.101
SFGW_OPS	SSO#2_S	2019-11-05	0.133
SFGW_OPS	SSO#2_S	2019-11-19	0.136
SFGW_OPS	SSO#2_S	2019-11-26	0.134
SFGW_RUNS	SSO#2_S	2019-11-27	0.133
SFGW_OPS	SSO#2_S	2019-12-03	0.111
SFGW_OPS	SSO#2_S	2019-12-11	0.13
SFGW_RUNS	SSO#2_S	2019-12-17	0.09
SFGW_OPS	SSO#2_S	2019-12-19	0.087
SFGW_OPS	SSO#2_S	2019-12-24	0.081

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_OPS	SSO#2_S	2019-12-31	0.526
SFGW_OPS	SSO#2_S	2020-01-07	0.317
SFGW_OPS	SSO#2_S	2020-01-21	0.233
SFGW_RUNS	SSO#2_S	2020-01-21	0.24
SFGW_OPS	SSO#2_S	2020-01-24	0.195
SFGW_OPS	SSO#2_S	2020-01-28	0.143
SFGW_OPS	SSO#2_S	2020-02-04	0.144
SFGW_OPS	SSO#2_S	2020-02-11	0.079
SFGW_RUNS	SSO#2_S	2020-02-18	0.07
SFGW_OPS	SSO#2_S	2020-02-18	0.083
SFGW_OPS	SSO#2_S	2020-02-25	0.523
SFGW_OPS	SSO#2_S	2020-03-03	0.209
SFGW_OPS	SSO#2_S	2020-03-10	0.46
SFGW_OPS	SSO#2_S	2020-03-17	0.235
SFGW_RUNS	SSO#2_S	2020-03-17	0.243
SFGW_OPS	SSO#2_S	2020-03-24	0.175
SFGW_OPS	SSO#2_S	2020-03-31	0.179
SFGW_OPS	SSO#2_S	2020-04-07	0.195
SFGW_OPS	SSO#2_S	2020-04-14	0.122
SFGW_OPS	SSO#2_S	2020-04-21	0.15
SFGW_RUNS	SSO#2_S	2020-04-21	0.157
SFGW_OPS	SSO#2_S	2020-04-28	0.427
SFGW_OPS	SSO#2_S	2020-05-05	0.636
SFGW_OPS	SSO#2_S	2020-05-12	0.971
SFGW_RUNS	SSO#2_S	2020-05-19	1.15
SFGW_OPS	SSO#2_S	2020-05-19	1.09
SFGW_OPS	SSO#2_S	2020-05-26	1.11
SFGW_OPS	SSO#2_S	2020-06-02	1.25
SFGW_OPS	SSO#2_S	2020-06-09	0.482
SFGW_OPS	SSO#2_S	2020-06-16	0.119
SFGW_RUNS	SSO#2_S	2020-06-17	0.253
SFGW_OPS	SSO#2_S	2020-06-23	0.191
SFGW_OPS	SSO#2_S	2020-06-30	0.187
SFGW_OPS	SSO#2_S	2020-07-07	0.136
SFGW_RUNS	SSO#2_S	2020-07-09	0.137
SFGW_RUNS	SSO#2_S	2020-07-09	0.135
SFGW_OPS	SSO#2_S	2020-07-14	0.12
SFGW_OPS	SSO#2_S	2020-07-21	0.095
SFGW_OPS	SSO#2_S	2020-07-28	0.098
SFGW_OPS	SSO#2_S	2020-08-04	0.484
SFGW_OPS	SSO#2_S	2020-08-11	0.425

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_OPS	SSO#2_S	2020-08-18	0.245
SFGW_RUNS	SSO#2_S	2020-08-18	0.247
SFGW_OPS	SSO#2_S	2020-08-25	0.561
SFGW_OPS	SSO#2_S	2020-09-02	0.406
SFGW_OPS	SSO#2_S	2020-09-08	0.302
SFGW_RUNS	SSO#2_S	2020-09-15	0.194
SFGW_OPS	SSO#2_S	2020-09-15	0.186
SFGW_OPS	SSO#2_S	2020-09-22	0.175
SFGW_OPS	SSO#2_S	2020-09-29	0.132
SFGW_OPS	SSO#2_S	2020-10-06	0.12
SFGW_OPS	SSO#2_S	2020-10-13	0.098
SFDS_RUNS	SUTO	2017-04-23	0.0954
SFDS_RUNS	SUTO	2017-05-02	0.106
SFDS_RUNS	SUTO	2017-05-09	0.0963
SFDS_RUNS	SUTO	2017-05-16	0.13
SFDS_RUNS	SUTO	2017-05-23	0.14
SFDS_RUNS	SUTO	2017-05-30	0.15
SFDS_RUNS	SUTO	2017-06-06	0.14
SFDS_RUNS	SUTO	2017-06-13	0.21
SFDS_RUNS	SUTO	2017-06-20	0.13
SFDS_RUNS	SUTO	2017-06-27	0.062
SFDS_RUNS	SUTO	2017-07-04	0.075
SFDS_RUNS	SUTO	2017-07-11	0.058
SFDS_RUNS	SUTO	2017-07-18	0.1
SFDS_RUNS	SUTO	2017-07-25	0.12
SFDS_RUNS	SUTO	2017-08-01	0.07
SFDS_RUNS	SUTO	2017-08-08	0.087
SFDS_RUNS	SUTO	2017-08-15	0.067
SFDS_RUNS	SUTO	2017-08-22	0.07
SFDS_RUNS	SUTO	2017-08-29	0.066
SFDS_RUNS	SUTO	2017-09-05	0.0545
SFDS_RUNS	SUTO	2017-09-12	0.0533
SFDS_RUNS	SUTO	2017-09-19	0.0587
SFDS_RUNS	SUTO	2017-09-26	0.0793
SFDS_RUNS	SUTO	2017-10-03	0.0871
SFDS_RUNS	SUTO	2017-10-10	0.032
SFDS_RUNS	SUTO	2017-10-17	0.0338
SFDS_RUNS	SUTO	2017-10-24	0.0605
SFDS_RUNS	SUTO	2017-10-31	0.0857
SFDS_RUNS	SUTO	2017-11-07	0.106
SFDS_RUNS	SUTO	2017-11-14	0.105

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFDS_RUNS	SUTO	2017-11-21	0.0744
SFDS_RUNS	SUTO	2017-11-28	0.0836
SFDS_RUNS	SUTO	2017-12-05	0.0562
SFDS_RUNS	SUTO	2017-12-12	0.0422
SFDS_RUNS	SUTO	2017-12-19	0.0393
SFDS_RUNS	SUTO	2017-12-26	0.0425
SFDS_RUNS	SUTO	2018-01-02	0.0529
SFDS_RUNS	SUTO	2018-01-09	0.0379
SFDS_RUNS	SUTO	2018-01-16	0.0595
SFDS_RUNS	SUTO	2018-01-23	0.0973
SFDS_RUNS	SUTO	2018-01-30	0.0615
SFDS_RUNS	SUTO	2018-02-06	0.0523
SFDS_RUNS	SUTO	2018-02-13	0.0896
SFDS_RUNS	SUTO	2018-02-20	0.121
SFDS_RUNS	SUTO	2018-02-27	0.0908
SFDS_RUNS	SUTO	2018-03-06	0.0386
SFDS_RUNS	SUTO	2018-03-13	0.0873
SFDS_RUNS	SUTO	2018-03-20	0.056
SFDS_RUNS	SUTO	2018-03-27	0.0812
SFDS_RUNS	SUTO	2018-04-03	0.101
SFDS_RUNS	SUTO	2018-04-10	0.0764
SFDS_RUNS	SUTO	2018-04-17	0.0489
SFDS_RUNS	SUTO	2018-04-24	0.0763
SFDS_RUNS	SUTO	2018-05-01	0.0655
SFDS_RUNS	SUTO	2018-05-08	0.076
SFDS_RUNS	SUTO	2018-05-15	0.034
SFDS_RUNS	SUTO	2018-05-22	0.047
SFDS_RUNS	SUTO	2018-05-29	0.031
SFDS_RUNS	SUTO	2018-06-05	0.054
SFDS_RUNS	SUTO	2018-06-12	0.038
SFDS_RUNS	SUTO	2018-06-19	0.027
SFDS_RUNS	SUTO	2018-06-26	0.03
SFDS_RUNS	SUTO	2018-07-03	0.042
SFDS_RUNS	SUTO	2018-07-10	0.04
SFDS_RUNS	SUTO	2018-07-17	0.046
SFGW_OPS	SUTO	2018-07-24	0.092
SFGW_OPS	SUTO	2018-07-31	0.096
SFGW_OPS	SUTO	2018-08-08	0.097
SFGW_OPS	SUTO	2018-08-14	0.09
SFGW_OPS	SUTO	2018-08-21	0.069
SFGW_OPS	SUTO	2018-08-28	0.067

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_OPS	SUTO	2018-09-04	0.065
SFGW_OPS	SUTO	2018-09-11	0.082
SFGW_OPS	SUTO	2018-09-18	0.106
SFGW_OPS	SUTO	2018-09-25	0.105
SFGW_OPS	SUTO	2018-10-02	0.091
SFGW_OPS	SUTO	2018-10-09	0.05
SFGW_OPS	SUTO	2018-10-16	0.06
SFGW_OPS	SUTO	2018-10-23	0.051
SFGW_OPS	SUTO	2018-10-30	0.039
SFGW_OPS	SUTO	2018-11-06	0.076
SFGW_OPS	SUTO	2018-11-13	0.066
SFGW_OPS	SUTO	2018-11-20	0.084
SFGW_OPS	SUTO	2018-11-27	0.105
SFGW_OPS	SUTO	2018-12-04	0.101
SFGW_OPS	SUTO	2018-12-11	0.117
SFGW_OPS	SUTO	2018-12-18	0.096
SFGW_OPS	SUTO	2018-12-26	0.529
SFGW_OPS	SUTO	2019-01-02	0.252
SFGW_OPS	SUTO	2019-01-08	0.124
SFGW_OPS	SUTO	2019-01-15	0.11
SFGW_OPS	SUTO	2019-01-22	0.082
SFGW_OPS	SUTO	2019-01-29	0.068
SFGW_OPS	SUTO	2019-02-05	0.088
SFGW_OPS	SUTO	2019-02-12	0.081
SFGW_OPS	SUTO	2019-02-19	0.178
SFGW_OPS	SUTO	2019-03-01	0.113
SFGW_OPS	SUTO	2019-03-05	0.106
SFGW_OPS	SUTO	2019-03-12	0.094
SFGW_OPS	SUTO	2019-03-19	0.109
SFGW_OPS	SUTO	2019-03-26	0.094
SFGW_OPS	SUTO	2019-04-02	0.064
SFGW_OPS	SUTO	2019-04-09	0.128
SFGW_OPS	SUTO	2019-04-16	0.214
SFGW_OPS	SUTO	2019-04-23	0.196
SFGW_OPS	SUTO	2019-04-30	0.221
SFGW_OPS	SUTO	2019-05-07	0.262
SFGW_OPS	SUTO	2019-05-14	0.308
SFGW_OPS	SUTO	2019-05-21	0.315
SFGW_OPS	SUTO	2019-05-28	0.198
SFGW_OPS	SUTO	2019-06-04	0.201
SFGW_OPS	SUTO	2019-06-11	0.114

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_OPS	SUTO	2019-06-18	0.104
SFGW_OPS	SUTO	2019-06-25	0.101
SFGW_OPS	SUTO	2019-07-02	0.11
SFGW_OPS	SUTO	2019-07-09	0.139
SFGW_OPS	SUTO	2019-07-16	0.116
SFGW_OPS	SUTO	2019-07-23	0.157
SFGW_OPS	SUTO	2019-07-30	0.089
SFGW_OPS	SUTO	2019-08-06	0.109
SFGW_OPS	SUTO	2019-08-13	0.121
SFGW_OPS	SUTO	2019-08-20	0.13
SFGW_OPS	SUTO	2019-08-27	0.125
SFGW_OPS	SUTO	2019-09-03	0.103
SFGW_OPS	SUTO	2019-09-10	0.137
SFGW_OPS	SUTO	2019-09-17	0.199
SFGW_OPS	SUTO	2019-09-24	0.223
SFGW_OPS	SUTO	2019-10-01	0.222
SFGW_OPS	SUTO	2019-10-10	0.278
SFGW_OPS	SUTO	2019-10-16	0.301
SFGW_OPS	SUTO	2019-10-22	0.243
SFGW_OPS	SUTO	2019-10-29	0.159
SFGW_OPS	SUTO	2019-11-05	0.184
SFGW_OPS	SUTO	2019-11-19	0.196
SFGW_OPS	SUTO	2019-11-26	0.158
SFGW_OPS	SUTO	2019-12-03	0.237
SFGW_OPS	SUTO	2019-12-11	0.234
SFGW_OPS	SUTO	2019-12-19	0.182
SFGW_OPS	SUTO	2019-12-24	0.225
SFGW_OPS	SUTO	2019-12-31	0.218
SFGW_OPS	SUTO	2020-01-07	0.238
SFGW_OPS	SUTO	2020-01-21	0.357
SFGW_OPS	SUTO	2020-01-24	0.308
SFGW_OPS	SUTO	2020-01-28	0.304
SFGW_OPS	SUTO	2020-02-04	0.197
SFGW_OPS	SUTO	2020-02-11	0.12
SFGW_OPS	SUTO	2020-02-18	0.077
SFGW_OPS	SUTO	2020-02-25	0.224
SFGW_OPS	SUTO	2020-03-03	0.073
SFGW_OPS	SUTO	2020-03-10	0.195
SFGW_OPS	SUTO	2020-03-17	0.243
SFGW_OPS	SUTO	2020-03-24	0.148
SFGW_OPS	SUTO	2020-03-31	0.145

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_OPS	SUTO	2020-04-07	0.123
SFGW_OPS	SUTO	2020-04-14	0.097
SFGW_OPS	SUTO	2020-04-21	0.166
SFGW_OPS	SUTO	2020-04-28	0.181
SFGW_OPS	SUTO	2020-05-05	0.201
SFGW_OPS	SUTO	2020-05-12	0.102
SFGW_OPS	SUTO	2020-05-19	0.247
SFGW_OPS	SUTO	2020-05-26	0.281
SFGW_OPS	SUTO	2020-06-02	0.28
SFGW_OPS	SUTO	2020-06-09	0.106
SFGW_OPS	SUTO	2020-06-16	0.208
SFGW_OPS	SUTO	2020-06-23	0.158
SFGW_OPS	SUTO	2020-06-30	0.22
SFGW_OPS	SUTO	2020-07-07	0.212
SFGW_OPS	SUTO	2020-07-14	0.24
SFGW_OPS	SUTO	2020-07-21	0.175
SFGW_OPS	SUTO	2020-07-28	0.244
SFGW_OPS	SUTO	2020-08-04	0.245
SFGW_OPS	SUTO	2020-08-11	0.241
SFGW_OPS	SUTO	2020-08-18	0.28
SFGW_OPS	SUTO	2020-08-25	0.26
SFGW_OPS	SUTO	2020-09-02	0.269
SFGW_OPS	SUTO	2020-09-08	0.261
SFGW_OPS	SUTO	2020-09-15	0.184
SFGW_OPS	SUTO	2020-09-22	0.236
SFGW_OPS	SUTO	2020-09-29	0.255
SFGW_OPS	SUTO	2020-10-06	0.252
SFGW_OPS	SUTO	2020-10-13	0.238
SFGW_OPS	SUTO	2020-10-20	0.25
SFGW_OPS	SUTO	2020-10-29	0.256
SFGW_OPS	SUTO	2020-11-03	0.212
SFGW_OPS	SUTO	2020-11-10	0.203
SFGW_OPS	SUTO	2020-11-17	0.13
SFGW_OPS	SUTO	2020-11-24	0.053
SFGW_OPS	SUTO	2020-12-01	0.062
SFGW_OPS	SUTO	2020-12-08	0.034
SFGW_OPS	SUTO	2020-12-17	0.2
SFGW_OPS	SUTO	2020-12-22	0.193
SFGW_OPS	SUTO	2020-12-29	0.2
SFGW_OPS	SUTO	2021-01-05	0.31
SFGW_OPS	SUTO	2021-01-12	0.379

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_OPS	SUTO	2021-01-19	0.334
SFGW_OPS	SUTO	2021-01-26	0.185
SFGW_OPS	SUTO	2021-02-02	0.575
SFGW_OPS	SUTO	2021-02-09	0.506
SFGW_OPS	SUTO	2021-02-16	0.343
SFGW_OPS	SUTO	2021-02-23	0.38
SFGW_OPS	SUTO	2021-03-02	0.1
SFGW_OPS	SUTO	2021-03-09	0.31
SFGW_OPS	SUTO	2021-03-16	0.076
SFGW_OPS	SUTO	2021-03-23	0.049
SFGW_OPS	SUTO	2021-03-30	0.062
SFGW_OPS	SUTO	2021-04-06	0.098
SFGW_OPS	SUTO	2021-04-13	0.084
SFGW_OPS	SUTO	2021-04-20	0.17
SFGW_OPS	SUTO	2021-04-27	0.166
SFGW_OPS	SUTO	2021-05-04	0.22
SFGW_OPS	SUTO	2021-05-11	0.25
SFGW_OPS	SUTO	2021-05-18	0.243
SFGW_OPS	SUTO	2021-05-25	0.253
SFGW_OPS	SUTO	2021-06-01	0.266
SFGW_OPS	SUTO	2021-06-08	0.181
SFGW_OPS	SUTO	2021-06-15	0.271
SFGW_OPS	SUTO	2021-06-22	0.245
SFGW_OPS	SUTO	2021-06-29	0.275
SFGW_OPS	SUTO	2021-07-07	0.226
SFGW_OPS	SUTO	2021-07-13	0.247
SFGW_OPS	SUTO	2021-07-21	0.223
SFGW_OPS	SUTO	2021-07-27	0.216
SFGW_OPS	SUTO	2021-08-03	0.333
SFGW_OPS	SUTO	2021-08-10	0.212
SFGW_OPS	SUTO	2021-08-17	0.326
SFGW_OPS	SUTO	2021-08-24	0.238
SFGW_OPS	SUTO	2021-08-31	0.16
SFGW_OPS	SUTO	2021-09-07	0.035
SFGW_OPS	SUTO	2021-09-14	0.028
SFGW_OPS	SUTO	2021-09-21	0.031
SFGW_OPS	SUTO	2021-09-28	0.026
SFGW_OPS	SUTO	2021-10-05	0.039
SFGW_OPS	SUTO	2021-10-12	0.036
SFGW_OPS	SUTO	2021-10-19	0.045
SFGW_OPS	SUTO	2021-10-26	<0.02

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
SFGW_OPS	SUTO	2021-11-02	0.057
SFGW_OPS	SUTO	2021-11-09	0.273
SFGW_OPS	SUTO	2021-11-16	0.135
SFGW_OPS	SUTO	2021-11-23	0.116
SFGW_OPS	SUTO	2021-11-30	0.074
SFGW_OPS	SUTO	2021-12-07	0.088
SFGW_OPS	SUTO	2021-12-15	0.044
SFGW_OPS	SUTO	2021-12-21	0.073
SFGW_OPS	SUTO	2021-12-28	0.089
SPECIAL			
WSB_SPECIAL	WSB_SF57_SWD57	2019-10-17	14.1
WSB_SPECIAL	WSB_SF57_SWD57 DUP	2019-10-17	14.2
WSB_SPECIAL	WSB_SF58_SWD140	2019-10-17	19.1
WSB_SPECIAL	WSB_SF_DUP	2019-10-21	0.067
WSB_SPECIAL	WSB_SF34_KIR130	2019-10-21	19.8
WSB_SPECIAL	WSB_SF34_KIR130 DUP	2019-10-21	20.4
WSB_SPECIAL	WSB_SF35_KIR255	2019-10-21	17.3
WSB_SPECIAL	WSB_SF36_KIR385	2019-10-21	<0.02
WSB_SPECIAL	WSB_SF37_KIR435	2019-10-21	<0.02
WSB_SPECIAL	WSB_SF49LMPS575	2019-10-21	0.064
WSB_SPECIAL	WSB_SF_DUP	2019-10-22	0.201
WSB_SPECIAL	WSB_SF13_LM4SS	2019-10-22	0.16
WSB_SPECIAL	WSB_SF30_ORT125	2019-10-22	22.7
WSB_SPECIAL	WSB_SF31_ORT265	2019-10-22	16.6
WSB_SPECIAL	WSB_SF32_ORT400	2019-10-22	15.9
WSB_SPECIAL	WSB_SF32_ORT400 DUP	2019-10-22	16.1
WSB_SPECIAL	WSB_SF33_ORT475	2019-10-22	<0.02
WSB_SPECIAL	WSB_SF46LMPS155	2019-10-22	5.63
WSB_SPECIAL	WSB_SF47LMPS270	2019-10-22	<0.02
WSB_SPECIAL	WSB_SF48LMPS440	2019-10-22	0.218
WSB_SPECIAL	WSB_SF70_SWM3	2019-10-22	23.8
WSB_SPECIAL	WSB_SF70_SWM3 DUP	2019-10-22	23.7
WSB_SPECIAL	WSB_SF_DUP	2019-10-23	<0.02
WSB_SPECIAL	WSB_SF12_LM4S	2019-10-23	20.2
WSB_SPECIAL	WSB_SF14_LM5S	2019-10-23	<0.02
WSB_SPECIAL	WSB_SF67_GGPSF1	2019-10-23	3.67
WSB_SPECIAL	WSB_SF68_GGPNL1	2019-10-23	2.15
WSB_SPECIAL	WSB_SF69_NWM3	2019-10-23	15.6
WSB_SPECIAL	WSB_SF69_NWM3 DUP	2019-10-23	13.1
WSB_SPECIAL	WSB_SF72_LM5SS	2019-10-23	<0.02
WSB_SPECIAL	WSB_SF_DUP	2019-10-24	<0.02

Rasprojectno_(Project_ID)	ClSampNo	Date	Chromium (VI) µg/L
WSB_SPECIAL	WSB_SF41_WSPLAY	2019-10-24	<0.02
WSB_SPECIAL	WSB_SF41_WSPLAY DUP	2019-10-24	<0.02
WSB_SPECIAL	WSB_SF52_CPS190	2019-10-24	18.8
WSB_SPECIAL	WSB_SF53_CPS270	2019-10-24	<0.02
WSB_SPECIAL	WSB_SF_DUP	2019-10-28	19.3
WSB_SPECIAL	WSB_SF06_GG-SL1	2019-10-28	19.3
WSB_SPECIAL	WSB_SF26_TAR145	2019-10-28	10.5
WSB_SPECIAL	WSB_SF27_TAR240	2019-10-28	20
WSB_SPECIAL	WSB_SF28_TAR400	2019-10-28	<0.02
WSB_SPECIAL	WSB_SF28_TAR400 DUP	2019-10-28	<0.02
WSB_SPECIAL	WSB_SF29_TAR530	2019-10-28	<0.02
WSB_SPECIAL	WSB_SF75_GG-EC1	2019-10-28	5.12
WSB_SPECIAL	WSB_SF_DUP	2019-10-29	9.38
WSB_SPECIAL	WSB_SF23_PIN_LK	2019-10-29	20.3
WSB_SPECIAL	WSB_SF42_ZOO275	2019-10-29	<0.02
WSB_SPECIAL	WSB_SF42_ZOO275 DUP	2019-10-29	<0.02
WSB_SPECIAL	WSB_SF43_ZOO450	2019-10-29	6.53
WSB_SPECIAL	WSB_SF44_ZOO5	2019-10-29	10.3
WSB_SPECIAL	WSB_SF45_ZOO565	2019-10-29	<0.02
WSB_SPECIAL	WSB_SF_DUP	2019-10-30	16.5
WSB_SPECIAL	WSB_SF02_EDGEWD	2019-10-30	16.6
WSB_SPECIAL	WSB_SF73_ALVORDLAKE	2019-10-30	<0.02
WSB_SPECIAL	WSB_SF_DUP	2019-10-31	30.2
WSB_SPECIAL	WSB_SF03_ELKGLN	2019-10-31	0.095
WSB_SPECIAL	WSB_SF74_ARB07	2019-10-31	30.3
LOG_CABIN_RUNS	LOG_CABIN_RAW	2016-03-03	0.12
LOG_CABIN_RUNS	LOG_CABIN_RAW	2017-03-14	0.22
LOG_CABIN_RUNS	LOG_CABIN_WELL1	2017-03-14	<0.02
LOG_CABIN_RUNS	LOG_CABIN_WELL2	2017-03-14	<0.02
LOG_CABIN_RUNS	LOG_CABIN_RAW	2018-03-12	0.102
CDD_SPECIAL	SPECIAL	2016-08-25	<0.8
CDD_SPECIAL	SPECIAL	2016-08-25	<0.8
CDD_SPECIAL	SPECIAL	2016-08-25	<0.8
CDD_SPECIAL	SPECIAL	2016-08-25	<0.8
CDD_SPECIAL	SPECIAL	2016-08-25	<0.8
BA_SAN_BRUNO_SPECIAL	Well 17	2019-04-16	4.45

Table 6-7. Cobalt SFPUC Monitoring Results, 2016, and Special Sampling of Sunset Reservoirs in 2020. Cobalt - EPA 200.8

Rasprojectno_(Project_ID)	ClSampNo	Date	Cobalt, Co µg/L
SURFACE WATER HETCH HETCHY			
T22_ANNUAL_RUNS	HHR	2016-06-15	<1
T22_ANNUAL_RUNS	CHERRY_RES	2016-06-13	<1
T22_ANNUAL_RUNS	CHERRY_CREEK	2016-06-14	<1
T22_ANNUAL_RUNS	LK_ELEANOR	2016-06-13	<1
T22_ANNUAL_RUNS	MOC_RES	2016-06-15	<1
T22_ANNUAL_RUNS	EI_RES	2016-06-14	<1
WQ_ENG_SPECIAL	SP1 MtnTnl@PriestRes	2017-01-12	1.99
WQ_ENG_SPECIAL	SP4 MtnTnl@EarlyInt	2017-01-12	0.0696
EAST BAY SURFACE WATER			
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2016-06-15	<1
T22_ANNUAL_RUNS	CAL_SURF	2016-06-15	<1
T22_ANNUAL_RUNS	SANT_SURF	2016-06-15	<1
WEST BAY SURFACE WATER			
T22_ANNUAL_RUNS	SA_SURF	2016-06-14	<1
T22_ANNUAL_RUNS	LCS_SURF	2016-06-14	<1
T22_ANNUAL_RUNS	PIL_SURF	2016-06-14	<1
T22_ANNUAL_RUNS	STONE_DAM_SURF	2016-06-14	<1
GROUNDWATER SF CITY			
T22_ANNUAL_RUNS	LK_MERCED_S	2016-06-20	<1
T22_ANNUAL_RUNS	SF_ZOO_WELL_5	2016-06-14	<1
GROUNDWATER EAST BAY			
T22_ANNUAL_RUNS	SUNOL_FILTER	2016-06-14	<1
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2016-06-14	<1
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2016-06-14	<1
DRINKING WATER			
T22_ANNUAL_RUNS	MOC_TK	2016-06-15	<1
T22_ANNUAL_RUNS	EI_TK	2016-06-14	<1
T22_ANNUAL_RUNS	OSH_TK	2016-06-15	<1
T22_ANNUAL_RUNS	SVWTP_EFF	2016-06-14	<1
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	2016-06-14	<1
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2016-06-21	<1
T22_ANNUAL_RUNS	CS#2_BADEN	2016-06-14	<1
BA_HILLSBOROUGH_SPECIAL	SPECIAL	2017-07-31	<1
WQ_ENG_SPECIAL	SS#01	2020-02-27	<1
WQ_ENG_SPECIAL	SS#03	2020-02-27	<1
WQ_ENG_SPECIAL	SS#04	2020-02-27	<1
WQ_ENG_SPECIAL	SS#05	2020-02-27	<1
WQ_ENG_SPECIAL	SS#06	2020-02-27	<1

Rasprojectno_(Project_ID)	ClSampNo	Date	Cobalt, Co µg/L
WQ_ENG_SPECIAL	SS#07	2020-02-27	<1
WQ_ENG_SPECIAL	SS#08	2020-02-27	<1
WQ_ENG_SPECIAL	SS#09	2020-02-27	<1
WQ_ENG_SPECIAL	SS#10	2020-02-27	<1
WQ_ENG_SPECIAL	SS#11	2020-02-27	<1

Table 6-8. Germanium - UCMR4 SFPUC Monitoring Results, 2018 - 2019

Rasprojectno_(Project_ID)	ClSampNo	Date	Germanium, Ge µg/L
DRINKING WATER			
UCMR4_SPECIAL	ALAMEDA_EAST	2018-01-22	<0.3
UCMR4_SPECIAL	ALAMEDA_EAST	2018-04-23	<0.3
UCMR4_SPECIAL	ALAMEDA_EAST	2018-07-23	<0.3
UCMR4_SPECIAL	ALAMEDA_EAST	2018-10-22	<0.3
UCMR4	SSL_BADEN	2018-01-22	<0.3
UCMR4	SSL_BADEN	2018-04-23	<0.3
UCMR4	SSL_BADEN	2018-07-23	<0.3
UCMR4	SSL_BADEN	2018-10-22	<0.3
UCMR4	SA#2_BADEN	2018-01-22	<0.3
UCMR4	SA#2_BADEN	2018-04-23	<0.3
UCMR4	SA#2_BADEN	2018-07-23	<0.3
UCMR4	SA#2_BADEN	2018-10-22	<0.3
UCMR4	LMPS_SUTRO_DISCH	2018-01-22	<0.3
UCMR4	LMPS_SUTRO_DISCH	2018-04-23	<0.3
UCMR4	LMPS_SUTRO_DISCH	2018-09-19	<0.3
UCMR4	LMPS_SUTRO_DISCH	2018-12-11	<0.3
UCMR4	LMPS_SUNSET_DISCH	2018-01-22	<0.3
UCMR4	LMPS_SUNSET_DISCH	2018-04-23	<0.3
UCMR4	LMPS_SUNSET_DISCH	2018-09-19	<0.3
UCMR4	LMPS_SUNSET_DISCH	2018-12-11	<0.3
UCMR4	SSO#1_N	2018-01-22	<0.3
UCMR4	SSO#1_N	2018-04-23	<0.3
UCMR4	SSO#1_N	2018-08-30	<0.3
UCMR4	SSO#1_N	2018-12-11	<0.3
UCMR4	SSO#2_S	2018-01-22	<0.3
UCMR4	SSO#2_S	2018-04-23	<0.3
UCMR4	SSO#2_S	2018-08-30	<0.3
UCMR4_SPECIAL	SVWTP_TWR_EFF	2018-02-14	<0.3
UCMR4_SPECIAL	SVWTP_TWR_EFF	2018-04-23	<0.3
UCMR4_SPECIAL	SVWTP_TWR_EFF	2018-09-21	<0.3
UCMR4_SPECIAL	SVWTP_TWR_EFF	2018-10-22	<0.3
UCMR4_SPECIAL	HTWTP_EFF_POST	2018-01-22	<0.3
UCMR4_SPECIAL	HTWTP_EFF_POST	2018-04-23	<0.3
UCMR4_SPECIAL	HTWTP_EFF_POST	2018-07-23	<0.3
UCMR4_SPECIAL	HTWTP_EFF_POST	2018-10-22	<0.3
BA_SAN_BRUNO_UCMR4	Entry Point to Dist System	2018-02-12	<0.3
BA_SAN_BRUNO_UCMR4	EP#11 Well 16-Treated	2018-02-12	<0.3
BA_SAN_BRUNO_UCMR4	EP#12 Well 17-Treated	2018-02-12	<0.3

Rasprojectno_(Project_ID)	ClSampNo	Date	Germanium, Ge µg/L
BA_SAN_BRUNO_UCMR4	EP# 15-Well 20 Treated	2018-03-13	<0.3
BA_SAN_BRUNO_UCMR4	EP#13-Well 18 Treated	2018-03-13	<0.3
BA_SAN_BRUNO_UCMR4	Entry Point to Dist System	2018-05-07	<0.3
BA_SAN_BRUNO_UCMR4	Entry Point to Dist System	2018-08-08	<0.3
BA_SAN_BRUNO_UCMR4	EP#12-Well 17 Treated	2018-08-09	<0.3
BA_SAN_BRUNO_UCMR4	EP# 15-Well 20 Treated	2018-09-10	<0.3
BA_SAN_BRUNO_UCMR4	EP#13-Well 18 Treated	2018-09-10	<0.3
BA_SAN_BRUNO_UCMR4	Entry Point to Dist System	2018-11-05	<0.3
BA_SAN_BRUNO_UCMR4	EP#11-Well 16 Treated	2018-12-06	<0.3
BA_BURLINGAME_UCMR4	Magnolia/Trousdale Turnout	2018-09-11	<0.3
BA_BURLINGAME_UCMR4	Magnolia/Trousdale Turnout	2018-12-10	<0.3
BA_BURLINGAME_UCMR4	Magnolia/Trousdale Turnout	2019-03-11	<0.3
BA_BURLINGAME_UCMR4	Magnolia/Trousdale Turnout	2019-06-10	<0.3
BA_SFO_UCMR4	SouthField Turnout Tap	2019-01-07	<0.3
BA_SFO_UCMR4	SouthField Turnout Tap	2019-04-01	<0.3
BA_SFO_UCMR4	SouthField Turnout Tap	2019-07-08	<0.3
BA_SFO_UCMR4	SouthField Turnout Tap	2019-10-07	<0.3

Table 6-9. Manganese SFPUC Monitoring Results, 2016 - 2021

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
Surface Water Hetch Hetchy			
T22_ANNUAL_RUNS	HHR	2018-06-18	<2
T22_ANNUAL_RUNS	CHERRY_RES	2016-06-13	2.39
T22_ANNUAL_RUNS	CHERRY_RES	2017-06-26	2.77
T22_ANNUAL_RUNS	CHERRY_CREEK	2016-06-14	11.6
T22_ANNUAL_RUNS	CHERRY_CREEK	2017-06-26	4.85
T22_ANNUAL_RUNS	CHERRY_CREEK	2020-06-24	<2
T22_ANNUAL_RUNS	LK_ELEANOR	2016-06-13	2.87
T22_ANNUAL_RUNS	LK_ELEANOR	2017-06-26	3.87
T22_ANNUAL_RUNS	LK_ELEANOR	2020-06-22	3.03
T22_ANNUAL_RUNS	EI_RES	2016-06-14	3.12
T22_ANNUAL_RUNS	EI_RES	2017-06-19	3.76
T22_ANNUAL_RUNS	EI_RES	2020-06-23	6.96
T22_ANNUAL_RUNS	MOC_RES	2016-06-15	2.86
T22_ANNUAL_RUNS	MOC_RES	2017-07-19	3.96
T22_ANNUAL_RUNS	MOC_TAILRACE	2017-06-20	3.41
T22_ANNUAL_RUNS	MOC_TAILRACE	2018-06-18	2.63
TS_RUNS	TESLA_PORTL_RAW	2016-01-03	6.46
TS_RUNS	TESLA_PORTL_RAW	2016-02-14	5.37
TS_RUNS	TESLA_PORTL_RAW	2016-02-21	3.2
TS_RUNS	TESLA_PORTL_RAW	2016-02-28	3.08
TS_RUNS	TESLA_PORTL_RAW	2016-03-06	3.85
TS_RUNS	TESLA_PORTL_RAW	2016-03-13	2.68
TS_RUNS	TESLA_PORTL_RAW	2016-03-20	<2
TS_RUNS	TESLA_PORTL_RAW	2016-03-27	<2
TS_RUNS	TESLA_PORTL_RAW	2016-04-03	<2
TS_RUNS	TESLA_PORTL_RAW	2016-04-10	2.02
TS_RUNS	TESLA_PORTL_RAW	2016-04-17	<2
TS_RUNS	TESLA_PORTL_RAW	2016-04-24	4.66
TS_RUNS	TESLA_PORTL_RAW	2016-05-01	3.43
TS_RUNS	TESLA_PORTL_RAW	2016-05-08	3.36
TS_RUNS	TESLA_PORTL_RAW	2016-05-15	3.12
TS_RUNS	TESLA_PORTL_RAW	2016-05-22	3.26
TS_RUNS	TESLA_PORTL_RAW	2016-05-29	2.69
TS_RUNS	TESLA_PORTL_RAW	2016-06-05	3.53
TS_RUNS	TESLA_PORTL_RAW	2016-06-12	3.99
TS_RUNS	TESLA_PORTL_RAW	2016-06-19	3.11
TS_RUNS	TESLA_PORTL_RAW	2016-06-26	<2
TS_RUNS	TESLA_PORTL_RAW	2016-07-03	2.24

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	TESLA_PORTL_RAW	2016-07-10	<2
TS_RUNS	TESLA_PORTL_RAW	2016-07-17	<2
TS_RUNS	TESLA_PORTL_RAW	2016-07-24	<2
TS_RUNS	TESLA_PORTL_RAW	2016-07-31	9.24
TS_RUNS	TESLA_PORTL_RAW	2016-08-07	4.74
TS_RUNS	TESLA_PORTL_RAW	2016-08-14	4.55
TS_RUNS	TESLA_PORTL_RAW	2016-08-21	5.12
TS_RUNS	TESLA_PORTL_RAW	2016-08-28	4.15
TS_RUNS	TESLA_PORTL_RAW	2016-09-04	4.53
TS_RUNS	TESLA_PORTL_RAW	2016-09-11	5.43
TS_RUNS	TESLA_PORTL_RAW	2016-09-18	6.07
TS_RUNS	TESLA_PORTL_RAW	2016-09-25	5.09
TS_RUNS	TESLA_PORTL_RAW	2016-10-02	4.48
TS_RUNS	TESLA_PORTL_RAW	2016-10-09	4.12
TS_RUNS	TESLA_PORTL_RAW	2016-10-16	5.15
TS_RUNS	TESLA_PORTL_RAW	2016-10-23	5.36
TS_RUNS	TESLA_PORTL_RAW	2016-10-30	6.06
TS_RUNS	TESLA_PORTL_RAW	2016-11-06	4.89
TS_RUNS	TESLA_PORTL_RAW	2016-11-13	4.2
TS_RUNS	TESLA_PORTL_RAW	2016-11-20	5.46
TS_RUNS	TESLA_PORTL_RAW	2016-11-27	4.72
TS_RUNS	TESLA_PORTL_RAW	2016-11-27	5.86
TS_RUNS	TESLA_PORTL_RAW	2016-12-04	2.79
TS_RUNS	TESLA_PORTL_RAW	2016-12-11	9.58
TS_RUNS	TESLA_PORTL_RAW	2017-03-19	3.13
TS_RUNS	TESLA_PORTL_RAW	2017-03-26	4.62
TS_RUNS	TESLA_PORTL_RAW	2017-04-02	<2
TS_RUNS	TESLA_PORTL_RAW	2017-04-09	<2
TS_RUNS	TESLA_PORTL_RAW	2017-04-16	<2
TS_RUNS	TESLA_PORTL_RAW	2017-04-23	<2
TS_RUNS	TESLA_PORTL_RAW	2017-04-30	<2
TS_RUNS	TESLA_PORTL_RAW	2017-05-07	2.36
TS_RUNS	TESLA_PORTL_RAW	2017-05-21	2.45
TS_RUNS	TESLA_PORTL_RAW	2017-05-28	<2
TS_RUNS	TESLA_PORTL_RAW	2017-06-04	3.82
TS_RUNS	TESLA_PORTL_RAW	2017-06-11	3.94
TS_RUNS	TESLA_PORTL_RAW	2017-06-18	5.08
TS_RUNS	TESLA_PORTL_RAW	2017-06-25	3.77
TS_RUNS	TESLA_PORTL_RAW	2017-07-02	4.16
TS_RUNS	TESLA_PORTL_RAW	2017-07-09	4.23

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	TESLA_PORTL_RAW	2017-07-16	3.99
TS_RUNS	TESLA_PORTL_RAW	2017-07-23	3.59
TS_RUNS	TESLA_PORTL_RAW	2017-07-30	4.26
TS_RUNS	TESLA_PORTL_RAW	2017-08-06	4.09
TS_RUNS	TESLA_PORTL_RAW	2017-08-13	4.05
TS_RUNS	TESLA_PORTL_RAW	2017-08-20	4.92
TS_RUNS	TESLA_PORTL_RAW	2017-08-27	3.88
TS_RUNS	TESLA_PORTL_RAW	2017-09-03	3.82
TS_RUNS	TESLA_PORTL_RAW	2017-09-10	4.33
TS_RUNS	TESLA_PORTL_RAW	2017-09-17	3.16
TS_RUNS	TESLA_PORTL_RAW	2017-09-24	4.34
TS_RUNS	TESLA_PORTL_RAW	2017-10-01	5.82
TS_RUNS	TESLA_PORTL_RAW	2017-10-08	6
TS_RUNS	TESLA_PORTL_RAW	2017-10-15	6.03
TS_RUNS	TESLA_PORTL_RAW	2017-10-22	9.22
TS_RUNS	TESLA_PORTL_RAW	2017-10-29	7.73
TS_RUNS	TESLA_PORTL_RAW	2017-11-12	6.36
TS_RUNS	TESLA_PORTL_RAW	2017-11-19	7.11
TS_RUNS	TESLA_PORTL_RAW	2017-11-26	6.75
TS_RUNS	TESLA_PORTL_RAW	2017-12-03	7.54
TS_RUNS	TESLA_PORTL_RAW	2017-12-10	6.64
TS_RUNS	TESLA_PORTL_RAW	2017-12-17	6.96
TS_RUNS	TESLA_PORTL_RAW	2017-12-24	6.56
TS_RUNS	TESLA_PORTL_RAW	2017-12-31	8.06
TS_RUNS	TESLA_PORTL_RAW	2018-01-07	7.05
TS_RUNS	TESLA_PORTL_RAW	2018-01-14	5.62
TS_RUNS	TESLA_PORTL_RAW	2018-01-21	5.11
TS_RUNS	TESLA_PORTL_RAW	2018-01-28	5.19
TS_RUNS	TESLA_PORTL_RAW	2018-02-04	11.8
TS_RUNS	TESLA_PORTL_RAW	2018-02-11	5.25
TS_RUNS	TESLA_PORTL_RAW	2018-02-18	4.73
TS_RUNS	TESLA_PORTL_RAW	2018-02-25	5.21
TS_RUNS	TESLA_PORTL_RAW	2018-03-04	4.75
TS_RUNS	TESLA_PORTL_RAW	2018-03-11	5.15
TS_RUNS	TESLA_PORTL_RAW	2018-03-18	5.08
TS_RUNS	TESLA_PORTL_RAW	2018-04-08	4.82
TS_RUNS	TESLA_PORTL_RAW	2018-04-15	4.59
TS_RUNS	TESLA_PORTL_RAW	2018-04-22	3.79
TS_RUNS	TESLA_PORTL_RAW	2018-04-29	3.9
TS_RUNS	TESLA_PORTL_RAW	2018-05-06	2.75

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	TESLA_PORTL_RAW	2018-05-13	3.28
TS_RUNS	TESLA_PORTL_RAW	2018-05-20	2.84
TS_RUNS	TESLA_PORTL_RAW	2018-05-27	2.72
TS_RUNS	TESLA_PORTL_RAW	2018-06-03	2.74
TS_RUNS	TESLA_PORTL_RAW	2018-06-10	2.67
TS_RUNS	TESLA_PORTL_RAW	2018-06-17	2.67
TS_RUNS	TESLA_PORTL_RAW	2018-06-24	3.04
TS_RUNS	TESLA_PORTL_RAW	2018-07-01	3.01
TS_RUNS	TESLA_PORTL_RAW	2018-07-08	2.81
TS_RUNS	TESLA_PORTL_RAW	2018-07-15	2.79
TS_RUNS	TESLA_PORTL_RAW	2018-07-22	3.14
TS_RUNS	TESLA_PORTL_RAW	2018-07-29	3.59
TS_RUNS	TESLA_PORTL_RAW	2018-08-05	4.21
TS_RUNS	TESLA_PORTL_RAW	2018-08-12	4.27
TS_RUNS	TESLA_PORTL_RAW	2018-08-19	4.99
TS_RUNS	TESLA_PORTL_RAW	2018-08-26	4.66
TS_RUNS	TESLA_PORTL_RAW	2018-09-02	5.4
TS_RUNS	TESLA_PORTL_RAW	2018-09-09	5.45
TS_RUNS	TESLA_PORTL_RAW	2018-09-16	6.32
TS_RUNS	TESLA_PORTL_RAW	2018-09-23	5.51
TS_RUNS	TESLA_PORTL_RAW	2018-09-30	5.68
TS_RUNS	TESLA_PORTL_RAW	2018-10-07	5.59
TS_RUNS	TESLA_PORTL_RAW	2018-10-14	5.82
TS_RUNS	TESLA_PORTL_RAW	2018-10-21	5.27
TS_RUNS	TESLA_PORTL_RAW	2018-10-28	6.14
TS_RUNS	TESLA_PORTL_RAW	2018-11-11	5.23
TS_RUNS	TESLA_PORTL_RAW	2018-11-18	4.2
TS_RUNS	TESLA_PORTL_RAW	2018-11-25	11.4
TS_RUNS	TESLA_PORTL_RAW	2018-12-02	6.13
TS_RUNS	TESLA_PORTL_RAW	2018-12-09	5.77
TS_RUNS	TESLA_PORTL_RAW	2018-12-16	5.56
TS_RUNS	TESLA_PORTL_RAW	2018-12-23	5.85
TS_RUNS	TESLA_PORTL_RAW	2018-12-30	6.29
TS_RUNS	TESLA_PORTL_RAW	2019-01-06	9.51
TS_RUNS	TESLA_PORTL_RAW	2019-03-17	3.55
TS_RUNS	TESLA_PORTL_RAW	2019-03-24	4.48
TS_RUNS	TESLA_PORTL_RAW	2019-03-31	3.85
TS_RUNS	TESLA_PORTL_RAW	2019-04-07	3.78
TS_RUNS	TESLA_PORTL_RAW	2019-04-14	2.7
TS_RUNS	TESLA_PORTL_RAW	2019-04-21	3.21

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	TESLA_PORTL_RAW	2019-04-28	2.71
TS_RUNS	TESLA_PORTL_RAW	2019-05-05	4.47
TS_RUNS	TESLA_PORTL_RAW	2019-05-12	3.16
TS_RUNS	TESLA_PORTL_RAW	2019-05-19	2.3
TS_RUNS	TESLA_PORTL_RAW	2019-05-26	2.55
TS_RUNS	TESLA_PORTL_RAW	2019-06-02	<2
TS_RUNS	TESLA_PORTL_RAW	2019-06-09	2.18
TS_RUNS	TESLA_PORTL_RAW	2019-06-16	2.81
TS_RUNS	TESLA_PORTL_RAW	2019-06-23	3.01
TS_RUNS	TESLA_PORTL_RAW	2019-06-30	3.33
TS_RUNS	TESLA_PORTL_RAW	2019-07-07	3.39
TS_RUNS	TESLA_PORTL_RAW	2019-07-14	3.38
TS_RUNS	TESLA_PORTL_RAW	2019-07-21	3.07
TS_RUNS	TESLA_PORTL_RAW	2019-07-28	3.12
TS_RUNS	TESLA_PORTL_RAW	2019-08-04	3.79
TS_RUNS	TESLA_PORTL_RAW	2019-08-11	3.42
TS_RUNS	TESLA_PORTL_RAW	2019-08-18	3.3
TS_RUNS	TESLA_PORTL_RAW	2019-08-25	3.88
TS_RUNS	TESLA_PORTL_RAW	2019-09-01	3.99
TS_RUNS	TESLA_PORTL_RAW	2019-09-08	4.18
TS_RUNS	TESLA_PORTL_RAW	2019-09-15	3.44
TS_RUNS	TESLA_PORTL_RAW	2019-09-22	3.82
TS_RUNS	TESLA_PORTL_RAW	2019-09-29	10.6
TS_RUNS	TESLA_PORTL_RAW	2019-10-06	3.88
TS_RUNS	TESLA_PORTL_RAW	2019-10-13	4.44
TS_RUNS	TESLA_PORTL_RAW	2019-10-20	4.09
TS_RUNS	TESLA_PORTL_RAW	2019-10-27	4.31
TS_RUNS	TESLA_PORTL_RAW	2019-11-03	5.6
TS_RUNS	TESLA_PORTL_RAW	2019-11-10	5.97
TS_RUNS	TESLA_PORTL_RAW	2019-11-17	5.31
TS_RUNS	TESLA_PORTL_RAW	2019-11-24	4.72
TS_RUNS	TESLA_PORTL_RAW	2019-12-01	5.43
TS_RUNS	TESLA_PORTL_RAW	2019-12-08	7.44
TS_RUNS	TESLA_PORTL_RAW	2019-12-15	6.28
TS_RUNS	TESLA_PORTL_RAW	2019-12-22	4.66
TS_RUNS	TESLA_PORTL_RAW	2019-12-29	5.05
TS_RUNS	TESLA_PORTL_RAW	2020-01-05	7.07
TS_RUNS	TESLA_PORTL_RAW	2020-02-09	4.16
TS_RUNS	TESLA_PORTL_RAW	2020-02-16	4.69
TS_RUNS	TESLA_PORTL_RAW	2020-02-23	3.65

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	TESLA_PORTL_RAW	2020-03-01	4.2
TS_RUNS	TESLA_PORTL_RAW	2020-03-08	3.52
TS_RUNS	TESLA_PORTL_RAW	2020-03-15	8.53
TS_RUNS	TESLA_PORTL_RAW	2020-03-22	2.69
TS_RUNS	TESLA_PORTL_RAW	2020-03-29	3.11
TS_RUNS	TESLA_PORTL_RAW	2020-04-05	2.86
TS_RUNS	TESLA_PORTL_RAW	2020-04-12	3.55
TS_RUNS	TESLA_PORTL_RAW	2020-04-19	9.08
TS_RUNS	TESLA_PORTL_RAW	2020-04-26	2.58
TS_RUNS	TESLA_PORTL_RAW	2020-05-03	2.67
TS_RUNS	TESLA_PORTL_RAW	2020-05-10	3.07
TS_RUNS	TESLA_PORTL_RAW	2020-05-17	2.82
TS_RUNS	TESLA_PORTL_RAW	2020-05-24	2.85
TS_RUNS	TESLA_PORTL_RAW	2020-05-31	2.77
TS_RUNS	TESLA_PORTL_RAW	2020-06-07	5
TS_RUNS	TESLA_PORTL_RAW	2020-06-14	3.86
TS_RUNS	TESLA_PORTL_RAW	2020-06-21	3.32
TS_RUNS	TESLA_PORTL_RAW	2020-06-28	3.44
TS_RUNS	TESLA_PORTL_RAW	2020-07-05	3.47
TS_RUNS	TESLA_PORTL_RAW	2020-07-12	3.71
TS_RUNS	TESLA_PORTL_RAW	2020-07-19	4.19
TS_RUNS	TESLA_PORTL_RAW	2020-07-26	3.86
TS_RUNS	TESLA_PORTL_RAW	2020-08-02	3.26
TS_RUNS	TESLA_PORTL_RAW	2020-08-09	3.91
TS_RUNS	TESLA_PORTL_RAW	2020-08-16	3.27
TS_RUNS	TESLA_PORTL_RAW	2020-08-23	4.33
TS_RUNS	TESLA_PORTL_RAW	2020-08-30	5.85
TS_RUNS	TESLA_PORTL_RAW	2020-08-30	6.45
TS_RUNS	TESLA_PORTL_RAW	2020-09-06	4.55
TS_RUNS	TESLA_PORTL_RAW	2020-09-06	3.89
TS_RUNS	TESLA_PORTL_RAW	2020-09-13	3.8
TS_RUNS	TESLA_PORTL_RAW	2020-09-13	3.27
TS_RUNS	TESLA_PORTL_RAW	2020-09-20	3.29
TS_RUNS	TESLA_PORTL_RAW	2020-09-27	4.44
TS_RUNS	TESLA_PORTL_RAW	2020-10-04	4.27
TS_RUNS	TESLA_PORTL_RAW	2020-10-04	4.89
TS_RUNS	TESLA_PORTL_RAW	2020-10-11	5.39
TS_RUNS	TESLA_PORTL_RAW	2020-10-18	5.33
TS_RUNS	TESLA_PORTL_RAW	2020-10-25	6.21
TS_RUNS	TESLA_PORTL_RAW	2020-11-01	5.56

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	TESLA_PORTL_RAW	2020-11-08	5.65
TS_RUNS	TESLA_PORTL_RAW	2020-11-15	6.56
TS_RUNS	TESLA_PORTL_RAW	2020-11-22	6.92
TS_RUNS	TESLA_PORTL_RAW	2020-11-29	6.18
TS_RUNS	TESLA_PORTL_RAW	2020-12-06	6.78
TS_RUNS	TESLA_PORTL_RAW	2020-12-13	8.77
TS_RUNS	TESLA_PORTL_RAW	2020-12-20	8.67
TS_RUNS	TESLA_PORTL_RAW	2020-12-27	8.21
TS_RUNS	TESLA_PORTL_RAW	2021-01-03	8.73
TS_RUNS	TESLA_PORTL_RAW	2021-01-10	6.74
TS_RUNS	TESLA_PORTL_RAW	2021-01-17	5.23
TS_RUNS	TESLA_PORTL_RAW	2021-01-24	6.32
TS_RUNS	TESLA_PORTL_RAW	2021-01-31	13.4
TS_RUNS	TESLA_PORTL_RAW	2021-02-07	5.09
TS_RUNS	TESLA_PORTL_RAW	2021-02-28	5.89
TS_RUNS	TESLA_PORTL_RAW	2021-03-07	3.89
TS_RUNS	TESLA_PORTL_RAW	2021-03-14	4.55
TS_RUNS	TESLA_PORTL_RAW	2021-03-21	4.54
TS_RUNS	TESLA_PORTL_RAW	2021-03-28	3.35
TS_RUNS	TESLA_PORTL_RAW	2021-04-04	3.68
TS_RUNS	TESLA_PORTL_RAW	2021-04-11	3.49
TS_RUNS	TESLA_PORTL_RAW	2021-04-18	3.45
TS_RUNS	TESLA_PORTL_RAW	2021-04-25	3.26
TS_RUNS	TESLA_PORTL_RAW	2021-05-02	3.35
TS_RUNS	TESLA_PORTL_RAW	2021-05-09	3
TS_RUNS	TESLA_PORTL_RAW	2021-05-16	3.29
TS_RUNS	TESLA_PORTL_RAW	2021-05-23	3.67
TS_RUNS	TESLA_PORTL_RAW	2021-05-30	3.31
TS_RUNS	TESLA_PORTL_RAW	2021-06-06	3.52
TS_RUNS	TESLA_PORTL_RAW	2021-06-13	3.51
TS_RUNS	TESLA_PORTL_RAW	2021-06-20	3.43
TS_RUNS	TESLA_PORTL_RAW	2021-06-27	3.43
TS_RUNS	TESLA_PORTL_RAW	2021-07-04	3.49
TS_RUNS	TESLA_PORTL_RAW	2021-07-11	2.73
TS_RUNS	TESLA_PORTL_RAW	2021-07-18	3.08
TS_RUNS	TESLA_PORTL_RAW	2021-07-25	3.47
TS_RUNS	TESLA_PORTL_RAW	2021-08-01	3.51
TS_RUNS	TESLA_PORTL_RAW	2021-08-08	3.71
TS_RUNS	TESLA_PORTL_RAW	2021-08-15	3.66
TS_RUNS	TESLA_PORTL_RAW	2021-08-22	4.11

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	TESLA_PORTL_RAW	2021-08-29	4.13
TS_RUNS	TESLA_PORTL_RAW	2021-09-05	4.18
TS_RUNS	TESLA_PORTL_RAW	2021-09-12	3.7
TS_RUNS	TESLA_PORTL_RAW	2021-09-26	6.55
TS_RUNS	TESLA_PORTL_RAW	2021-10-03	6.87
TS_RUNS	TESLA_PORTL_RAW	2021-10-10	5.16
TS_RUNS	TESLA_PORTL_RAW	2021-10-10	6.65
TS_RUNS	TESLA_PORTL_RAW	2021-10-17	4.49
TS_RUNS	TESLA_PORTL_RAW	2021-10-24	4.05
TS_RUNS	TESLA_PORTL_RAW	2021-10-31	3.63
TS_RUNS	TESLA_PORTL_RAW	2021-11-07	4.19
TS_RUNS	TESLA_PORTL_RAW	2021-11-14	4.4
TS_RUNS	TESLA_PORTL_RAW	2021-11-21	4.48
TS_RUNS	TESLA_PORTL_RAW	2021-11-28	4.68
TS_RUNS	TESLA_PORTL_RAW	2021-12-05	5.4
TS_RUNS	TESLA_PORTL_RAW	2021-12-12	6.74
TS_RUNS	TESLA_PORTL_RAW	2021-12-19	5.18
TS_RUNS	TESLA_PORTL_RAW	2021-12-26	11
EAST BAY SURFACE WATER			
ALAMEDA_CR_RECAP	ALAMEDA_CR_P_F2EA	2016-01-20	2.69
ALAMEDA_CR_RECAP	ALAMEDA_CR_P_F2EA	2016-02-17	4.68
ALAMEDA_CR_RECAP	ALAMEDA_CR_P_F2EA	2016-03-16	5.75
ALAMEDA_CR_RECAP	ALAMEDA_CR_P_F2EA	2016-04-20	5.89
ALAMEDA_CR_RECAP	ALAMEDA_CR_P_F2EA	2016-05-18	4.13
ALAMEDA_CR_RECAP	ALAMEDA_CR_P_F2EA	2016-06-15	5.43
ALAMEDA_CR_RECAP	ALAMEDA_CR_P_F2EA	2016-07-20	5.76
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2018-06-18	2.3
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2018-06-18	8.49
T22_ANNUAL_RUNS	CAL_SURF	2016-06-15	9.21
T22_ANNUAL_RUNS	CAL_SURF	2017-06-19	12
T22_ANNUAL_RUNS	CAL_SURF	2018-06-18	4.93
T22_ANNUAL_RUNS	SANT_SURF	2018-06-18	4.14
TS_RUNS	SVWTP_RAW_CAL	2016-01-11	69.3
TS_RUNS	SVWTP_RAW_CAL	2016-01-19	51.4
TS_RUNS	SVWTP_RAW_CAL	2016-01-25	48.4
TS_RUNS	SVWTP_RAW_CAL	2016-02-01	44.2
TS_RUNS	SVWTP_RAW_CAL	2016-02-08	30.9
TS_RUNS	SVWTP_RAW_CAL	2016-03-07	8.48
TS_RUNS	SVWTP_RAW_CAL	2016-03-14	25
TS_RUNS	SVWTP_RAW_CAL	2016-03-15	20.3

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	SVWTP_RAW_CAL	2016-03-15	<2
TS_RUNS	SVWTP_RAW_CAL	2016-12-26	29.6
TS_RUNS	SVWTP_RAW_CAL	2017-01-02	44
TS_RUNS	SVWTP_RAW_CAL	2017-01-09	37
TS_RUNS	SVWTP_RAW_CAL	2017-03-24	18.2
TS_RUNS	SVWTP_RAW_CAL	2017-03-27	17.6
TS_RUNS	SVWTP_RAW_CAL	2017-04-03	19.9
TS_RUNS	SVWTP_RAW_CAL	2017-04-10	18.8
TS_RUNS	SVWTP_RAW_CAL	2017-04-17	16.9
TS_RUNS	SVWTP_RAW_CAL	2017-04-24	12.2
TS_RUNS	SVWTP_RAW_CAL	2017-09-11	12.4
TS_RUNS	SVWTP_RAW_CAL	2017-09-18	11.7
TS_RUNS	SVWTP_RAW_CAL	2017-10-26	16.1
TS_RUNS	SVWTP_RAW_CAL	2017-10-30	3.3
TS_RUNS	SVWTP_RAW_CAL	2017-11-02	7.88
TS_RUNS	SVWTP_RAW_CAL	2017-11-06	11.3
TS_RUNS	SVWTP_RAW_CAL	2017-12-11	31
TS_RUNS	SVWTP_RAW_CAL	2017-12-18	11.4
TS_RUNS	SVWTP_RAW_CAL	2017-12-25	8.21
TS_RUNS	SVWTP_RAW_CAL	2018-01-01	45.2
TS_RUNS	SVWTP_RAW_CAL	2018-01-08	30.2
TS_RUNS	SVWTP_RAW_CAL	2018-01-08	30.7
TS_RUNS	SVWTP_RAW_CAL	2018-01-15	17.8
TS_RUNS	SVWTP_RAW_CAL	2018-01-15	17.1
TS_RUNS	SVWTP_RAW_CAL	2018-03-22	12.1
TS_RUNS	SVWTP_RAW_CAL	2018-03-26	17.8
TS_RUNS	SVWTP_RAW_CAL	2018-04-02	10.1
TS_RUNS	SVWTP_RAW_CAL	2018-04-09	6.67
TS_RUNS	SVWTP_RAW_CAL	2018-04-16	3.48
TS_RUNS	SVWTP_RAW_CAL	2018-04-23	3.49
TS_RUNS	SVWTP_RAW_CAL	2018-04-30	4.34
TS_RUNS	SVWTP_RAW_CAL	2018-05-07	4.48
TS_RUNS	SVWTP_RAW_CAL	2018-05-14	4.3
TS_RUNS	SVWTP_RAW_CAL	2018-05-21	9.13
TS_RUNS	SVWTP_RAW_CAL	2019-01-14	22.1
TS_RUNS	SVWTP_RAW_CAL	2019-01-21	40
TS_RUNS	SVWTP_RAW_CAL	2019-02-18	34.7
TS_RUNS	SVWTP_RAW_CAL	2019-02-25	18.7
TS_RUNS	SVWTP_RAW_CAL	2019-03-11	12.9
TS_RUNS	SVWTP_RAW_CAL	2019-04-08	14.7

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	SVWTP_RAW_CAL	2019-04-15	15.2
TS_RUNS	SVWTP_RAW_CAL	2019-05-23	477
TS_RUNS	SVWTP_RAW_CAL	2019-05-27	9.82
TS_RUNS	SVWTP_RAW_CAL	2019-06-03	12.8
TS_RUNS	SVWTP_RAW_CAL	2019-06-10	14.4
TS_RUNS	SVWTP_RAW_CAL	2020-01-20	12.5
TS_RUNS	SVWTP_RAW_CAL	2020-01-27	11.7
TS_RUNS	SVWTP_RAW_CAL	2020-02-03	61.1
TS_RUNS	SVWTP_RAW_CAL	2020-02-05	28.9
TS_RUNS	SVWTP_RAW_CAL	2020-04-10	74.9
TS_RUNS	SVWTP_RAW_CAL	2020-04-13	20.5
TS_RUNS	SVWTP_RAW_CAL	2020-05-18	61.3
TS_RUNS	SVWTP_RAW_CAL	2020-08-28	39.4
TS_RUNS	SVWTP_RAW_CAL	2020-08-31	72.9
TS_RUNS	SVWTP_RAW_CAL	2020-09-01	44.6
TS_RUNS	SVWTP_RAW_CAL	2020-09-07	62.6
TS_RUNS	SVWTP_RAW_CAL	2020-10-19	48.7
TS_RUNS	SVWTP_RAW_CAL	2020-10-26	97.8
TS_RUNS	SVWTP_RAW_CAL	2020-11-02	93.4
TS_RUNS	SVWTP_RAW_CAL	2020-11-09	65.4
TS_RUNS	SVWTP_RAW_CAL	2020-11-16	64.7
TS_RUNS	SVWTP_RAW_CAL	2020-11-23	58
TS_RUNS	SVWTP_RAW_CAL	2021-02-24	9.97
TS_RUNS	SVWTP_RAW_SANT	2016-01-11	3
TS_RUNS	SVWTP_RAW_SANT	2016-01-19	6.93
TS_RUNS	SVWTP_RAW_SANT	2016-01-25	6.13
TS_RUNS	SVWTP_RAW_SANT	2016-02-01	4.27
TS_RUNS	SVWTP_RAW_SANT	2016-02-08	3.99
TS_RUNS	SVWTP_RAW_SANT	2016-02-16	5.7
TS_RUNS	SVWTP_RAW_SANT	2016-02-22	10.2
TS_RUNS	SVWTP_RAW_SANT	2016-02-29	4.73
TS_RUNS	SVWTP_RAW_SANT	2016-03-02	4.88
TS_RUNS	SVWTP_RAW_SANT	2016-03-21	5.38
TS_RUNS	SVWTP_RAW_SANT	2016-03-28	6.86
TS_RUNS	SVWTP_RAW_SANT	2016-04-04	6.38
TS_RUNS	SVWTP_RAW_SANT	2016-04-11	7.24
TS_RUNS	SVWTP_RAW_SANT	2016-04-18	4.74
TS_RUNS	SVWTP_RAW_SANT	2016-04-25	3.76
TS_RUNS	SVWTP_RAW_SANT	2016-05-02	4.29
TS_RUNS	SVWTP_RAW_SANT	2016-05-09	4.43

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	SVWTP_RAW_SANT	2016-05-16	4.78
TS_RUNS	SVWTP_RAW_SANT	2016-05-23	3.78
TS_RUNS	SVWTP_RAW_SANT	2016-05-31	5.02
TS_RUNS	SVWTP_RAW_SANT	2016-06-14	<2
TS_RUNS	SVWTP_RAW_SANT	2016-07-29	19
TS_RUNS	SVWTP_RAW_SANT	2016-09-20	3.86
TS_RUNS	SVWTP_RAW_SANT	2016-10-06	3.88
TS_RUNS	SVWTP_RAW_SANT	2016-10-11	2.45
TS_RUNS	SVWTP_RAW_SANT	2016-11-17	<2
TS_RUNS	SVWTP_RAW_SANT	2016-11-21	<2
TS_RUNS	SVWTP_RAW_SANT	2016-11-28	3.33
TS_RUNS	SVWTP_RAW_SANT	2016-12-05	<2
TS_RUNS	SVWTP_RAW_SANT	2017-01-12	14.8
TS_RUNS	SVWTP_RAW_SANT	2017-01-16	40.7
TS_RUNS	SVWTP_RAW_SANT	2017-01-23	19.1
TS_RUNS	SVWTP_RAW_SANT	2017-01-30	27.4
TS_RUNS	SVWTP_RAW_SANT	2017-02-06	15.7
TS_RUNS	SVWTP_RAW_SANT	2017-02-13	19.2
TS_RUNS	SVWTP_RAW_SANT	2017-02-20	8.99
TS_RUNS	SVWTP_RAW_SANT	2017-03-06	21.8
TS_RUNS	SVWTP_RAW_SANT	2017-03-13	13.1
TS_RUNS	SVWTP_RAW_SANT	2017-03-20	18.1
TS_RUNS	SVWTP_RAW_SANT	2017-03-27	17.5
TS_RUNS	SVWTP_RAW_SANT	2017-04-03	16.7
TS_RUNS	SVWTP_RAW_SANT	2017-04-10	13.2
TS_RUNS	SVWTP_RAW_SANT	2017-04-17	14.8
TS_RUNS	SVWTP_RAW_SANT	2017-04-24	16
TS_RUNS	SVWTP_RAW_SANT	2017-05-01	19.8
TS_RUNS	SVWTP_RAW_SANT	2017-05-08	10.6
TS_RUNS	SVWTP_RAW_SANT	2017-05-15	2.36
TS_RUNS	SVWTP_RAW_SANT	2017-05-22	10.4
TS_RUNS	SVWTP_RAW_SANT	2017-05-29	7.56
TS_RUNS	SVWTP_RAW_SANT	2017-06-05	7.97
TS_RUNS	SVWTP_RAW_SANT	2017-06-12	13.2
TS_RUNS	SVWTP_RAW_SANT	2017-06-19	11.6
TS_RUNS	SVWTP_RAW_SANT	2017-08-02	11.9
TS_RUNS	SVWTP_RAW_SANT	2017-11-02	7.04
TS_RUNS	SVWTP_RAW_SANT	2017-11-06	4.89
TS_RUNS	SVWTP_RAW_SANT	2018-02-05	5.12
TS_RUNS	SVWTP_RAW_SANT	2018-02-12	3.15

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	SVWTP_RAW_SANT	2018-02-19	4.4
TS_RUNS	SVWTP_RAW_SANT	2018-03-22	5.08
TS_RUNS	SVWTP_RAW_SANT	2018-03-26	5.53
TS_RUNS	SVWTP_RAW_SANT	2018-04-02	5.14
TS_RUNS	SVWTP_RAW_SANT	2018-06-28	7.96
TS_RUNS	SVWTP_RAW_SANT	2018-09-21	5.31
TS_RUNS	SVWTP_RAW_SANT	2018-09-24	6.04
TS_RUNS	SVWTP_RAW_SANT	2018-10-01	5.45
TS_RUNS	SVWTP_RAW_SANT	2018-10-08	4.73
TS_RUNS	SVWTP_RAW_SANT	2018-10-15	6.13
TS_RUNS	SVWTP_RAW_SANT	2018-10-22	4.77
TS_RUNS	SVWTP_RAW_SANT	2018-10-29	8.54
TS_RUNS	SVWTP_RAW_SANT	2018-11-05	109
TS_RUNS	SVWTP_RAW_SANT	2018-11-12	8.8
TS_RUNS	SVWTP_RAW_SANT	2018-12-28	14.8
TS_RUNS	SVWTP_RAW_SANT	2018-12-31	8.1
TS_RUNS	SVWTP_RAW_SANT	2019-01-07	3.56
TS_RUNS	SVWTP_RAW_SANT	2019-01-14	2.82
TS_RUNS	SVWTP_RAW_SANT	2019-01-21	4.12
TS_RUNS	SVWTP_RAW_SANT	2019-01-28	3.95
TS_RUNS	SVWTP_RAW_SANT	2019-02-04	3.49
TS_RUNS	SVWTP_RAW_SANT	2019-02-11	5.82
TS_RUNS	SVWTP_RAW_SANT	2019-02-18	7.03
TS_RUNS	SVWTP_RAW_SANT	2019-03-04	10.2
TS_RUNS	SVWTP_RAW_SANT	2019-03-11	11.1
TS_RUNS	SVWTP_RAW_SANT	2019-03-18	13.4
TS_RUNS	SVWTP_RAW_SANT	2019-03-25	14
TS_RUNS	SVWTP_RAW_SANT	2019-04-01	14.6
TS_RUNS	SVWTP_RAW_SANT	2019-06-17	41.3
TS_RUNS	SVWTP_RAW_SANT	2019-06-24	4.25
TS_RUNS	SVWTP_RAW_SANT	2019-07-01	4.66
TS_RUNS	SVWTP_RAW_SANT	2019-09-19	7.33
TS_RUNS	SVWTP_RAW_SANT	2019-09-23	8
TS_RUNS	SVWTP_RAW_SANT	2019-12-06	4.58
TS_RUNS	SVWTP_RAW_SANT	2019-12-09	4.13
TS_RUNS	SVWTP_RAW_SANT	2019-12-16	2.25
TS_RUNS	SVWTP_RAW_SANT	2019-12-23	2.23
TS_RUNS	SVWTP_RAW_SANT	2019-12-30	2.77
TS_RUNS	SVWTP_RAW_SANT	2020-01-06	3.76
TS_RUNS	SVWTP_RAW_SANT	2020-01-13	2.08

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	SVWTP_RAW_SANT	2020-01-20	3.19
TS_RUNS	SVWTP_RAW_SANT	2020-01-27	2.92
TS_RUNS	SVWTP_RAW_SANT	2020-02-03	2.59
TS_RUNS	SVWTP_RAW_SANT	2020-06-23	9.94
TS_RUNS	SVWTP_RAW_SANT	2021-02-02	3.05
TS_RUNS	SVWTP_RAW_SANT	2021-02-08	<2
TS_RUNS	SVWTP_RAW_SANT	2021-02-15	2.97
TS_RUNS	SVWTP_RAW_SANT	2021-02-22	2.82
TS_RUNS	SVWTP_RAW_SANT	2021-05-05	4.26
TS_RUNS	SVWTP_RAW_SANT	2021-06-11	2.62
TS_RUNS	SVWTP_RAW_SANT	2021-06-14	3.18
TS_RUNS	SVWTP_RAW_SANT	2021-07-21	108
TS_RUNS	SVWTP_RAW_SANT	2021-07-26	3.8
TS_RUNS	SVWTP_RAW_SANT	2021-08-02	4.82
TS_RUNS	SVWTP_RAW_SANT	2021-08-09	6.41
TS_RUNS	SVWTP_RAW_SANT	2021-08-16	5.69
TS_RUNS	SVWTP_RAW_SANT	2021-08-23	5.99
TS_RUNS	SVWTP_RAW_SANT	2021-08-30	5.11
TS_RUNS	SVWTP_RAW_SANT	2021-09-06	7.24
TS_RUNS	SVWTP_RAW_SANT	2021-09-13	4.77
TS_RUNS	SVWTP_RAW_SANT	2021-09-20	6.31
TS_RUNS	SVWTP_RAW_SANT	2021-10-20	2.47
TS_RUNS	SVWTP_RAW_SANT	2021-10-25	2.91
TS_RUNS	SVWTP_RAW_SANT	2021-12-28	12.1
WEST BAY SURFACE WATER			
T22_ANNUAL_RUNS	LCS_SURF	2016-06-14	17.7
T22_ANNUAL_RUNS	LCS_SURF	2017-06-19	9.43
T22_ANNUAL_RUNS	LCS_SURF	2018-06-18	7.33
T22_ANNUAL_RUNS	LCS_SURF	2019-06-17	7.3
T22_ANNUAL_RUNS	LCS_SURF	2020-07-28	11.7
T22_ANNUAL_RUNS	LCS_SURF	2021-06-14	7.84
T22_ANNUAL_RUNS	SA_SURF	2016-06-14	9.51
T22_ANNUAL_RUNS	SA_SURF	2017-06-19	6.66
T22_ANNUAL_RUNS	SA_SURF	2018-06-18	6.64
T22_ANNUAL_RUNS	PIL_SURF	2016-06-14	20.3
T22_ANNUAL_RUNS	PIL_SURF	2017-06-19	11.7
T22_ANNUAL_RUNS	PIL_SURF	2018-06-18	12.9
T22_ANNUAL_RUNS	PIL_SURF	2019-06-17	8.1
T22_ANNUAL_RUNS	PIL_SURF	2020-07-21	25.7
T22_ANNUAL_RUNS	PIL_SURF	2021-06-22	12.8

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
T22_ANNUAL_RUNS	STONE_DAM_SURF	2016-06-14	49.3
T22_ANNUAL_RUNS	STONE_DAM_SURF	2017-06-19	41.2
T22_ANNUAL_RUNS	STONE_DAM_SURF	2018-06-18	43.4
T22_ANNUAL_RUNS	STONE_DAM_SURF	2019-06-17	43.8
T22_ANNUAL_RUNS	STONE_DAM_SURF	2020-07-21	40.4
T22_ANNUAL_RUNS	STONE_DAM_SURF	2021-06-29	60.1
TS_RUNS	HTWTP_RAW	2016-01-04	14.2
TS_RUNS	HTWTP_RAW	2016-01-11	12.4
TS_RUNS	HTWTP_RAW	2016-01-19	15.7
TS_RUNS	HTWTP_RAW	2016-01-25	9.98
TS_RUNS	HTWTP_RAW	2016-02-01	11
TS_RUNS	HTWTP_RAW	2016-02-08	11.4
TS_RUNS	HTWTP_RAW	2016-02-16	12.5
TS_RUNS	HTWTP_RAW	2016-02-22	10.9
TS_RUNS	HTWTP_RAW	2016-02-29	13.2
TS_RUNS	HTWTP_RAW	2016-03-21	13.2
TS_RUNS	HTWTP_RAW	2016-03-28	9.44
TS_RUNS	HTWTP_RAW	2016-04-04	7.41
TS_RUNS	HTWTP_RAW	2016-04-11	7.77
TS_RUNS	HTWTP_RAW	2016-04-18	11
TS_RUNS	HTWTP_RAW	2016-04-25	9.16
TS_RUNS	HTWTP_RAW	2016-05-02	7.7
TS_RUNS	HTWTP_RAW	2016-06-06	11.3
TS_RUNS	HTWTP_RAW	2016-06-20	7.05
TS_RUNS	HTWTP_RAW	2016-06-27	6.07
TS_RUNS	HTWTP_RAW	2016-07-05	5.74
TS_RUNS	HTWTP_RAW	2016-07-11	4.9
TS_RUNS	HTWTP_RAW	2016-07-18	5.32
TS_RUNS	HTWTP_RAW	2016-07-25	3.74
TS_RUNS	HTWTP_RAW	2016-08-01	6.44
TS_RUNS	HTWTP_RAW	2016-08-08	6.41
TS_RUNS	HTWTP_RAW	2016-08-15	6.09
TS_RUNS	HTWTP_RAW	2016-08-22	5.14
TS_RUNS	HTWTP_RAW	2016-08-29	3.83
TS_RUNS	HTWTP_RAW	2016-09-06	4.05
TS_RUNS	HTWTP_RAW	2016-09-12	4
TS_RUNS	HTWTP_RAW	2016-09-19	3.14
TS_RUNS	HTWTP_RAW	2016-09-26	3.88
TS_RUNS	HTWTP_RAW	2016-10-03	3.6
TS_RUNS	HTWTP_RAW	2016-10-11	3.81

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	HTWTP_RAW	2016-10-17	3.73
TS_RUNS	HTWTP_RAW	2016-10-24	4.12
TS_RUNS	HTWTP_RAW	2016-10-31	3.15
TS_RUNS	HTWTP_RAW	2016-11-07	3.93
TS_RUNS	HTWTP_RAW	2016-11-14	4.2
TS_RUNS	HTWTP_RAW	2016-11-21	3.64
TS_RUNS	HTWTP_RAW	2016-12-12	5.52
TS_RUNS	HTWTP_RAW	2016-12-19	6.21
TS_RUNS	HTWTP_RAW	2016-12-26	5.97
TS_RUNS	HTWTP_RAW	2017-01-02	5.03
TS_RUNS	HTWTP_RAW	2017-01-09	4.84
TS_RUNS	HTWTP_RAW	2017-01-16	7.56
TS_RUNS	HTWTP_RAW	2017-01-23	6.23
TS_RUNS	HTWTP_RAW	2017-01-30	5.79
TS_RUNS	HTWTP_RAW	2017-02-06	5.86
TS_RUNS	HTWTP_RAW	2017-02-13	6.58
TS_RUNS	HTWTP_RAW	2017-02-20	4.43
TS_RUNS	HTWTP_RAW	2017-02-27	5.56
TS_RUNS	HTWTP_RAW	2017-03-06	4.61
TS_RUNS	HTWTP_RAW	2017-03-13	6.29
TS_RUNS	HTWTP_RAW	2017-03-20	5.8
TS_RUNS	HTWTP_RAW	2017-04-10	7.96
TS_RUNS	HTWTP_RAW	2017-04-17	9.2
TS_RUNS	HTWTP_RAW	2017-04-24	7.97
TS_RUNS	HTWTP_RAW	2017-05-01	8.29
TS_RUNS	HTWTP_RAW	2017-05-08	6.16
TS_RUNS	HTWTP_RAW	2017-05-15	5.35
TS_RUNS	HTWTP_RAW	2017-05-22	5.59
TS_RUNS	HTWTP_RAW	2017-05-29	7.63
TS_RUNS	HTWTP_RAW	2017-06-05	6.53
TS_RUNS	HTWTP_RAW	2017-06-12	12.6
TS_RUNS	HTWTP_RAW	2017-06-19	4.38
TS_RUNS	HTWTP_RAW	2017-06-26	5.23
TS_RUNS	HTWTP_RAW	2017-07-03	5.69
TS_RUNS	HTWTP_RAW	2017-07-10	5.2
TS_RUNS	HTWTP_RAW	2017-07-17	4.17
TS_RUNS	HTWTP_RAW	2017-07-24	6.48
TS_RUNS	HTWTP_RAW	2017-07-31	5.95
TS_RUNS	HTWTP_RAW	2017-08-07	9.59
TS_RUNS	HTWTP_RAW	2017-08-14	20

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	HTWTP_RAW	2017-08-21	10.7
TS_RUNS	HTWTP_RAW	2017-08-28	15.1
TS_RUNS	HTWTP_RAW	2017-09-04	8.65
TS_RUNS	HTWTP_RAW	2017-09-25	17.7
TS_RUNS	HTWTP_RAW	2017-10-02	14
TS_RUNS	HTWTP_RAW	2017-10-09	17
TS_RUNS	HTWTP_RAW	2017-10-16	13.6
TS_RUNS	HTWTP_RAW	2017-10-23	9.1
TS_RUNS	HTWTP_RAW	2017-10-30	10.7
TS_RUNS	HTWTP_RAW	2017-11-06	6.63
TS_RUNS	HTWTP_RAW	2017-11-13	6.61
TS_RUNS	HTWTP_RAW	2017-11-20	6.14
TS_RUNS	HTWTP_RAW	2017-11-27	6.63
TS_RUNS	HTWTP_RAW	2017-12-04	5.07
TS_RUNS	HTWTP_RAW	2017-12-11	4.87
TS_RUNS	HTWTP_RAW	2017-12-18	4.49
TS_RUNS	HTWTP_RAW	2017-12-25	13.5
TS_RUNS	HTWTP_RAW	2018-01-01	6.52
TS_RUNS	HTWTP_RAW	2018-01-08	4.92
TS_RUNS	HTWTP_RAW	2018-01-15	5.35
TS_RUNS	HTWTP_RAW	2018-01-22	8.48
TS_RUNS	HTWTP_RAW	2018-01-29	4.69
TS_RUNS	HTWTP_RAW	2018-02-26	9.3
TS_RUNS	HTWTP_RAW	2018-03-05	8.38
TS_RUNS	HTWTP_RAW	2018-03-12	9.63
TS_RUNS	HTWTP_RAW	2018-03-19	7.86
TS_RUNS	HTWTP_RAW	2018-03-26	8.33
TS_RUNS	HTWTP_RAW	2018-04-02	7.68
TS_RUNS	HTWTP_RAW	2018-04-09	7.33
TS_RUNS	HTWTP_RAW	2018-04-16	7.05
TS_RUNS	HTWTP_RAW	2018-04-23	7.83
TS_RUNS	HTWTP_RAW	2018-04-30	6.94
TS_RUNS	HTWTP_RAW	2018-05-07	7.26
TS_RUNS	HTWTP_RAW	2018-05-14	6.8
TS_RUNS	HTWTP_RAW	2018-05-21	8.62
TS_RUNS	HTWTP_RAW	2018-05-28	8.24
TS_RUNS	HTWTP_RAW	2018-06-04	6.09
TS_RUNS	HTWTP_RAW	2018-06-11	4.69
TS_RUNS	HTWTP_RAW	2018-06-18	6.06
TS_RUNS	HTWTP_RAW	2018-06-25	7.72

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	HTWTP_RAW	2018-07-02	8.39
TS_RUNS	HTWTP_RAW	2018-07-09	6.14
TS_RUNS	HTWTP_RAW	2018-07-16	7.11
TS_RUNS	HTWTP_RAW	2018-07-23	8.81
TS_RUNS	HTWTP_RAW	2018-07-30	9.38
TS_RUNS	HTWTP_RAW	2018-08-06	7.26
TS_RUNS	HTWTP_RAW	2018-08-13	9.97
TS_RUNS	HTWTP_RAW	2018-08-20	13.1
TS_RUNS	HTWTP_RAW	2018-08-27	18.3
TS_RUNS	HTWTP_RAW	2018-09-03	17.3
TS_RUNS	HTWTP_RAW	2018-09-10	15.7
TS_RUNS	HTWTP_RAW	2018-09-17	7.58
TS_RUNS	HTWTP_RAW	2018-09-24	8.61
TS_RUNS	HTWTP_RAW	2018-10-22	12.1
TS_RUNS	HTWTP_RAW	2018-10-29	8.3
TS_RUNS	HTWTP_RAW	2018-11-05	8.38
TS_RUNS	HTWTP_RAW	2018-11-12	8.06
TS_RUNS	HTWTP_RAW	2018-11-19	6.68
TS_RUNS	HTWTP_RAW	2018-11-26	7.45
TS_RUNS	HTWTP_RAW	2018-12-03	7.43
TS_RUNS	HTWTP_RAW	2018-12-10	10.7
TS_RUNS	HTWTP_RAW	2018-12-17	9.13
TS_RUNS	HTWTP_RAW	2018-12-24	11.8
TS_RUNS	HTWTP_RAW	2018-12-31	9.92
TS_RUNS	HTWTP_RAW	2019-01-07	8.49
TS_RUNS	HTWTP_RAW	2019-01-14	7.8
TS_RUNS	HTWTP_RAW	2019-01-21	6.31
TS_RUNS	HTWTP_RAW	2019-01-28	5.85
TS_RUNS	HTWTP_RAW	2019-02-04	6.11
TS_RUNS	HTWTP_RAW	2019-02-11	6.38
TS_RUNS	HTWTP_RAW	2019-02-18	6.78
TS_RUNS	HTWTP_RAW	2019-02-25	5.95
TS_RUNS	HTWTP_RAW	2019-03-04	6.48
TS_RUNS	HTWTP_RAW	2019-03-11	6.99
TS_RUNS	HTWTP_RAW	2019-03-18	7.28
TS_RUNS	HTWTP_RAW	2019-03-25	7.42
TS_RUNS	HTWTP_RAW	2019-04-01	7.08
TS_RUNS	HTWTP_RAW	2019-04-08	7.38
TS_RUNS	HTWTP_RAW	2019-04-15	10.8
TS_RUNS	HTWTP_RAW	2019-04-22	6.38

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	HTWTP_RAW	2019-04-29	6.05
TS_RUNS	HTWTP_RAW	2019-05-06	7.01
TS_RUNS	HTWTP_RAW	2019-05-13	7.55
TS_RUNS	HTWTP_RAW	2019-05-20	8.33
TS_RUNS	HTWTP_RAW	2019-05-27	9.25
TS_RUNS	HTWTP_RAW	2019-07-08	16
TS_RUNS	HTWTP_RAW	2019-07-15	10.5
TS_RUNS	HTWTP_RAW	2019-07-22	10.7
TS_RUNS	HTWTP_RAW	2019-07-29	11.5
TS_RUNS	HTWTP_RAW	2019-08-05	6.57
TS_RUNS	HTWTP_RAW	2019-08-12	7.2
TS_RUNS	HTWTP_RAW	2019-08-19	36.4
TS_RUNS	HTWTP_RAW	2019-08-26	7.83
TS_RUNS	HTWTP_RAW	2019-09-02	8.28
TS_RUNS	HTWTP_RAW	2019-09-09	10.6
TS_RUNS	HTWTP_RAW	2019-09-16	6.18
TS_RUNS	HTWTP_RAW	2019-09-30	18.8
TS_RUNS	HTWTP_RAW	2019-10-07	18.6
TS_RUNS	HTWTP_RAW	2019-10-14	13.5
TS_RUNS	HTWTP_RAW	2019-10-21	11.2
TS_RUNS	HTWTP_RAW	2019-10-28	10.1
TS_RUNS	HTWTP_RAW	2019-11-04	9.5
TS_RUNS	HTWTP_RAW	2019-11-11	10.5
TS_RUNS	HTWTP_RAW	2019-11-18	10
TS_RUNS	HTWTP_RAW	2019-11-25	8.64
TS_RUNS	HTWTP_RAW	2019-12-02	8.6
TS_RUNS	HTWTP_RAW	2019-12-09	7.63
TS_RUNS	HTWTP_RAW	2019-12-16	8.12
TS_RUNS	HTWTP_RAW	2019-12-23	7.61
TS_RUNS	HTWTP_RAW	2019-12-30	7.87
TS_RUNS	HTWTP_RAW	2020-01-06	9.38
TS_RUNS	HTWTP_RAW	2020-01-13	7.37
TS_RUNS	HTWTP_RAW	2020-01-20	5.69
TS_RUNS	HTWTP_RAW	2020-01-27	4.96
TS_RUNS	HTWTP_RAW	2020-02-03	5.49
TS_RUNS	HTWTP_RAW	2020-02-10	6.01
TS_RUNS	HTWTP_RAW	2020-02-17	12
TS_RUNS	HTWTP_RAW	2020-02-24	9.19
TS_RUNS	HTWTP_RAW	2020-03-02	8.74
TS_RUNS	HTWTP_RAW	2020-03-09	11.3

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	HTWTP_RAW	2020-03-16	9.1
TS_RUNS	HTWTP_RAW	2020-03-23	9.8
TS_RUNS	HTWTP_RAW	2020-03-30	9.44
TS_RUNS	HTWTP_RAW	2020-04-06	6.87
TS_RUNS	HTWTP_RAW	2020-05-04	19.5
TS_RUNS	HTWTP_RAW	2020-05-11	13.3
TS_RUNS	HTWTP_RAW	2020-05-18	15.5
TS_RUNS	HTWTP_RAW	2020-05-25	13.2
TS_RUNS	HTWTP_RAW	2020-06-01	20.5
TS_RUNS	HTWTP_RAW	2020-06-08	13.2
TS_RUNS	HTWTP_RAW	2020-06-15	9.51
TS_RUNS	HTWTP_RAW	2020-06-22	11.5
TS_RUNS	HTWTP_RAW	2020-06-29	21.9
TS_RUNS	HTWTP_RAW	2020-07-06	13.8
TS_RUNS	HTWTP_RAW	2020-07-13	8.92
TS_RUNS	HTWTP_RAW	2020-07-20	12.6
TS_RUNS	HTWTP_RAW	2020-07-27	13
TS_RUNS	HTWTP_RAW	2020-08-03	7.2
TS_RUNS	HTWTP_RAW	2020-08-10	8.49
TS_RUNS	HTWTP_RAW	2020-08-17	9.37
TS_RUNS	HTWTP_RAW	2020-08-24	6.57
TS_RUNS	HTWTP_RAW	2020-08-31	9.49
TS_RUNS	HTWTP_RAW	2020-09-07	11.7
TS_RUNS	HTWTP_RAW	2020-09-14	11.1
TS_RUNS	HTWTP_RAW	2020-09-21	13.8
TS_RUNS	HTWTP_RAW	2020-09-28	17.2
TS_RUNS	HTWTP_RAW	2020-10-05	26.7
TS_RUNS	HTWTP_RAW	2020-10-12	17.2
TS_RUNS	HTWTP_RAW	2020-11-24	29.4
TS_RUNS	HTWTP_RAW	2020-11-30	21.3
TS_RUNS	HTWTP_RAW	2020-12-07	19.6
TS_RUNS	HTWTP_RAW	2020-12-14	14.9
TS_RUNS	HTWTP_RAW	2020-12-21	13.2
TS_RUNS	HTWTP_RAW	2020-12-28	12.5
TS_RUNS	HTWTP_RAW	2021-01-04	13.1
TS_RUNS	HTWTP_RAW	2021-01-11	12.1
TS_RUNS	HTWTP_RAW	2021-01-18	13.2
TS_RUNS	HTWTP_RAW	2021-01-25	10.2
TS_RUNS	HTWTP_RAW	2021-02-01	7.13
TS_RUNS	HTWTP_RAW	2021-02-08	7.8

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	HTWTP_RAW	2021-02-15	5.55
TS_RUNS	HTWTP_RAW	2021-02-22	6.07
TS_RUNS	HTWTP_RAW	2021-03-01	6.5
TS_RUNS	HTWTP_RAW	2021-03-08	7.03
TS_RUNS	HTWTP_RAW	2021-03-15	7.25
TS_RUNS	HTWTP_RAW	2021-03-22	6.55
TS_RUNS	HTWTP_RAW	2021-03-29	5.08
TS_RUNS	HTWTP_RAW	2021-04-05	4.86
TS_RUNS	HTWTP_RAW	2021-04-12	4.47
TS_RUNS	HTWTP_RAW	2021-04-19	4.16
TS_RUNS	HTWTP_RAW	2021-04-26	4.43
TS_RUNS	HTWTP_RAW	2021-05-03	4.05
TS_RUNS	HTWTP_RAW	2021-05-10	5.21
TS_RUNS	HTWTP_RAW	2021-05-17	7.96
TS_RUNS	HTWTP_RAW	2021-05-24	5.37
TS_RUNS	HTWTP_RAW	2021-05-31	5
TS_RUNS	HTWTP_RAW	2021-06-07	4.48
TS_RUNS	HTWTP_RAW	2021-06-14	4.9
TS_RUNS	HTWTP_RAW	2021-06-21	5.78
TS_RUNS	HTWTP_RAW	2021-06-28	6.93
TS_RUNS	HTWTP_RAW	2021-07-05	<2
TS_RUNS	HTWTP_RAW	2021-07-12	5.67
TS_RUNS	HTWTP_RAW	2021-07-19	6.46
TS_RUNS	HTWTP_RAW	2021-09-21	65.3
TS_RUNS	HTWTP_RAW	2021-09-27	41.3
TS_RUNS	HTWTP_RAW	2021-10-04	43.5
TS_RUNS	HTWTP_RAW	2021-10-11	35.9
TS_RUNS	HTWTP_RAW	2021-11-01	28.1
TS_RUNS	HTWTP_RAW	2021-11-08	17.7
TS_RUNS	HTWTP_RAW	2021-11-15	23.7
TS_RUNS	HTWTP_RAW	2021-11-22	21
TS_RUNS	HTWTP_RAW	2021-11-29	27.3
TS_RUNS	HTWTP_RAW	2021-12-06	26.8
TS_RUNS	HTWTP_RAW	2021-12-13	15.6
TS_RUNS	HTWTP_RAW	2021-12-20	12.9
TS_RUNS	HTWTP_RAW	2021-12-27	14.6
GROUNDWATER SF CITY			
T22_ANNUAL_RUNS	LK_MERCED_S	2020-07-14	59.1
T22_ANNUAL_RUNS	SF_ZOO_WELL_5	2020-06-17	25.2
SFGW_1ST-YR	SFGW-LMW	2018-01-11	3.26

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFGW_1ST-YR	SFGW-GCW	2018-03-06	<2
SFGW_1ST-YR	SFGW-SSW	2018-03-06	<2
SFGW_1ST-YR	SFGW-WSW	2018-03-08	<2
SFGW_1ST-YR	SFGW-GCW	2018-03-20	<2
SFGW_1ST-YR	SFGW-SSW	2018-03-20	<2
SFGW_1ST-YR	SFGW-WSW	2018-03-20	<2
SFGW_1ST-YR	SFGW-NLW	2020-07-16	7.47
SFGW_1ST-YR	SFGW-SWW	2020-07-20	<2
SFGW_7DAY	SFGW-LMW	2017-10-26	3.68
SFGW_7DAY	SFGW-WSW	2018-02-12	<2
SFGW_7DAY	SFGW-SSW	2018-02-20	<2
SFGW_7DAY	SFGW-GCW	2018-02-27	<2
SFGW_7DAY	SFGW-WSW	2018-02-27	<2
SFGW_7DAY	SFGW-NLW	2020-07-20	7.01
SFGW_7DAY	SFGW-SWW	2020-07-20	<2
SFGW_7WEEK	SFGW-LMW	2017-12-26	3.53
SFGW_7WEEK	SFGW-LMW	2018-01-10	3.29
SFGW_7WEEK	SFGW-LMW	2018-01-16	3.42
SFGW_7WEEK	SFGW-LMW	2018-01-23	3.32
SFGW_7WEEK	SFGW-LMW	2018-01-30	3.18
SFGW_7WEEK	SFGW-LMW	2018-02-06	2.67
SFGW_7WEEK	SFGW-GCW	2018-02-13	<2
SFGW_7WEEK	SFGW-LMW	2018-02-13	2.98
SFGW_7WEEK	SFGW-GCW	2018-02-20	<2
SFGW_7WEEK	SFGW-WSW	2018-02-20	<2
SFGW_7WEEK	SFGW-GCW	2018-03-06	<2
SFGW_7WEEK	SFGW-SSW	2018-03-06	<2
SFGW_7WEEK	SFGW-WSW	2018-03-08	<2
SFGW_7WEEK	SFGW-GCW	2018-03-13	<2
SFGW_7WEEK	SFGW-SSW	2018-03-13	<2
SFGW_7WEEK	SFGW-WSW	2018-03-13	<2
SFGW_7WEEK	SFGW-GCW	2018-03-27	<2
SFGW_7WEEK	SFGW-SSW	2018-03-27	<2
SFGW_7WEEK	SFGW-WSW	2018-03-27	<2
SFGW_7WEEK	SFGW-SSW	2018-04-04	<2
SFGW_7WEEK	SFGW-SSW	2018-04-10	<2
SFGW_7WEEK	SFGW-WSW	2018-04-10	<2
SFGW_7WEEK	SFGW-SSW	2018-04-17	<2
SFGW_7WEEK	SFGW-SSW	2018-04-19	<2
SFGW_7WEEK	SFGW-WSW	2018-04-19	10.4

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFGW_HISTORICAL	SFGW-LMW	2017-06-14	3.16
SFGW_HISTORICAL	SFGW-LMW	2017-06-28	2.62
SFGW_HISTORICAL	SFGW-LMW	2017-07-05	<2
SFGW_OPS	LMW FRP Tank	2018-07-20	2.73
SFGW_OPS	SFGW - WSW	2018-10-04	<2
SFGW_RUNS	SFGW-GCW	2019-06-17	<2
SFGW_RUNS	SFGW-LMW	2019-06-17	3.86
SFGW_RUNS	SFGW-SSW	2019-06-17	<2
SFGW_RUNS	SFGW-WSW	2019-06-17	<2
SFGW_RUNS	SFGW-LMW	2020-07-14	3.51
SFGW_RUNS	SFGW-SSW	2020-07-14	<2
SFGW_RUNS	SFGW-GCW	2020-07-15	<2
SFGW_RUNS	SFGW-WSW	2020-07-15	<2
SFGW_RUNS	SFGW-LMW	2021-07-13	3.55
SFGW_RUNS	SFGW-SSW	2021-07-13	<2
SFGW_RUNS	SFGW-WSW	2021-07-13	<2
SFGW_RUNS	SFGW-GCW	2021-07-20	<2
SFGW_RUNS	SFGW-NLW	2021-07-20	9.02
SFGW_RUNS	SFGW-SWW	2021-07-20	<2
WESTSIDE_BASIN	WSB_SB_DUP	2016-05-09	<2
WESTSIDE_BASIN	WSB_SB_DUP	2016-05-09	<2
WESTSIDE_BASIN	WSB_SB-M-1	2016-05-09	<2
WESTSIDE_BASIN	WSB_SB-M-1	2016-05-09	<2
WESTSIDE_BASIN	WSB_SS_DUP	2018-05-01	324
WESTSIDE_BASIN	WSB_SS-36-1-455	2018-05-01	322
WESTSIDE_BASIN	WSB_CAL-22A-545	2018-05-07	<2
WESTSIDE_BASIN	WSB_CAL-18-230	2018-05-08	<2
WESTSIDE_BASIN	WSB_DC_DUP	2018-05-14	253
WESTSIDE_BASIN	WSB_DC-10A-710	2018-05-14	247
GROUNDWATER PENINSULA			
GSR_1ST-YR	GSR-HBW	2020-07-07	5.22
GSR_1ST-YR	GSR-PDW	2020-07-07	<2
GSR_1ST-YR	GSR-CBW	2020-07-08	25.1
GSR_1ST-YR	GSR-FSW	2020-07-08	5.53
GSR_1ST-YR	GSR-MYW	2020-07-08	<2
GSR_1ST-YR	GSR-BSW	2021-07-14	<2
GSR_1ST-YR	GSR-SBW	2021-08-18	3.07
GSR_7DAY	GSR-FSCP	2020-01-13	<2
GSR_7DAY	GSR-FSCP	2020-01-14	<2
GSR_7DAY	GSR-FSCP	2020-01-15	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
GSR_7DAY	GSR-FSCP	2020-01-16	<2
GSR_7DAY	GSR-FSW	2020-01-16	4.88
GSR_7DAY	GSR-FSCP	2020-01-27	<2
GSR_7DAY	GSR-FSCP	2020-01-28	<2
GSR_7DAY	GSR-FSCP	2020-01-29	<2
GSR_7DAY	GSR-FSCP	2020-01-30	<2
GSR_7DAY	GSR-FSW	2020-01-30	4.81
GSR_7DAY	GSR-FSCP	2020-02-19	<2
GSR_7DAY	GSR-FSCP	2020-02-20	<2
GSR_7DAY	GSR-CBW	2020-02-21	18.8
GSR_7DAY	GSR-FSCP	2020-02-21	<2
GSR_7DAY	GSR-FSCP	2020-02-22	<2
GSR_7DAY	GSR-FSCP	2020-03-02	<2
GSR_7DAY	GSR-FSCP	2020-03-03	2.7
GSR_7DAY	GSR-FSCP	2020-03-04	2.28
GSR_7DAY	GSR-CBW	2020-03-05	21.1
GSR_7DAY	GSR-FSCP	2020-03-05	2.52
GSR_7DAY	GSR-FSW	2020-03-05	4.9
GSR_7DAY	GSR-HBCP	2020-03-09	<2
GSR_7DAY	GSR-HBCP	2020-03-10	<2
GSR_7DAY	GSR-HBCP	2020-05-11	<2
GSR_7DAY	GSR-HBCP	2020-05-12	2.06
GSR_7DAY	GSR-HBCP	2020-05-13	<2
GSR_7DAY	GSR-HBCP	2020-05-14	<2
GSR_7DAY	GSR-HBW	2020-05-14	5.52
GSR_7DAY	GSR-MYCP	2020-06-01	3.27
GSR_7DAY	GSR-MYCP	2020-06-02	3.76
GSR_7DAY	GSR-MYCP	2020-06-03	3.13
GSR_7DAY	GSR-MYCP	2020-06-04	2.97
GSR_7DAY	GSR-MYW	2020-06-04	<2
GSR_7DAY	GSR-MYCP	2020-06-05	2.94
GSR_7DAY	GSR-PDCP	2020-06-23	4.07
GSR_7DAY	GSR-PDCP	2020-06-24	3.66
GSR_7DAY	GSR-PDCP	2020-06-25	3.31
GSR_7DAY	GSR-PDCP	2020-06-26	2.05
GSR_7DAY	GSR-PDWLGWLGW	2020-06-26	<2
GSR_7DAY	GSR-FSCP	2021-03-02	<2
GSR_7DAY	GSR-FSCP	2021-03-03	<2
GSR_7DAY	GSR-FSCP	2021-03-04	<2
GSR_7DAY	GSR-BSW	2021-03-05	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
GSR_7DAY	GSR-CBW	2021-03-05	24.2
GSR_7DAY	GSR-FSCP	2021-03-05	<2
GSR_7DAY	GSR-FSW	2021-03-05	3.61
GSR_7DAY	GSR-FSCP	2021-03-06	<2
GSR_7DAY	GSR-MSW	2021-12-08	8.5
GSR_7WEEK	GSR-MYCP	2021-06-01	3.3
GSR_7WEEK	GSR-MYW	2021-06-01	<2
GSR_7WEEK	GSR-MYCP	2021-06-09	3.35
GSR_7WEEK	GSR-MYW	2021-06-09	<2
GSR_7WEEK	GSR-MYCP	2021-06-16	3.71
GSR_7WEEK	GSR-MYW	2021-06-16	<2
GSR_7WEEK	GSR-BSW	2021-06-23	<2
GSR_7WEEK	GSR-CBW	2021-06-23	28.1
GSR_7WEEK	GSR-FSCP	2021-06-23	<2
GSR_7WEEK	GSR-FSW	2021-06-23	5.92
GSR_7WEEK	GSR-MYCP	2021-06-23	4.5
GSR_7WEEK	GSR-MYW	2021-06-23	<2
GSR_7WEEK	GSR-BSW	2021-07-01	<2
GSR_7WEEK	GSR-CBW	2021-07-01	31.7
GSR_7WEEK	GSR-FSCP	2021-07-01	<2
GSR_7WEEK	GSR-FSW	2021-07-01	6.42
GSR_7WEEK	GSR-MYCP	2021-07-01	3.84
GSR_7WEEK	GSR-MYW	2021-07-01	<2
GSR_7WEEK	GSR-MYCP	2021-07-07	2.81
GSR_7WEEK	GSR-MYW	2021-07-07	<2
GSR_7WEEK	GSR-BSW	2021-08-12	<2
GSR_7WEEK	GSR-CBW	2021-08-12	19.2
GSR_7WEEK	GSR-FSCP	2021-08-12	5.15
GSR_7WEEK	GSR-FSW	2021-08-12	5.07
GSR_7WEEK	GSR-BSW	2021-08-18	<2
GSR_7WEEK	GSR-CBW	2021-08-18	18.6
GSR_7WEEK	GSR-FSCP	2021-08-18	4.12
GSR_7WEEK	GSR-FSW	2021-08-18	4.45
GSR_7WEEK	GSR-BSW	2021-08-26	<2
GSR_7WEEK	GSR-CBW	2021-08-26	23
GSR_7WEEK	GSR-FSCP	2021-08-26	3.76
GSR_7WEEK	GSR-FSW	2021-08-26	4.57
GSR_7WEEK	GSR-BSW	2021-09-01	<2
GSR_7WEEK	GSR-CBW	2021-09-01	25.8
GSR_7WEEK	GSR-FSCP	2021-09-01	5.21

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
GSR_7WEEK	GSR-FSW	2021-09-01	4.21
GSR_HISTORICAL	GSR-FHW	2018-08-01	267
GSR_HISTORICAL	GSR-FHW	2018-08-01	269
GSR_HISTORICAL	GSR-FHW	2018-08-01	273
GSR_HISTORICAL	GSR-FHW	2018-08-02	354
GSR_HISTORICAL	GSR-FHW	2018-08-02	358
GSR_HISTORICAL	GSR-FHW	2018-08-02	353
GSR_HISTORICAL	GSR-MSW	2018-08-29	6.96
GSR_HISTORICAL	GSR-MSW	2018-08-29	7.21
GSR_HISTORICAL	GSR-MSW	2018-08-29	7.02
GSR_HISTORICAL	GSR-TIW	2018-08-30	9.31
GSR_HISTORICAL	GSR-TIW	2018-08-30	9.38
GSR_HISTORICAL	GSR-TIW	2018-08-30	9.79
GSR_HISTORICAL	GSR-CBW	2018-09-05	66.5
GSR_HISTORICAL	GSR-CBW	2018-09-05	53.3
GSR_HISTORICAL	GSR-CBW	2018-09-05	59.5
GSR_HISTORICAL	GSR-CRW	2018-09-05	6.33
GSR_HISTORICAL	GSR-CRW	2018-09-05	6.98
GSR_HISTORICAL	GSR-CRW	2018-09-05	6.15
GSR_HISTORICAL	GSR-CBW	2018-09-06	11.7
GSR_HISTORICAL	GSR-CBW	2018-09-06	10.9
GSR_HISTORICAL	GSR-CBW	2018-09-06	11.7
GSR_HISTORICAL	GSR-CRW	2018-09-06	5.57
GSR_HISTORICAL	GSR-CRW	2018-09-06	5.51
GSR_HISTORICAL	GSR-CRW	2018-09-06	5.47
GSR_HISTORICAL	GSR-LGW	2018-09-12	<2
GSR_HISTORICAL	GSR-LGW	2018-09-12	<2
GSR_HISTORICAL	GSR-LGW	2018-09-12	<2
GSR_HISTORICAL	GSR-SBW	2018-09-12	<2
GSR_HISTORICAL	GSR-SBW	2018-09-12	<2
GSR_HISTORICAL	GSR-SBW	2018-09-12	<2
GSR_HISTORICAL	GSR-LGW	2018-09-13	<2
GSR_HISTORICAL	GSR-LGW	2018-09-13	<2
GSR_HISTORICAL	GSR-LGW	2018-09-13	<2
GSR_HISTORICAL	GSR-SBW	2018-09-13	<2
GSR_HISTORICAL	GSR-SBW	2018-09-13	<2
GSR_HISTORICAL	GSR-SBW	2018-09-13	<2
GSR_HISTORICAL	GSR-HBW	2018-09-19	5.72
GSR_HISTORICAL	GSR-HBW	2018-09-19	5.95
GSR_HISTORICAL	GSR-HBW	2018-09-19	5.71

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
GSR_HISTORICAL	GSR-SRW	2018-09-19	<2
GSR_HISTORICAL	GSR-SRW	2018-09-19	<2
GSR_HISTORICAL	GSR-SRW	2018-09-19	<2
GSR_HISTORICAL	GSR-HBW	2018-09-20	5.72
GSR_HISTORICAL	GSR-HBW	2018-09-20	5.73
GSR_HISTORICAL	GSR-HBW	2018-09-20	5.77
GSR_HISTORICAL	GSR-SRW	2018-09-20	<2
GSR_HISTORICAL	GSR-SRW	2018-09-20	<2
GSR_HISTORICAL	GSR-SRW	2018-09-20	<2
GSR_HISTORICAL	GSR-MYW	2018-09-26	<2
GSR_HISTORICAL	GSR-MYW	2018-09-26	<2
GSR_HISTORICAL	GSR-MYW	2018-09-26	<2
GSR_HISTORICAL	GSR-MYW	2018-09-27	<2
GSR_HISTORICAL	GSR-MYW	2018-09-27	<2
GSR_HISTORICAL	GSR-MYW	2018-09-27	<2
GSR_HISTORICAL	GSR-SDW	2020-08-05	256
GSR_PARTNER	GSR-BFW	2020-08-12	<2
GSR_PARTNER	GSR-BFW	2018-10-04	<2
GSR_PARTNER	GSR-BFW	2018-10-04	<2
GSR_PARTNER	GSR-BFW	2018-10-04	<2
GSR_PARTNER	GSR-BFW	2018-10-03	<2
GSR_PARTNER	GSR-BFW	2018-10-03	<2
GSR_PARTNER	GSR-LPW	2020-08-26	121
GSR_PARTNER	GSR-LPW	2018-07-25	452
GSR_PARTNER	GSR-LPW	2018-07-25	448
GSR_PARTNER	GSR-LPW	2018-07-25	448
GSR_PARTNER	GSR-PPW	2018-10-03	<2
GSR_PARTNER	GSR-PPW	2018-10-04	<2
GSR_PARTNER	GSR-PPW	2018-10-03	<2
GSR_PARTNER	GSR-PPW	2018-10-03	<2
GSR_PARTNER	GSR-PPW	2018-10-04	<2
GSR_PARTNER	GSR-PPW	2018-10-04	<2
GSR_PARTNER	GSR-SMW	2016-02-17	216
GSR_PARTNER	GSR-SMW	2016-02-17	197
GSR_PARTNER	GSR-SMW	2016-02-17	189
GSR_PRE-COMP	GSR-BSW	2019-06-26	<2
GSR_PRE-COMP	GSR-CBW	2019-06-26	11.9
GSR_PRE-COMP	GSR-FSW	2019-06-26	4.44
GSR_PRE-COMP	GSR-HBW	2019-06-24	4.98
GSR_PRE-COMP	GSR-MSW	2019-06-25	9.19

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
GSR_PRE-COMP	GSR-MYW	2019-06-25	<2
GSR_PRE-COMP	GSR-PDWLGWLGW	2019-06-24	<2
GSR_PRE-COMP	GSR-SBW	2019-06-24	3.02
GSR_PRE-COMP	GSR-SDW	2019-06-25	212
GSR_RUNS	GSR-MYCP	2021-07-07	3.33
GSR_RUNS	GSR-MYW	2021-07-07	<2
GSR_RUNS	GSR-HBW	2021-07-08	5.43
GSR_RUNS	GSR-PDW	2021-07-08	<2
GSR_RUNS	GSR-CBW	2021-07-14	23.1
GSR_RUNS	GSR-FSW	2021-07-14	6.11
GSR_RUNS	GSR-FSCP	2021-08-12	6.09
GROUNDWATER EAST BAY			
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2016-06-14	<2
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2017-06-19	<2
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2018-06-18	<2
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2019-06-26	<2
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2020-06-16	<2
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2016-06-14	<2
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2017-06-19	<2
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2018-06-18	<2
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2019-06-17	<2
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2020-06-16	<2
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2021-06-23	<2
T22_ANNUAL_RUNS	SUNOL_FILTER	2016-06-14	<2
T22_ANNUAL_RUNS	SUNOL_FILTER	2017-06-19	9.95
T22_ANNUAL_RUNS	SUNOL_FILTER	2018-06-18	31.3
DRINKING WATER			
T22_ANNUAL_RUNS	MOC_TK	2016-06-15	2.92
T22_ANNUAL_RUNS	MOC_TK	2017-07-20	3.28
T22_ANNUAL_RUNS	MOC_TK	2018-06-18	2.22
T22_ANNUAL_RUNS	MOC_TK	2019-06-18	3.82
T22_ANNUAL_RUNS	MOC_TK	2020-06-15	8.67
T22_ANNUAL_RUNS	MOC_TK	2021-07-14	3.05
T22_ANNUAL_RUNS	OSH_TK	2016-06-15	2.64
T22_ANNUAL_RUNS	OSH_TK	2017-06-19	2.43
T22_ANNUAL_RUNS	OSH_TK	2018-06-19	<2
T22_ANNUAL_RUNS	OSH_TK	2019-06-18	2.08
T22_ANNUAL_RUNS	OSH_TK	2020-06-16	2.32
T22_ANNUAL_RUNS	OSH_TK	2021-07-14	4.43
T22_ANNUAL_RUNS	EI_TK	2016-06-14	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
T22_ANNUAL_RUNS	EI_TK	2017-06-19	3.19
T22_ANNUAL_RUNS	EI_TK	2018-06-19	4.1
T22_ANNUAL_RUNS	EI_TK	2019-06-19	3.3
T22_ANNUAL_RUNS	EI_TK	2020-06-23	2.36
T22_ANNUAL_RUNS	EI_TK	2021-07-14	3.95
UCMR4_SPECIAL	ALAMEDA_EAST	2018-01-22	4.7
UCMR4_SPECIAL	ALAMEDA_EAST	2018-04-23	3.8
UCMR4_SPECIAL	ALAMEDA_EAST	2018-07-23	0.41
UCMR4_SPECIAL	ALAMEDA_EAST	2018-10-22	4.9
T22_ANNUAL_RUNS	ALAMEDA_EAST	2018-06-18	2.6
T22_ANNUAL_RUNS	ALAMEDA_EAST	2019-06-17	2.99
T22_ANNUAL_RUNS	ALAMEDA_EAST	2020-06-15	4.13
T22_ANNUAL_RUNS	ALAMEDA_EAST	2021-06-22	3.96
TS_RUNS	SVWTP_EFF	2016-01-11	7.3
TS_RUNS	SVWTP_EFF	2016-01-19	31.5
TS_RUNS	SVWTP_EFF	2016-01-25	5.81
TS_RUNS	SVWTP_EFF	2016-02-01	2.56
TS_RUNS	SVWTP_EFF	2016-02-08	<2
TS_RUNS	SVWTP_EFF	2016-02-16	2.5
TS_RUNS	SVWTP_EFF	2016-02-22	<2
TS_RUNS	SVWTP_EFF	2016-02-29	2.13
TS_RUNS	SVWTP_EFF	2016-03-07	4.06
TS_RUNS	SVWTP_EFF	2016-03-14	2.5
TS_RUNS	SVWTP_EFF	2016-03-15	<2
TS_RUNS	SVWTP_EFF	2016-03-15	<2
TS_RUNS	SVWTP_EFF	2016-03-21	<2
TS_RUNS	SVWTP_EFF	2016-03-28	2.53
TS_RUNS	SVWTP_EFF	2016-04-04	2.87
TS_RUNS	SVWTP_EFF	2016-04-11	<2
TS_RUNS	SVWTP_EFF	2016-04-18	<2
TS_RUNS	SVWTP_EFF	2016-04-25	2.45
TS_RUNS	SVWTP_EFF	2016-05-02	<2
TS_RUNS	SVWTP_EFF	2016-05-09	2.44
TS_RUNS	SVWTP_EFF	2016-05-16	<2
TS_RUNS	SVWTP_EFF	2016-05-23	2.57
TS_RUNS	SVWTP_EFF	2016-05-31	<2
TS_RUNS	SVWTP_EFF	2016-06-15	<2
TS_RUNS	SVWTP_EFF	2016-07-29	4.85
T22_ANNUAL_RUNS	SVWTP_EFF	2016-06-14	<2
T22_ANNUAL_RUNS	SVWTP_EFF	2017-06-19	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
T22_ANNUAL_RUNS	SVWTP_EFF	2018-06-28	<2
T22_ANNUAL_RUNS	SVWTP_EFF	2019-06-17	<2
T22_ANNUAL_RUNS	SVWTP_EFF	2020-06-24	3.2
TS_RUNS	SVWTP_TWR_EFF	2016-09-20	2.73
TS_RUNS	SVWTP_TWR_EFF	2016-10-06	2.85
TS_RUNS	SVWTP_TWR_EFF	2016-10-11	<2
TS_RUNS	SVWTP_TWR_EFF	2016-11-17	<2
TS_RUNS	SVWTP_TWR_EFF	2016-11-21	<2
TS_RUNS	SVWTP_TWR_EFF	2016-11-28	<2
TS_RUNS	SVWTP_TWR_EFF	2016-12-05	<2
TS_RUNS	SVWTP_TWR_EFF	2016-12-26	10.8
TS_RUNS	SVWTP_TWR_EFF	2017-01-02	28
TS_RUNS	SVWTP_TWR_EFF	2017-01-09	14
TS_RUNS	SVWTP_TWR_EFF	2017-01-16	<2
TS_RUNS	SVWTP_TWR_EFF	2017-01-23	<2
TS_RUNS	SVWTP_TWR_EFF	2017-01-30	<2
TS_RUNS	SVWTP_TWR_EFF	2017-02-06	<2
TS_RUNS	SVWTP_TWR_EFF	2017-02-13	<2
TS_RUNS	SVWTP_TWR_EFF	2017-02-20	<2
TS_RUNS	SVWTP_TWR_EFF	2017-02-27	<2
TS_RUNS	SVWTP_TWR_EFF	2017-03-06	<2
TS_RUNS	SVWTP_TWR_EFF	2017-03-13	<2
TS_RUNS	SVWTP_TWR_EFF	2017-03-20	<2
TS_RUNS	SVWTP_TWR_EFF	2017-03-27	2.43
TS_RUNS	SVWTP_TWR_EFF	2017-04-03	3.8
TS_RUNS	SVWTP_TWR_EFF	2017-04-10	4.48
TS_RUNS	SVWTP_TWR_EFF	2017-04-17	4.58
TS_RUNS	SVWTP_TWR_EFF	2017-04-24	<2
TS_RUNS	SVWTP_TWR_EFF	2017-05-01	<2
TS_RUNS	SVWTP_TWR_EFF	2017-05-08	<2
TS_RUNS	SVWTP_TWR_EFF	2017-05-15	2.06
TS_RUNS	SVWTP_TWR_EFF	2017-05-22	<2
TS_RUNS	SVWTP_TWR_EFF	2017-05-29	<2
TS_RUNS	SVWTP_TWR_EFF	2017-06-05	<2
TS_RUNS	SVWTP_TWR_EFF	2017-06-12	<2
TS_RUNS	SVWTP_TWR_EFF	2017-06-19	<2
TS_RUNS	SVWTP_TWR_EFF	2017-08-02	2.44
TS_RUNS	SVWTP_TWR_EFF	2017-09-11	3.26
TS_RUNS	SVWTP_TWR_EFF	2017-09-18	2.71
TS_RUNS	SVWTP_TWR_EFF	2017-10-26	18.2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	SVWTP_TWR_EFF	2017-10-30	2.93
TS_RUNS	SVWTP_TWR_EFF	2017-11-02	5.93
TS_RUNS	SVWTP_TWR_EFF	2017-11-06	20
TS_RUNS	SVWTP_TWR_EFF	2017-12-11	21.8
TS_RUNS	SVWTP_TWR_EFF	2017-12-18	13.1
TS_RUNS	SVWTP_TWR_EFF	2017-12-25	14
TS_RUNS	SVWTP_TWR_EFF	2018-01-01	24.4
TS_RUNS	SVWTP_TWR_EFF	2018-01-08	31.6
TS_RUNS	SVWTP_TWR_EFF	2018-01-08	29.7
TS_RUNS	SVWTP_TWR_EFF	2018-01-15	16.8
TS_RUNS	SVWTP_TWR_EFF	2018-01-15	15.5
TS_RUNS	SVWTP_TWR_EFF	2018-02-05	5.68
TS_RUNS	SVWTP_TWR_EFF	2018-02-12	3.06
TS_RUNS	SVWTP_TWR_EFF	2018-02-19	<2
TS_RUNS	SVWTP_TWR_EFF	2018-03-22	<2
TS_RUNS	SVWTP_TWR_EFF	2018-03-26	<2
TS_RUNS	SVWTP_TWR_EFF	2018-04-02	<2
TS_RUNS	SVWTP_TWR_EFF	2018-04-09	2.1
TS_RUNS	SVWTP_TWR_EFF	2018-04-16	5.16
TS_RUNS	SVWTP_TWR_EFF	2018-04-23	4.31
TS_RUNS	SVWTP_TWR_EFF	2018-04-30	2.94
TS_RUNS	SVWTP_TWR_EFF	2018-05-07	2.09
TS_RUNS	SVWTP_TWR_EFF	2018-05-14	<2
TS_RUNS	SVWTP_TWR_EFF	2018-05-21	4.12
TS_RUNS	SVWTP_TWR_EFF	2018-06-28	2.62
TS_RUNS	SVWTP_TWR_EFF	2018-09-21	<2
TS_RUNS	SVWTP_TWR_EFF	2018-09-21	<2
TS_RUNS	SVWTP_TWR_EFF	2018-09-24	<2
TS_RUNS	SVWTP_TWR_EFF	2018-10-01	2
TS_RUNS	SVWTP_TWR_EFF	2018-10-08	2.03
TS_RUNS	SVWTP_TWR_EFF	2018-10-15	<2
TS_RUNS	SVWTP_TWR_EFF	2018-10-22	<2
TS_RUNS	SVWTP_TWR_EFF	2018-10-29	5.56
TS_RUNS	SVWTP_TWR_EFF	2018-11-05	5.93
TS_RUNS	SVWTP_TWR_EFF	2018-11-12	4
TS_RUNS	SVWTP_TWR_EFF	2018-12-28	<2
TS_RUNS	SVWTP_TWR_EFF	2018-12-31	<2
TS_RUNS	SVWTP_TWR_EFF	2019-01-07	<2
TS_RUNS	SVWTP_TWR_EFF	2019-01-14	3.98
TS_RUNS	SVWTP_TWR_EFF	2019-01-21	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	SVWTP_TWR_EFF	2019-01-28	<2
TS_RUNS	SVWTP_TWR_EFF	2019-02-04	<2
TS_RUNS	SVWTP_TWR_EFF	2019-02-11	<2
TS_RUNS	SVWTP_TWR_EFF	2019-02-18	<2
TS_RUNS	SVWTP_TWR_EFF	2019-02-25	4.99
TS_RUNS	SVWTP_TWR_EFF	2019-03-04	<2
TS_RUNS	SVWTP_TWR_EFF	2019-03-11	<2
TS_RUNS	SVWTP_TWR_EFF	2019-03-18	<2
TS_RUNS	SVWTP_TWR_EFF	2019-03-25	<2
TS_RUNS	SVWTP_TWR_EFF	2019-04-01	<2
TS_RUNS	SVWTP_TWR_EFF	2019-04-08	<2
TS_RUNS	SVWTP_TWR_EFF	2019-04-15	<2
TS_RUNS	SVWTP_TWR_EFF	2019-05-23	4.58
TS_RUNS	SVWTP_TWR_EFF	2019-05-27	4.33
TS_RUNS	SVWTP_TWR_EFF	2019-06-03	3.97
TS_RUNS	SVWTP_TWR_EFF	2019-06-10	4.73
TS_RUNS	SVWTP_TWR_EFF	2019-06-17	<2
TS_RUNS	SVWTP_TWR_EFF	2019-06-24	2.14
TS_RUNS	SVWTP_TWR_EFF	2019-07-01	2.27
TS_RUNS	SVWTP_TWR_EFF	2019-09-19	<2
TS_RUNS	SVWTP_TWR_EFF	2019-09-23	<2
TS_RUNS	SVWTP_TWR_EFF	2019-12-06	<2
TS_RUNS	SVWTP_TWR_EFF	2019-12-09	<2
TS_RUNS	SVWTP_TWR_EFF	2019-12-16	<2
TS_RUNS	SVWTP_TWR_EFF	2019-12-23	<2
TS_RUNS	SVWTP_TWR_EFF	2019-12-30	<2
TS_RUNS	SVWTP_TWR_EFF	2020-01-06	<2
TS_RUNS	SVWTP_TWR_EFF	2020-01-13	<2
TS_RUNS	SVWTP_TWR_EFF	2020-01-20	<2
TS_RUNS	SVWTP_TWR_EFF	2020-01-27	<2
TS_RUNS	SVWTP_TWR_EFF	2020-02-03	<2
TS_RUNS	SVWTP_TWR_EFF	2020-02-05	5.13
TS_RUNS	SVWTP_TWR_EFF	2020-04-10	7.52
TS_RUNS	SVWTP_TWR_EFF	2020-04-13	11.7
TS_RUNS	SVWTP_TWR_EFF	2020-05-18	3.44
TS_RUNS	SVWTP_TWR_EFF	2020-06-23	5.4
TS_RUNS	SVWTP_TWR_EFF	2020-08-28	<2
TS_RUNS	SVWTP_TWR_EFF	2020-08-31	<2
TS_RUNS	SVWTP_TWR_EFF	2020-09-01	<2
TS_RUNS	SVWTP_TWR_EFF	2020-09-07	3.09

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	SVWTP_TWR_EFF	2020-10-19	3.67
TS_RUNS	SVWTP_TWR_EFF	2020-10-26	2.21
TS_RUNS	SVWTP_TWR_EFF	2020-11-02	2.95
TS_RUNS	SVWTP_TWR_EFF	2020-11-09	3.17
TS_RUNS	SVWTP_TWR_EFF	2020-11-16	3.13
TS_RUNS	SVWTP_TWR_EFF	2020-11-23	2.96
TS_RUNS	SVWTP_TWR_EFF	2021-02-02	3.16
TS_RUNS	SVWTP_TWR_EFF	2021-02-08	<2
TS_RUNS	SVWTP_TWR_EFF	2021-02-15	<2
TS_RUNS	SVWTP_TWR_EFF	2021-02-22	2.2
TS_RUNS	SVWTP_TWR_EFF	2021-05-05	<2
TS_RUNS	SVWTP_TWR_EFF	2021-06-11	<2
TS_RUNS	SVWTP_TWR_EFF	2021-06-14	<2
T22_ANNUAL_RUNS	SVWTP_TWR_EFF	2021-06-15	<2
TS_RUNS	SVWTP_TWR_EFF	2021-07-21	3.72
TS_RUNS	SVWTP_TWR_EFF	2021-07-26	4.35
TS_RUNS	SVWTP_TWR_EFF	2021-08-02	4.58
TS_RUNS	SVWTP_TWR_EFF	2021-08-09	3.5
TS_RUNS	SVWTP_TWR_EFF	2021-08-16	3.66
TS_RUNS	SVWTP_TWR_EFF	2021-08-23	3.39
TS_RUNS	SVWTP_TWR_EFF	2021-08-30	<2
TS_RUNS	SVWTP_TWR_EFF	2021-09-06	<2
TS_RUNS	SVWTP_TWR_EFF	2021-09-13	<2
TS_RUNS	SVWTP_TWR_EFF	2021-09-20	<2
TS_RUNS	SVWTP_TWR_EFF	2021-10-20	<2
TS_RUNS	SVWTP_TWR_EFF	2021-10-25	<2
TS_RUNS	SVWTP_TWR_EFF	2021-12-28	2.06
UCMR4_SPECIAL	SVWTP_TWR_EFF	2018-02-14	2.3
UCMR4_SPECIAL	SVWTP_TWR_EFF	2018-04-23	4.5
UCMR4_SPECIAL	SVWTP_TWR_EFF	2018-09-21	1.3
UCMR4_SPECIAL	SVWTP_TWR_EFF	2018-10-22	1.9
TS_RUNS	HTWTP_EFF_POST	2016-01-04	<2
TS_RUNS	HTWTP_EFF_POST	2016-01-11	<2
TS_RUNS	HTWTP_EFF_POST	2016-01-19	<2
TS_RUNS	HTWTP_EFF_POST	2016-01-25	<2
TS_RUNS	HTWTP_EFF_POST	2016-02-01	<2
TS_RUNS	HTWTP_EFF_POST	2016-02-08	<2
TS_RUNS	HTWTP_EFF_POST	2016-02-16	<2
TS_RUNS	HTWTP_EFF_POST	2016-02-22	<2
TS_RUNS	HTWTP_EFF_POST	2016-02-29	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	HTWTP_EFF_POST	2016-03-21	<2
TS_RUNS	HTWTP_EFF_POST	2016-03-28	<2
TS_RUNS	HTWTP_EFF_POST	2016-04-04	<2
TS_RUNS	HTWTP_EFF_POST	2016-04-11	<2
TS_RUNS	HTWTP_EFF_POST	2016-04-18	<2
TS_RUNS	HTWTP_EFF_POST	2016-04-25	<2
TS_RUNS	HTWTP_EFF_POST	2016-05-02	<2
TS_RUNS	HTWTP_EFF_POST	2016-06-06	<2
TS_RUNS	HTWTP_EFF_POST	2016-06-20	<2
TS_RUNS	HTWTP_EFF_POST	2016-06-27	<2
TS_RUNS	HTWTP_EFF_POST	2016-07-05	<2
TS_RUNS	HTWTP_EFF_POST	2016-07-11	<2
TS_RUNS	HTWTP_EFF_POST	2016-07-18	<2
TS_RUNS	HTWTP_EFF_POST	2016-07-25	<2
TS_RUNS	HTWTP_EFF_POST	2016-08-01	<2
TS_RUNS	HTWTP_EFF_POST	2016-08-08	<2
TS_RUNS	HTWTP_EFF_POST	2016-08-15	<2
TS_RUNS	HTWTP_EFF_POST	2016-08-22	<2
TS_RUNS	HTWTP_EFF_POST	2016-08-29	<2
TS_RUNS	HTWTP_EFF_POST	2016-09-06	<2
TS_RUNS	HTWTP_EFF_POST	2016-09-12	<2
TS_RUNS	HTWTP_EFF_POST	2016-09-19	<2
TS_RUNS	HTWTP_EFF_POST	2016-09-26	<2
TS_RUNS	HTWTP_EFF_POST	2016-10-03	<2
TS_RUNS	HTWTP_EFF_POST	2016-10-11	<2
TS_RUNS	HTWTP_EFF_POST	2016-10-17	<2
TS_RUNS	HTWTP_EFF_POST	2016-10-24	<2
TS_RUNS	HTWTP_EFF_POST	2016-10-31	<2
TS_RUNS	HTWTP_EFF_POST	2016-11-07	<2
TS_RUNS	HTWTP_EFF_POST	2016-11-14	<2
TS_RUNS	HTWTP_EFF_POST	2016-11-21	<2
TS_RUNS	HTWTP_EFF_POST	2016-12-12	<2
TS_RUNS	HTWTP_EFF_POST	2016-12-19	<2
TS_RUNS	HTWTP_EFF_POST	2016-12-26	11.2
TS_RUNS	HTWTP_EFF_POST	2017-01-02	<2
TS_RUNS	HTWTP_EFF_POST	2017-01-09	9.43
TS_RUNS	HTWTP_EFF_POST	2017-01-16	4.8
TS_RUNS	HTWTP_EFF_POST	2017-01-23	5.05
TS_RUNS	HTWTP_EFF_POST	2017-01-30	3.62
TS_RUNS	HTWTP_EFF_POST	2017-02-06	2.39

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	HTWTP_EFF_POST	2017-02-13	2.33
TS_RUNS	HTWTP_EFF_POST	2017-02-20	2.07
TS_RUNS	HTWTP_EFF_POST	2017-02-27	<2
TS_RUNS	HTWTP_EFF_POST	2017-03-06	<2
TS_RUNS	HTWTP_EFF_POST	2017-03-13	2.31
TS_RUNS	HTWTP_EFF_POST	2017-03-20	<2
TS_RUNS	HTWTP_EFF_POST	2017-04-10	<2
TS_RUNS	HTWTP_EFF_POST	2017-04-17	3.64
TS_RUNS	HTWTP_EFF_POST	2017-04-24	<2
TS_RUNS	HTWTP_EFF_POST	2017-05-01	2.56
TS_RUNS	HTWTP_EFF_POST	2017-05-08	<2
TS_RUNS	HTWTP_EFF_POST	2017-05-15	<2
TS_RUNS	HTWTP_EFF_POST	2017-05-22	<2
TS_RUNS	HTWTP_EFF_POST	2017-05-29	<2
TS_RUNS	HTWTP_EFF_POST	2017-06-05	<2
TS_RUNS	HTWTP_EFF_POST	2017-06-12	<2
TS_RUNS	HTWTP_EFF_POST	2017-06-19	<2
TS_RUNS	HTWTP_EFF_POST	2017-06-26	<2
TS_RUNS	HTWTP_EFF_POST	2017-07-03	<2
TS_RUNS	HTWTP_EFF_POST	2017-07-10	<2
TS_RUNS	HTWTP_EFF_POST	2017-07-17	<2
TS_RUNS	HTWTP_EFF_POST	2017-07-24	<2
TS_RUNS	HTWTP_EFF_POST	2017-07-31	<2
TS_RUNS	HTWTP_EFF_POST	2017-08-07	<2
TS_RUNS	HTWTP_EFF_POST	2017-08-14	2.24
TS_RUNS	HTWTP_EFF_POST	2017-08-21	<2
TS_RUNS	HTWTP_EFF_POST	2017-08-28	<2
TS_RUNS	HTWTP_EFF_POST	2017-09-04	2.88
TS_RUNS	HTWTP_EFF_POST	2017-09-25	<2
TS_RUNS	HTWTP_EFF_POST	2017-10-02	<2
TS_RUNS	HTWTP_EFF_POST	2017-10-09	<2
TS_RUNS	HTWTP_EFF_POST	2017-10-16	<2
TS_RUNS	HTWTP_EFF_POST	2017-10-23	<2
TS_RUNS	HTWTP_EFF_POST	2017-10-30	5.83
TS_RUNS	HTWTP_EFF_POST	2017-11-06	2.5
TS_RUNS	HTWTP_EFF_POST	2017-11-13	2.18
TS_RUNS	HTWTP_EFF_POST	2017-11-20	<2
TS_RUNS	HTWTP_EFF_POST	2017-11-27	<2
TS_RUNS	HTWTP_EFF_POST	2017-12-04	<2
TS_RUNS	HTWTP_EFF_POST	2017-12-11	4.08

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	HTWTP_EFF_POST	2017-12-18	2.17
TS_RUNS	HTWTP_EFF_POST	2017-12-25	<2
TS_RUNS	HTWTP_EFF_POST	2018-01-01	<2
TS_RUNS	HTWTP_EFF_POST	2018-01-08	2.07
TS_RUNS	HTWTP_EFF_POST	2018-01-15	<2
TS_RUNS	HTWTP_EFF_POST	2018-01-22	2.27
TS_RUNS	HTWTP_EFF_POST	2018-01-29	<2
TS_RUNS	HTWTP_EFF_POST	2018-02-26	<2
TS_RUNS	HTWTP_EFF_POST	2018-03-05	<2
TS_RUNS	HTWTP_EFF_POST	2018-03-12	3.84
TS_RUNS	HTWTP_EFF_POST	2018-03-19	<2
TS_RUNS	HTWTP_EFF_POST	2018-03-26	<2
TS_RUNS	HTWTP_EFF_POST	2018-04-02	<2
TS_RUNS	HTWTP_EFF_POST	2018-04-09	<2
TS_RUNS	HTWTP_EFF_POST	2018-04-16	<2
TS_RUNS	HTWTP_EFF_POST	2018-04-23	<2
TS_RUNS	HTWTP_EFF_POST	2018-04-30	<2
TS_RUNS	HTWTP_EFF_POST	2018-05-07	<2
TS_RUNS	HTWTP_EFF_POST	2018-05-14	<2
TS_RUNS	HTWTP_EFF_POST	2018-05-21	<2
TS_RUNS	HTWTP_EFF_POST	2018-05-28	<2
TS_RUNS	HTWTP_EFF_POST	2018-06-04	<2
TS_RUNS	HTWTP_EFF_POST	2018-06-11	<2
TS_RUNS	HTWTP_EFF_POST	2018-06-18	<2
TS_RUNS	HTWTP_EFF_POST	2018-06-25	<2
TS_RUNS	HTWTP_EFF_POST	2018-07-02	<2
TS_RUNS	HTWTP_EFF_POST	2018-07-09	<2
TS_RUNS	HTWTP_EFF_POST	2018-07-16	<2
TS_RUNS	HTWTP_EFF_POST	2018-07-23	<2
TS_RUNS	HTWTP_EFF_POST	2018-07-30	<2
TS_RUNS	HTWTP_EFF_POST	2018-08-06	<2
TS_RUNS	HTWTP_EFF_POST	2018-08-13	<2
TS_RUNS	HTWTP_EFF_POST	2018-08-20	<2
TS_RUNS	HTWTP_EFF_POST	2018-08-27	<2
TS_RUNS	HTWTP_EFF_POST	2018-09-03	<2
TS_RUNS	HTWTP_EFF_POST	2018-09-10	<2
TS_RUNS	HTWTP_EFF_POST	2018-09-17	<2
TS_RUNS	HTWTP_EFF_POST	2018-09-24	<2
TS_RUNS	HTWTP_EFF_POST	2018-10-22	<2
TS_RUNS	HTWTP_EFF_POST	2018-10-29	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	HTWTP_EFF_POST	2018-11-05	<2
TS_RUNS	HTWTP_EFF_POST	2018-11-12	<2
TS_RUNS	HTWTP_EFF_POST	2018-11-19	<2
TS_RUNS	HTWTP_EFF_POST	2018-11-26	<2
TS_RUNS	HTWTP_EFF_POST	2018-12-03	<2
TS_RUNS	HTWTP_EFF_POST	2018-12-10	<2
TS_RUNS	HTWTP_EFF_POST	2018-12-17	<2
TS_RUNS	HTWTP_EFF_POST	2018-12-24	<2
TS_RUNS	HTWTP_EFF_POST	2018-12-31	<2
TS_RUNS	HTWTP_EFF_POST	2019-01-07	<2
TS_RUNS	HTWTP_EFF_POST	2019-01-14	<2
TS_RUNS	HTWTP_EFF_POST	2019-01-21	<2
TS_RUNS	HTWTP_EFF_POST	2019-01-28	<2
TS_RUNS	HTWTP_EFF_POST	2019-02-04	<2
TS_RUNS	HTWTP_EFF_POST	2019-02-11	<2
TS_RUNS	HTWTP_EFF_POST	2019-02-18	<2
TS_RUNS	HTWTP_EFF_POST	2019-02-25	<2
TS_RUNS	HTWTP_EFF_POST	2019-03-04	<2
TS_RUNS	HTWTP_EFF_POST	2019-03-11	<2
TS_RUNS	HTWTP_EFF_POST	2019-03-18	<2
TS_RUNS	HTWTP_EFF_POST	2019-03-25	<2
TS_RUNS	HTWTP_EFF_POST	2019-04-01	<2
TS_RUNS	HTWTP_EFF_POST	2019-04-08	<2
TS_RUNS	HTWTP_EFF_POST	2019-04-15	<2
TS_RUNS	HTWTP_EFF_POST	2019-04-22	<2
TS_RUNS	HTWTP_EFF_POST	2019-04-29	<2
TS_RUNS	HTWTP_EFF_POST	2019-05-06	<2
TS_RUNS	HTWTP_EFF_POST	2019-05-13	<2
TS_RUNS	HTWTP_EFF_POST	2019-05-20	<2
TS_RUNS	HTWTP_EFF_POST	2019-05-27	<2
TS_RUNS	HTWTP_EFF_POST	2019-07-08	<2
TS_RUNS	HTWTP_EFF_POST	2019-07-15	<2
TS_RUNS	HTWTP_EFF_POST	2019-07-22	<2
TS_RUNS	HTWTP_EFF_POST	2019-07-29	<2
TS_RUNS	HTWTP_EFF_POST	2019-08-05	<2
TS_RUNS	HTWTP_EFF_POST	2019-08-12	<2
TS_RUNS	HTWTP_EFF_POST	2019-08-19	<2
TS_RUNS	HTWTP_EFF_POST	2019-08-26	<2
TS_RUNS	HTWTP_EFF_POST	2019-09-02	<2
TS_RUNS	HTWTP_EFF_POST	2019-09-09	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	HTWTP_EFF_POST	2019-09-16	<2
TS_RUNS	HTWTP_EFF_POST	2019-09-30	<2
TS_RUNS	HTWTP_EFF_POST	2019-10-07	<2
TS_RUNS	HTWTP_EFF_POST	2019-10-14	<2
TS_RUNS	HTWTP_EFF_POST	2019-10-21	<2
TS_RUNS	HTWTP_EFF_POST	2019-10-28	<2
TS_RUNS	HTWTP_EFF_POST	2019-11-04	<2
TS_RUNS	HTWTP_EFF_POST	2019-11-11	<2
TS_RUNS	HTWTP_EFF_POST	2019-11-18	<2
TS_RUNS	HTWTP_EFF_POST	2019-11-25	<2
TS_RUNS	HTWTP_EFF_POST	2019-12-02	<2
TS_RUNS	HTWTP_EFF_POST	2019-12-09	<2
TS_RUNS	HTWTP_EFF_POST	2019-12-16	<2
TS_RUNS	HTWTP_EFF_POST	2019-12-23	<2
TS_RUNS	HTWTP_EFF_POST	2019-12-30	<2
TS_RUNS	HTWTP_EFF_POST	2020-01-06	<2
TS_RUNS	HTWTP_EFF_POST	2020-01-13	<2
TS_RUNS	HTWTP_EFF_POST	2020-01-20	<2
TS_RUNS	HTWTP_EFF_POST	2020-01-27	<2
TS_RUNS	HTWTP_EFF_POST	2020-02-03	<2
TS_RUNS	HTWTP_EFF_POST	2020-02-10	<2
TS_RUNS	HTWTP_EFF_POST	2020-02-17	<2
TS_RUNS	HTWTP_EFF_POST	2020-02-24	<2
TS_RUNS	HTWTP_EFF_POST	2020-03-02	<2
TS_RUNS	HTWTP_EFF_POST	2020-03-09	<2
TS_RUNS	HTWTP_EFF_POST	2020-03-16	<2
TS_RUNS	HTWTP_EFF_POST	2020-03-23	<2
TS_RUNS	HTWTP_EFF_POST	2020-03-30	<2
TS_RUNS	HTWTP_EFF_POST	2020-04-06	<2
TS_RUNS	HTWTP_EFF_POST	2020-05-04	<2
TS_RUNS	HTWTP_EFF_POST	2020-05-11	<2
TS_RUNS	HTWTP_EFF_POST	2020-05-18	<2
TS_RUNS	HTWTP_EFF_POST	2020-05-25	<2
TS_RUNS	HTWTP_EFF_POST	2020-06-01	<2
TS_RUNS	HTWTP_EFF_POST	2020-06-08	<2
TS_RUNS	HTWTP_EFF_POST	2020-06-15	<2
TS_RUNS	HTWTP_EFF_POST	2020-06-22	<2
TS_RUNS	HTWTP_EFF_POST	2020-06-29	<2
TS_RUNS	HTWTP_EFF_POST	2020-07-06	<2
TS_RUNS	HTWTP_EFF_POST	2020-07-13	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	HTWTP_EFF_POST	2020-07-20	<2
TS_RUNS	HTWTP_EFF_POST	2020-07-27	<2
TS_RUNS	HTWTP_EFF_POST	2020-08-03	<2
TS_RUNS	HTWTP_EFF_POST	2020-08-10	<2
TS_RUNS	HTWTP_EFF_POST	2020-08-17	<2
TS_RUNS	HTWTP_EFF_POST	2020-08-24	<2
TS_RUNS	HTWTP_EFF_POST	2020-08-24	<2
TS_RUNS	HTWTP_EFF_POST	2020-08-31	<2
TS_RUNS	HTWTP_EFF_POST	2020-09-07	<2
TS_RUNS	HTWTP_EFF_POST	2020-09-14	<2
TS_RUNS	HTWTP_EFF_POST	2020-09-21	<2
TS_RUNS	HTWTP_EFF_POST	2020-09-28	<2
TS_RUNS	HTWTP_EFF_POST	2020-10-05	<2
TS_RUNS	HTWTP_EFF_POST	2020-10-12	<2
TS_RUNS	HTWTP_EFF_POST	2020-11-24	5.61
TS_RUNS	HTWTP_EFF_POST	2020-11-30	<2
TS_RUNS	HTWTP_EFF_POST	2020-12-07	<2
TS_RUNS	HTWTP_EFF_POST	2020-12-14	<2
TS_RUNS	HTWTP_EFF_POST	2020-12-21	<2
TS_RUNS	HTWTP_EFF_POST	2020-12-28	<2
TS_RUNS	HTWTP_EFF_POST	2021-01-04	<2
TS_RUNS	HTWTP_EFF_POST	2021-01-11	<2
TS_RUNS	HTWTP_EFF_POST	2021-01-18	<2
TS_RUNS	HTWTP_EFF_POST	2021-01-25	<2
TS_RUNS	HTWTP_EFF_POST	2021-02-01	<2
TS_RUNS	HTWTP_EFF_POST	2021-02-08	<2
TS_RUNS	HTWTP_EFF_POST	2021-02-15	<2
TS_RUNS	HTWTP_EFF_POST	2021-02-22	<2
TS_RUNS	HTWTP_EFF_POST	2021-03-01	<2
TS_RUNS	HTWTP_EFF_POST	2021-03-08	<2
TS_RUNS	HTWTP_EFF_POST	2021-03-15	<2
TS_RUNS	HTWTP_EFF_POST	2021-03-22	<2
TS_RUNS	HTWTP_EFF_POST	2021-03-29	<2
TS_RUNS	HTWTP_EFF_POST	2021-04-05	<2
TS_RUNS	HTWTP_EFF_POST	2021-04-12	<2
TS_RUNS	HTWTP_EFF_POST	2021-04-19	<2
TS_RUNS	HTWTP_EFF_POST	2021-04-26	<2
TS_RUNS	HTWTP_EFF_POST	2021-05-03	<2
TS_RUNS	HTWTP_EFF_POST	2021-05-10	<2
TS_RUNS	HTWTP_EFF_POST	2021-05-17	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
TS_RUNS	HTWTP_EFF_POST	2021-05-24	<2
TS_RUNS	HTWTP_EFF_POST	2021-05-31	<2
TS_RUNS	HTWTP_EFF_POST	2021-06-07	<2
TS_RUNS	HTWTP_EFF_POST	2021-06-14	<2
TS_RUNS	HTWTP_EFF_POST	2021-06-21	<2
TS_RUNS	HTWTP_EFF_POST	2021-06-28	<2
TS_RUNS	HTWTP_EFF_POST	2021-07-05	6.47
TS_RUNS	HTWTP_EFF_POST	2021-07-12	<2
TS_RUNS	HTWTP_EFF_POST	2021-07-19	<2
TS_RUNS	HTWTP_EFF_POST	2021-09-21	33.3
TS_RUNS	HTWTP_EFF_POST	2021-09-27	2.22
TS_RUNS	HTWTP_EFF_POST	2021-10-04	<2
TS_RUNS	HTWTP_EFF_POST	2021-10-11	<2
TS_RUNS	HTWTP_EFF_POST	2021-11-01	<2
TS_RUNS	HTWTP_EFF_POST	2021-11-08	<2
TS_RUNS	HTWTP_EFF_POST	2021-11-15	<2
TS_RUNS	HTWTP_EFF_POST	2021-11-22	<2
TS_RUNS	HTWTP_EFF_POST	2021-11-29	<2
TS_RUNS	HTWTP_EFF_POST	2021-12-06	<2
TS_RUNS	HTWTP_EFF_POST	2021-12-13	<2
TS_RUNS	HTWTP_EFF_POST	2021-12-20	<2
TS_RUNS	HTWTP_EFF_POST	2021-12-27	<2
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2018-06-18	<2
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2019-07-02	2.1
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2020-06-15	<2
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2021-06-16	<2
UCMR4_SPECIAL	HTWTP_EFF_POST	2018-01-22	2.2
UCMR4_SPECIAL	HTWTP_EFF_POST	2018-04-23	1.1
UCMR4_SPECIAL	HTWTP_EFF_POST	2018-07-23	2.9
UCMR4_SPECIAL	HTWTP_EFF_POST	2018-10-22	0.75
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	2016-06-14	2.89
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	2017-06-19	2.71
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	2021-06-22	2.51
T22_ANNUAL_RUNS	CS#2_BADEN	2016-06-14	4.81
T22_ANNUAL_RUNS	CS#2_BADEN	2017-07-19	3.76
T22_ANNUAL_RUNS	CS#2_BADEN	2018-06-18	2.52
T22_ANNUAL_RUNS	CS#2_BADEN	2019-06-17	3.04
T22_ANNUAL_RUNS	CS#2_BADEN	2020-06-16	3.56
T22_ANNUAL_RUNS	CS#2_BADEN	2021-06-16	3.37
UCMR4	LMPS_SUNSET_DISCH	2018-01-22	4.3

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
UCMR4	LMPS_SUNSET_DISCH	2018-04-23	3.5
UCMR4	LMPS_SUNSET_DISCH	2018-09-19	6.6
UCMR4	LMPS_SUNSET_DISCH	2018-12-11	5.9
UCMR4	LMPS_SUTRO_DISCH	2018-01-22	4.2
UCMR4	LMPS_SUTRO_DISCH	2018-04-23	2.9
UCMR4	LMPS_SUTRO_DISCH	2018-09-19	1.3
UCMR4	LMPS_SUTRO_DISCH	2018-12-11	3.5
UCMR4	SA#2_BADEN	2018-01-22	2
UCMR4	SA#2_BADEN	2018-04-23	1.2
UCMR4	SA#2_BADEN	2018-07-23	0.62
UCMR4	SA#2_BADEN	2018-10-22	1
UCMR4	SSL_BADEN	2018-01-22	4.7
UCMR4	SSL_BADEN	2018-04-23	4.6
UCMR4	SSL_BADEN	2018-07-23	3.1
UCMR4	SSL_BADEN	2018-10-22	5.1
UCMR4	SSO#1_N	2018-01-22	3.8
UCMR4	SSO#1_N	2018-04-23	3.2
UCMR4	SSO#1_N	2018-08-30	3
UCMR4	SSO#1_N	2018-12-11	2.7
UCMR4	SSO#2_S	2018-01-22	4.1
UCMR4	SSO#2_S	2018-04-23	2.4
UCMR4	SSO#2_S	2018-08-30	2.8
CRP	SSO#2_S	2020-02-23	<2
DS_GW_CCM	HPS	2016-08-22	2.26
DS_GW_CCM	HPS	2016-09-19	6.65
DS_GW_CCM	HPS	2016-10-17	2.85
DS_GW_CCM	HPS	2017-02-27	2.86
DS_GW_CCM	CHS#03	2016-08-22	<2
DS_GW_CCM	CHS#03	2016-09-19	<2
DS_GW_CCM	CHS#03	2016-10-17	<2
DS_GW_CCM	CHS#03	2017-02-27	<2
DS_GW_CCM	CS#2_BADEN	2016-08-22	4.56
DS_GW_CCM	SA#2_BADEN	2016-08-22	<2
DS_GW_CCM	SA#3_BADEN	2016-08-22	<2
DS_GW_CCM	CS#2_BADEN	2016-09-19	5.02
DS_GW_CCM	SA#2_BADEN	2016-09-19	<2
DS_GW_CCM	SA#3_BADEN	2016-09-19	<2
DS_GW_CCM	CS#2_BADEN	2016-10-17	4.12
DS_GW_CCM	SA#2_BADEN	2016-10-17	<2
DS_GW_CCM	SA#3_BADEN	2016-10-17	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
DS_GW_CCM	CS#2_BADEN	2017-02-27	<2
DS_GW_CCM	SA#2_BADEN	2017-02-27	<2
DS_GW_CCM	SA#3_BADEN	2017-02-27	<2
DS_GW_CCM	SHS#01	2016-08-22	2.82
DS_GW_CCM	SHS#01	2016-09-19	3.32
DS_GW_CCM	SHS#01	2016-10-17	2.69
DS_GW_CCM	SHS#01	2017-02-27	2.37
DS_GW_CCM	LS	2016-08-22	2
DS_GW_CCM	LS	2016-09-19	3.28
DS_GW_CCM	LS	2016-10-17	2.04
DS_GW_CCM	LS	2017-02-27	2.06
DS_GW_CCM	MCS#02	2016-08-22	<2
DS_GW_CCM	MMS#02	2016-08-22	2.08
DS_GW_CCM	MCS#02	2016-09-19	2.33
DS_GW_CCM	MMS#02	2016-09-19	3.01
DS_GW_CCM	MCS#02	2016-10-17	2
DS_GW_CCM	MMS#02	2016-10-17	2.71
DS_GW_CCM	MCS#02	2017-02-27	<2
DS_GW_CCM	MMS#02	2017-02-27	2.47
DS_GW_CCM	PHS	2016-08-22	3.07
DS_GW_CCM	SS#05	2016-08-22	4.39
DS_GW_CCM	PHS	2016-09-19	3.2
DS_GW_CCM	SS#05	2016-09-19	2.58
DS_GW_CCM	PHS	2016-10-17	3.31
DS_GW_CCM	SS#05	2016-10-17	3.17
DS_GW_CCM	PHS	2017-02-27	<2
DS_GW_CCM	SS#05	2017-02-27	<2
DS_GW_CCM	SSL_BADEN	2016-08-22	3.58
DS_GW_CCM	SSL_BADEN	2016-09-19	4.88
DS_GW_CCM	SSL_BADEN	2016-10-17	4.22
DS_GW_CCM	SSL_BADEN	2017-02-27	<2
DS_GW_CCM	SSO#1_N	2016-08-22	2.25
DS_GW_CCM	SSO#2_S	2016-08-22	2.08
DS_GW_CCM	SSO#1_N	2016-09-19	2.82
DS_GW_CCM	SSO#2_S	2016-09-19	2.59
DS_GW_CCM	SSO#1_N	2016-10-17	<2
DS_GW_CCM	SSO#2_S	2016-10-17	2.1
DS_GW_CCM	SSO#1_N	2017-02-27	2.09
DS_GW_CCM	SSO#2_S	2017-02-27	2.12
DS_GW_CCM	SUMS	2016-08-22	2.28

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
DS_GW_CCM	SUMS	2016-09-19	2.97
DS_GW_CCM	SUMS	2016-10-17	<2
DS_GW_CCM	SUMS	2017-02-27	<2
DS_GW_CCM	SUTS#06	2016-08-22	2.96
DS_GW_CCM	SUTS#06	2016-09-19	3.77
DS_GW_CCM	SUTS#06	2016-10-17	2.1
DS_GW_CCM	SUTS#06	2017-02-27	2.1
DS_GW_CCM	UMS#04	2016-08-22	4.82
DS_GW_CCM	UMS#04	2016-09-19	5.9
DS_GW_CCM	UMS#04	2016-10-17	2.24
DS_GW_CCM	UMS#04	2017-02-27	<2
SFGW_7DAY	SSO#1_N	2017-10-23	4.44
SFGW_7DAY	SSO#2_S	2017-10-23	2.14
SFGW_7DAY	SSO#1_N	2017-10-24	2.95
SFGW_7DAY	SSO#2_S	2017-10-24	<2
SFGW_7DAY	SSO#1_N	2017-10-26	2.35
SFGW_7DAY	SSO#2_S	2017-10-26	<2
SFGW_7DAY	SSO#1_N	2017-10-30	3.22
SFGW_7DAY	SSO#2_S	2017-10-30	2.55
SFGW_7DAY	SSO#1_N	2017-11-16	2.67
SFGW_7DAY	SSO#2_S	2017-11-16	2.24
SFGW_7DAY	SSO#1_N	2017-12-18	3.26
SFGW_7DAY	SSO#2_S	2017-12-18	2.79
SFGW_7DAY	SSO#1_N	2017-12-20	3.98
SFGW_7DAY	SSO#2_S	2017-12-20	3.89
SFGW_7DAY	SSO#1_N	2018-01-24	3.18
SFGW_7DAY	SSO#2_S	2018-01-24	3.33
SFGW_7DAY	SSO#1_N	2018-01-25	4.56
SFGW_7DAY	SSO#2_S	2018-01-25	4.13
SFGW_7DAY	SSO#1_N	2018-01-29	3.06
SFGW_7DAY	SSO#2_S	2018-01-29	3.35
SFGW_7DAY	SSO#1_N	2018-01-31	2.73
SFGW_7DAY	SSO#2_S	2018-01-31	3.93
SFGW_7DAY	SSO#1_N	2018-02-01	2.07
SFGW_7DAY	SSO#2_S	2018-02-01	2.01
SFGW_7DAY	SSO#1_N	2018-02-05	2.62
SFGW_7DAY	SSO#2_S	2018-02-05	2.89
SFGW_7DAY	SSO#1_N	2018-02-07	2.84
SFGW_7DAY	SSO#2_S	2018-02-07	3.13
SFGW_7DAY	SSO#1_N	2018-02-08	2.72

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFGW_7DAY	SSO#2_S	2018-02-08	3.35
SFGW_7DAY	SSO#1_N	2018-02-12	3.19
SFGW_7DAY	SSO#2_S	2018-02-12	3.09
SFGW_7DAY	SSO#1_N	2018-02-14	6.67
SFGW_7DAY	SSO#2_S	2018-02-14	10.2
SFGW_7DAY	SSO#1_N	2018-02-15	2.47
SFGW_7DAY	SSO#2_S	2018-02-15	2.83
SFGW_7DAY	SSO#1_N	2018-02-21	2.64
SFGW_7DAY	SSO#2_S	2018-02-21	2.86
SFGW_7DAY	SSO#1_N	2018-02-22	2.55
SFGW_7DAY	SSO#2_S	2018-02-22	2.67
SFGW_7DAY	SSO#1_N	2018-02-26	3
SFGW_7DAY	SSO#2_S	2018-02-26	2.68
SFGW_7DAY	SSO#1_N	2018-02-28	2.23
SFGW_7DAY	SSO#2_S	2018-02-28	2.34
SFGW_7DAY	SSO#1_N	2018-03-01	2.57
SFGW_7DAY	SSO#2_S	2018-03-01	2.54
SFGW_HISTORICAL	SSO#1_N	2017-06-28	2.04
SFGW_HISTORICAL	SSO#2_S	2017-06-28	<2
SFGW_HISTORICAL	SSO#1_N	2017-06-29	<2
SFGW_HISTORICAL	SSO#2_S	2017-06-29	<2
SFGW_HISTORICAL	SSO#1_N	2017-07-05	<2
SFGW_HISTORICAL	SSO#2_S	2017-07-05	<2
SFGW_HISTORICAL	SSO#1_N	2017-07-06	<2
SFGW_HISTORICAL	SSO#2_S	2017-07-06	<2
SFGW_HISTORICAL	SSO#1_N	2017-07-12	<2
SFGW_HISTORICAL	SSO#2_S	2017-07-12	<2
SFGW_HISTORICAL	SSO#1_N	2017-07-13	<2
SFGW_HISTORICAL	SSO#2_S	2017-07-13	<2
SFGW_OPS	SSO#1_N	2018-07-24	<2
SFGW_OPS	SSO#1_N	2018-07-31	2
SFGW_OPS	SSO#1_N	2018-08-08	2.14
SFGW_OPS	SSO#1_N	2018-08-14	2.27
SFGW_OPS	SSO#1_N	2018-08-21	2.54
SFGW_OPS	SSO#1_N	2018-08-28	2.71
SFGW_OPS	SSO#1_N	2018-09-04	2.36
SFGW_OPS	SSO#1_N	2018-09-11	2.54
SFGW_OPS	SSO#1_N	2018-09-18	2.34
SFGW_OPS	SSO#1_N	2018-09-25	2.43
SFGW_OPS	SSO#1_N	2018-10-02	2.97

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFGW_OPS	SSO#1_N	2018-10-09	3.39
SFGW_OPS	SSO#1_N	2018-10-16	4.32
SFGW_OPS	SSO#1_N	2018-10-23	3.12
SFGW_OPS	SSO#1_N	2018-10-30	4.03
SFGW_OPS	SSO#1_N	2018-11-06	<2
SFGW_OPS	SSO#1_N	2018-11-13	2.45
SFGW_OPS	SSO#1_N	2018-11-20	3.89
SFGW_OPS	SSO#1_N	2018-11-27	4.22
SFGW_OPS	SSO#1_N	2018-12-04	3.4
SFGW_OPS	SSO#1_N	2018-12-11	3.07
SFGW_OPS	SSO#1_N	2018-12-18	2.76
SFGW_OPS	SSO#1_N	2018-12-26	3.62
SFGW_OPS	SSO#1_N	2019-01-02	2.88
SFGW_OPS	SSO#1_N	2019-01-08	2.72
SFGW_OPS	SSO#1_N	2019-01-15	<2
SFGW_OPS	SSO#1_N	2019-01-22	<2
SFGW_OPS	SSO#1_N	2019-01-29	<2
SFGW_OPS	SSO#1_N	2019-02-05	<2
SFGW_OPS	SSO#1_N	2019-02-12	<2
SFGW_OPS	SSO#1_N	2019-02-19	<2
SFGW_OPS	SSO#1_N	2019-03-01	<2
SFGW_OPS	SSO#1_N	2019-03-05	<2
SFGW_OPS	SSO#1_N	2019-03-12	<2
SFGW_OPS	SSO#1_N	2019-03-19	<2
SFGW_OPS	SSO#1_N	2019-03-26	<2
SFGW_OPS	SSO#1_N	2019-04-02	<2
SFGW_OPS	SSO#1_N	2019-04-09	<2
SFGW_OPS	SSO#1_N	2019-04-16	<2
SFGW_OPS	SSO#1_N	2019-04-23	2.2
SFGW_OPS	SSO#1_N	2019-04-30	<2
SFGW_OPS	SSO#1_N	2019-05-07	2.55
SFGW_OPS	SSO#1_N	2019-05-14	<2
SFGW_OPS	SSO#1_N	2019-05-21	<2
SFGW_OPS	SSO#1_N	2019-05-28	<2
SFGW_OPS	SSO#1_N	2019-06-04	<2
SFGW_OPS	SSO#1_N	2019-06-11	2.01
SFGW_OPS	SSO#1_N	2019-06-18	2.22
SFGW_OPS	SSO#1_N	2019-06-25	2.52
SFGW_OPS	SSO#1_N	2019-07-02	2.73
SFGW_OPS	SSO#1_N	2019-07-09	2.51

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFGW_OPS	SSO#1_N	2019-07-16	2.34
SFGW_OPS	SSO#1_N	2019-07-23	2.26
SFGW_OPS	SSO#1_N	2019-07-30	2.1
SFGW_OPS	SSO#1_N	2019-08-06	2.13
SFGW_OPS	SSO#1_N	2019-08-13	2.08
SFGW_OPS	SSO#1_N	2019-08-20	2.06
SFGW_OPS	SSO#1_N	2019-08-27	<2
SFGW_OPS	SSO#1_N	2019-09-03	2.21
SFGW_OPS	SSO#1_N	2019-09-10	2.71
SFGW_OPS	SSO#1_N	2019-09-17	2.19
SFGW_OPS	SSO#1_N	2019-09-24	2.53
SFGW_OPS	SSO#1_N	2019-10-01	2.62
SFGW_OPS	SSO#1_N	2019-10-08	2.28
SFGW_OPS	SSO#1_N	2019-10-16	2.08
SFGW_OPS	SSO#1_N	2019-10-22	2.74
SFGW_OPS	SSO#1_N	2019-10-29	2.77
SFGW_OPS	SSO#1_N	2019-11-05	3.09
SFGW_OPS	SSO#1_N	2019-11-19	2.36
SFGW_OPS	SSO#1_N	2019-11-26	2.73
SFGW_OPS	SSO#1_N	2019-12-03	2.47
SFGW_OPS	SSO#1_N	2019-12-11	2.49
SFGW_OPS	SSO#1_N	2019-12-19	2.89
SFGW_OPS	SSO#1_N	2019-12-24	2.76
SFGW_OPS	SSO#1_N	2019-12-31	2.7
SFGW_OPS	SSO#1_N	2020-01-07	2.89
SFGW_OPS	SSO#1_N	2020-01-14	<2
SFGW_OPS	SSO#1_N	2020-01-21	<2
SFGW_OPS	SSO#1_N	2020-01-28	<2
SFGW_OPS	SSO#1_N	2020-02-04	<2
SFGW_OPS	SSO#1_N	2020-02-11	<2
SFGW_OPS	SSO#1_N	2020-02-18	2.24
SFGW_OPS	SSO#1_N	2020-02-25	<2
SFGW_OPS	SSO#1_N	2020-03-03	2.08
SFGW_OPS	SSO#1_N	2020-03-10	<2
SFGW_OPS	SSO#1_N	2020-03-17	2.32
SFGW_OPS	SSO#1_N	2020-03-24	2.13
SFGW_OPS	SSO#1_N	2020-03-31	<2
SFGW_OPS	SSO#1_N	2020-04-07	2.21
SFGW_OPS	SSO#1_N	2020-04-14	2.14
SFGW_OPS	SSO#1_N	2020-04-21	2.38

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFGW_OPS	SSO#1_N	2020-04-28	3.04
SFGW_OPS	SSO#1_N	2020-05-05	2.19
SFGW_OPS	SSO#1_N	2020-05-12	<2
SFGW_OPS	SSO#1_N	2020-05-19	<2
SFGW_OPS	SSO#1_N	2020-05-26	<2
SFGW_OPS	SSO#1_N	2020-06-02	<2
SFGW_OPS	SSO#1_N	2020-06-09	2.14
SFGW_OPS	SSO#1_N	2020-06-16	<2
SFGW_OPS	SSO#1_N	2020-06-23	2
SFGW_OPS	SSO#1_N	2020-06-30	2.1
SFGW_OPS	SSO#1_N	2020-07-07	2.21
SFGW_OPS	SSO#1_N	2020-07-14	<2
SFGW_OPS	SSO#1_N	2020-07-21	<2
SFGW_OPS	SSO#1_N	2020-07-28	2.75
SFGW_OPS	SSO#1_N	2020-08-04	2.09
SFGW_OPS	SSO#1_N	2020-08-11	2.24
SFGW_OPS	SSO#1_N	2020-08-18	2.21
SFGW_OPS	SSO#1_N	2020-08-25	2.57
SFGW_OPS	SSO#1_N	2020-09-01	2.32
SFGW_OPS	SSO#1_N	2020-09-08	2.16
SFGW_OPS	SSO#1_N	2020-09-15	<2
SFGW_OPS	SSO#1_N	2020-09-22	<2
SFGW_OPS	SSO#1_N	2020-09-29	<2
SFGW_OPS	SSO#1_N	2020-10-06	<2
SFGW_OPS	SSO#1_N	2020-10-13	<2
SFGW_OPS	SSO#1_N	2020-10-20	2.31
SFGW_OPS	SSO#1_N	2020-10-29	3.11
SFGW_OPS	SSO#1_N	2020-11-03	3.25
SFGW_OPS	SSO#1_N	2020-11-10	3.18
SFGW_OPS	SSO#1_N	2020-11-17	3.71
SFGW_OPS	SSO#1_N	2020-11-24	3.71
SFGW_OPS	SSO#1_N	2020-12-01	3.17
SFGW_OPS	SSO#1_N	2020-12-08	3.17
SFGW_OPS	SSO#1_N	2020-12-17	3.92
SFGW_OPS	SSO#1_N	2020-12-22	4.44
SFGW_OPS	SSO#1_N	2020-12-29	4.32
SFGW_OPS	SSO#1_N	2021-01-05	3.08
SFGW_OPS	SSO#1_N	2021-01-12	4.46
SFGW_OPS	SSO#1_N	2021-01-19	3.67
SFGW_OPS	SSO#1_N	2021-01-26	3.6

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFGW_OPS	SSO#1_N	2021-02-02	7.48
SFGW_OPS	SSO#1_N	2021-02-09	4.33
SFGW_OPS	SSO#1_N	2021-02-16	<2
SFGW_OPS	SSO#1_N	2021-02-23	<2
SFGW_OPS	SSO#1_N	2021-03-02	<2
SFGW_OPS	SSO#1_N	2021-03-09	<2
SFGW_OPS	SSO#1_N	2021-03-16	3.69
SFGW_OPS	SSO#1_N	2021-03-23	3.77
SFGW_OPS	SSO#1_N	2021-03-30	3
SFGW_OPS	SSO#1_N	2021-04-06	2.26
SFGW_OPS	SSO#1_N	2021-04-13	2.94
SFGW_OPS	SSO#1_N	2021-04-20	3.01
SFGW_OPS	SSO#1_N	2021-04-27	<2
SFGW_OPS	SSO#1_N	2021-05-04	2.72
SFGW_OPS	SSO#1_N	2021-05-11	2.6
SFGW_OPS	SSO#1_N	2021-05-18	2.56
SFGW_OPS	SSO#1_N	2021-05-25	2.57
SFGW_OPS	SSO#1_N	2021-06-01	2.19
SFGW_OPS	SSO#1_N	2021-06-08	2.22
SFGW_OPS	SSO#1_N	2021-06-15	2.13
SFGW_OPS	SSO#1_N	2021-06-22	<2
SFGW_OPS	SSO#1_N	2021-06-29	<2
SFGW_OPS	SSO#1_N	2021-07-07	<2
SFGW_OPS	SSO#1_N	2021-07-13	<2
SFGW_OPS	SSO#1_N	2021-07-21	<2
SFGW_OPS	SSO#1_N	2021-07-27	2.03
SFGW_OPS	SSO#1_N	2021-08-03	2.44
SFGW_OPS	SSO#1_N	2021-08-10	2.76
SFGW_OPS	SSO#1_N	2021-08-17	2.47
SFGW_OPS	SSO#1_N	2021-08-24	3.36
SFGW_OPS	SSO#1_N	2021-08-31	2.14
SFGW_OPS	SSO#1_N	2021-09-07	2.91
SFGW_OPS	SSO#1_N	2021-09-14	2.34
SFGW_OPS	SSO#1_N	2021-09-21	2.52
SFGW_OPS	SSO#1_N	2021-09-28	4.15
SFGW_OPS	SSO#1_N	2021-10-05	2.94
SFGW_OPS	SSO#1_N	2021-10-12	3.28
SFGW_OPS	SSO#1_N	2021-10-19	2.84
SFGW_OPS	SSO#1_N	2021-10-26	3.87
SFGW_OPS	SSO#1_N	2021-11-02	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFGW_OPS	SSO#1_N	2021-11-09	<2
SFGW_OPS	SSO#1_N	2021-11-16	<2
SFGW_OPS	SSO#1_N	2021-11-23	<2
SFGW_OPS	SSO#1_N	2021-11-30	<2
SFGW_OPS	SSO#1_N	2021-12-07	<2
SFGW_OPS	SSO#1_N	2021-12-15	3.12
SFGW_OPS	SSO#1_N	2021-12-21	<2
SFGW_OPS	SSO#1_N	2021-12-28	<2
SFGW_OPS	SSO#2_S	2018-07-24	<2
SFGW_OPS	SSO#2_S	2018-07-31	<2
SFGW_OPS	SSO#2_S	2018-08-08	<2
SFGW_OPS	SSO#2_S	2018-08-14	2.17
SFGW_OPS	SSO#2_S	2018-08-21	2.34
SFGW_OPS	SSO#2_S	2018-08-28	2.24
SFGW_OPS	SSO#2_S	2018-09-04	2.09
SFGW_OPS	SSO#2_S	2018-09-11	2.22
SFGW_OPS	SSO#2_S	2018-09-18	<2
SFGW_OPS	SSO#2_S	2018-09-25	<2
SFGW_OPS	SSO#2_S	2018-10-02	3.14
SFGW_OPS	SSO#2_S	2018-10-09	3.21
SFGW_OPS	SSO#2_S	2018-10-16	3.67
SFGW_OPS	SSO#2_S	2018-10-23	3.23
SFGW_OPS	SSO#2_S	2019-08-20	<2
SFGW_OPS	SSO#2_S	2019-08-27	<2
SFGW_OPS	SSO#2_S	2019-09-03	2.23
SFGW_OPS	SSO#2_S	2019-09-10	2.45
SFGW_OPS	SSO#2_S	2019-09-17	2.07
SFGW_OPS	SSO#2_S	2019-09-24	2.48
SFGW_OPS	SSO#2_S	2019-10-01	<2
SFGW_OPS	SSO#2_S	2019-10-08	<2
SFGW_OPS	SSO#2_S	2019-10-16	<2
SFGW_OPS	SSO#2_S	2019-10-22	<2
SFGW_OPS	SSO#2_S	2019-10-29	2.02
SFGW_OPS	SSO#2_S	2019-11-05	2.12
SFGW_OPS	SSO#2_S	2019-11-19	2.08
SFGW_OPS	SSO#2_S	2019-11-26	2
SFGW_OPS	SSO#2_S	2019-12-03	<2
SFGW_OPS	SSO#2_S	2019-12-11	2.22
SFGW_OPS	SSO#2_S	2019-12-19	2.54
SFGW_OPS	SSO#2_S	2019-12-24	2.58

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFGW_OPS	SSO#2_S	2019-12-31	2.5
SFGW_OPS	SSO#2_S	2020-01-07	<2
SFGW_OPS	SSO#2_S	2020-01-14	<2
SFGW_OPS	SSO#2_S	2020-01-21	<2
SFGW_OPS	SSO#2_S	2020-01-28	<2
SFGW_OPS	SSO#2_S	2020-02-04	<2
SFGW_OPS	SSO#2_S	2020-02-11	<2
SFGW_OPS	SSO#2_S	2020-02-18	<2
SFGW_OPS	SSO#2_S	2020-02-25	<2
SFGW_OPS	SSO#2_S	2020-03-03	2
SFGW_OPS	SSO#2_S	2020-03-10	<2
SFGW_OPS	SSO#2_S	2020-03-17	<2
SFGW_OPS	SSO#2_S	2020-03-24	2.1
SFGW_OPS	SSO#2_S	2020-03-31	<2
SFGW_OPS	SSO#2_S	2020-04-07	<2
SFGW_OPS	SSO#2_S	2020-04-14	<2
SFGW_OPS	SSO#2_S	2020-04-21	2.17
SFGW_OPS	SSO#2_S	2020-04-28	2.74
SFGW_OPS	SSO#2_S	2020-05-05	2.15
SFGW_OPS	SSO#2_S	2020-05-12	<2
SFGW_OPS	SSO#2_S	2020-05-19	<2
SFGW_OPS	SSO#2_S	2020-05-26	<2
SFGW_OPS	SSO#2_S	2020-06-02	<2
SFGW_OPS	SSO#2_S	2020-06-09	<2
SFGW_OPS	SSO#2_S	2020-06-16	2.04
SFGW_OPS	SSO#2_S	2020-06-23	2.01
SFGW_OPS	SSO#2_S	2020-06-30	<2
SFGW_OPS	SSO#2_S	2020-07-07	<2
SFGW_OPS	SSO#2_S	2020-07-14	<2
SFGW_OPS	SSO#2_S	2020-07-21	<2
SFGW_OPS	SSO#2_S	2020-07-28	<2
SFGW_OPS	SSO#2_S	2020-08-04	<2
SFGW_OPS	SSO#2_S	2020-08-11	<2
SFGW_OPS	SSO#2_S	2020-08-18	2.05
SFGW_OPS	SSO#2_S	2020-08-25	2.02
SFGW_OPS	SSO#2_S	2020-09-01	<2
SFGW_OPS	SSO#2_S	2020-09-08	2.36
SFGW_OPS	SSO#2_S	2020-09-15	2.03
SFGW_OPS	SSO#2_S	2020-09-22	<2
SFGW_OPS	SSO#2_S	2020-09-29	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFGW_OPS	SSO#2_S	2020-10-06	<2
SFGW_OPS	SSO#2_S	2020-10-13	<2
SFGW_OPS	SUTO	2018-07-20	<2
SFGW_OPS	SUTO	2018-07-24	2.12
SFGW_OPS	SUTO	2018-07-31	<2
SFGW_OPS	SUTO	2018-08-08	2.43
SFGW_OPS	SUTO	2018-08-14	2.31
SFGW_OPS	SUTO	2018-08-21	2.45
SFGW_OPS	SUTO	2018-08-28	2.31
SFGW_OPS	SUTO	2018-09-04	2.19
SFGW_OPS	SUTO	2018-09-11	2.5
SFGW_OPS	SUTO	2018-09-18	<2
SFGW_OPS	SUTO	2018-09-25	2.27
SFGW_OPS	SUTO	2018-10-02	3.17
SFGW_OPS	SUTO	2018-10-09	3.16
SFGW_OPS	SUTO	2018-10-16	2.91
SFGW_OPS	SUTO	2018-10-23	2.8
SFGW_OPS	SUTO	2018-10-30	22.3
SFGW_OPS	SUTO	2018-11-06	<2
SFGW_OPS	SUTO	2018-11-13	2.07
SFGW_OPS	SUTO	2018-11-20	2.6
SFGW_OPS	SUTO	2018-11-27	35.3
SFGW_OPS	SUTO	2018-12-04	2.9
SFGW_OPS	SUTO	2018-12-11	3.65
SFGW_OPS	SUTO	2018-12-18	29.1
SFGW_OPS	SUTO	2018-12-26	2.11
SFGW_OPS	SUTO	2019-01-02	13.7
SFGW_OPS	SUTO	2019-01-08	2.11
SFGW_OPS	SUTO	2019-01-15	<2
SFGW_OPS	SUTO	2019-01-22	<2
SFGW_OPS	SUTO	2019-01-29	<2
SFGW_OPS	SUTO	2019-02-05	<2
SFGW_OPS	SUTO	2019-02-12	<2
SFGW_OPS	SUTO	2019-02-19	<2
SFGW_OPS	SUTO	2019-03-01	<2
SFGW_OPS	SUTO	2019-03-05	<2
SFGW_OPS	SUTO	2019-03-12	<2
SFGW_OPS	SUTO	2019-03-19	<2
SFGW_OPS	SUTO	2019-03-26	<2
SFGW_OPS	SUTO	2019-04-02	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFGW_OPS	SUTO	2019-04-09	<2
SFGW_OPS	SUTO	2019-04-16	<2
SFGW_OPS	SUTO	2019-04-23	2.86
SFGW_OPS	SUTO	2019-04-30	2.27
SFGW_OPS	SUTO	2019-05-07	2.69
SFGW_OPS	SUTO	2019-05-14	<2
SFGW_OPS	SUTO	2019-05-21	<2
SFGW_OPS	SUTO	2019-05-28	<2
SFGW_OPS	SUTO	2019-06-04	<2
SFGW_OPS	SUTO	2019-06-11	2.93
SFGW_OPS	SUTO	2019-06-18	2.14
SFGW_OPS	SUTO	2019-06-25	3.67
SFGW_OPS	SUTO	2019-07-02	2.53
SFGW_OPS	SUTO	2019-07-09	2.07
SFGW_OPS	SUTO	2019-07-16	2.1
SFGW_OPS	SUTO	2019-07-23	2.03
SFGW_OPS	SUTO	2019-07-30	<2
SFGW_OPS	SUTO	2019-08-06	<2
SFGW_OPS	SUTO	2019-08-13	<2
SFGW_OPS	SUTO	2019-08-20	<2
SFGW_OPS	SUTO	2019-08-27	<2
SFGW_OPS	SUTO	2019-09-03	<2
SFGW_OPS	SUTO	2019-09-10	2.59
SFGW_OPS	SUTO	2019-09-17	2.01
SFGW_OPS	SUTO	2019-09-24	2.39
SFGW_OPS	SUTO	2019-10-01	2.6
SFGW_OPS	SUTO	2019-10-10	2.18
SFGW_OPS	SUTO	2019-10-16	2.7
SFGW_OPS	SUTO	2019-10-22	<2
SFGW_OPS	SUTO	2019-10-29	<2
SFGW_OPS	SUTO	2019-11-05	<2
SFGW_OPS	SUTO	2019-11-19	<2
SFGW_OPS	SUTO	2019-11-26	<2
SFGW_OPS	SUTO	2019-12-03	<2
SFGW_OPS	SUTO	2019-12-11	<2
SFGW_OPS	SUTO	2019-12-19	2.36
SFGW_OPS	SUTO	2019-12-24	2.18
SFGW_OPS	SUTO	2019-12-31	<2
SFGW_OPS	SUTO	2020-01-07	<2
SFGW_OPS	SUTO	2020-01-14	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFGW_OPS	SUTO	2020-01-21	<2
SFGW_OPS	SUTO	2020-01-28	<2
SFGW_OPS	SUTO	2020-02-04	<2
SFGW_OPS	SUTO	2020-02-11	28.1
SFGW_OPS	SUTO	2020-02-18	<2
SFGW_OPS	SUTO	2020-02-25	<2
SFGW_OPS	SUTO	2020-03-03	2.48
SFGW_OPS	SUTO	2020-03-10	2.5
SFGW_OPS	SUTO	2020-03-17	<2
SFGW_OPS	SUTO	2020-03-24	<2
SFGW_OPS	SUTO	2020-03-31	<2
SFGW_OPS	SUTO	2020-04-07	<2
SFGW_OPS	SUTO	2020-04-14	2.06
SFGW_OPS	SUTO	2020-04-21	3.99
SFGW_OPS	SUTO	2020-04-28	2.31
SFGW_OPS	SUTO	2020-05-05	2.05
SFGW_OPS	SUTO	2020-05-12	2.03
SFGW_OPS	SUTO	2020-05-19	2.69
SFGW_OPS	SUTO	2020-05-26	14.4
SFGW_OPS	SUTO	2020-06-02	2.04
SFGW_OPS	SUTO	2020-06-09	2.31
SFGW_OPS	SUTO	2020-06-16	2.28
SFGW_OPS	SUTO	2020-06-23	2.21
SFGW_OPS	SUTO	2020-06-30	2.11
SFGW_OPS	SUTO	2020-07-07	2.06
SFGW_OPS	SUTO	2020-07-14	2.09
SFGW_OPS	SUTO	2020-07-21	2.51
SFGW_OPS	SUTO	2020-07-28	2.36
SFGW_OPS	SUTO	2020-08-04	2.6
SFGW_OPS	SUTO	2020-08-11	2.16
SFGW_OPS	SUTO	2020-08-18	2.31
SFGW_OPS	SUTO	2020-08-25	2.45
SFGW_OPS	SUTO	2020-09-01	2.7
SFGW_OPS	SUTO	2020-09-08	<2
SFGW_OPS	SUTO	2020-09-15	<2
SFGW_OPS	SUTO	2020-09-22	<2
SFGW_OPS	SUTO	2020-09-29	<2
SFGW_OPS	SUTO	2020-10-06	2.07
SFGW_OPS	SUTO	2020-10-13	2.21
SFGW_OPS	SUTO	2020-10-20	3.82

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFGW_OPS	SUTO	2020-10-29	3.37
SFGW_OPS	SUTO	2020-11-03	4.21
SFGW_OPS	SUTO	2020-11-10	3.55
SFGW_OPS	SUTO	2020-11-17	30.5
SFGW_OPS	SUTO	2020-11-24	3.44
SFGW_OPS	SUTO	2020-12-01	4.44
SFGW_OPS	SUTO	2020-12-08	3.64
SFGW_OPS	SUTO	2020-12-17	3
SFGW_OPS	SUTO	2020-12-22	3.49
SFGW_OPS	SUTO	2020-12-29	2.91
SFGW_OPS	SUTO	2021-01-05	3.23
SFGW_OPS	SUTO	2021-01-12	2.7
SFGW_OPS	SUTO	2021-01-19	2.03
SFGW_OPS	SUTO	2021-01-26	2.73
SFGW_OPS	SUTO	2021-02-02	2.82
SFGW_OPS	SUTO	2021-02-09	3.19
SFGW_OPS	SUTO	2021-02-16	<2
SFGW_OPS	SUTO	2021-02-23	<2
SFGW_OPS	SUTO	2021-03-02	<2
SFGW_OPS	SUTO	2021-03-09	<2
SFGW_OPS	SUTO	2021-03-16	3.1
SFGW_OPS	SUTO	2021-03-23	<2
SFGW_OPS	SUTO	2021-03-30	2.52
SFGW_OPS	SUTO	2021-04-06	<2
SFGW_OPS	SUTO	2021-04-13	<2
SFGW_OPS	SUTO	2021-04-20	3.29
SFGW_OPS	SUTO	2021-04-27	2.18
SFGW_OPS	SUTO	2021-05-04	3.23
SFGW_OPS	SUTO	2021-05-11	2.28
SFGW_OPS	SUTO	2021-05-18	2.49
SFGW_OPS	SUTO	2021-05-25	2.45
SFGW_OPS	SUTO	2021-06-01	2.42
SFGW_OPS	SUTO	2021-06-08	2.56
SFGW_OPS	SUTO	2021-06-15	<2
SFGW_OPS	SUTO	2021-06-22	6.91
SFGW_OPS	SUTO	2021-06-29	<2
SFGW_OPS	SUTO	2021-07-07	<2
SFGW_OPS	SUTO	2021-07-13	3.25
SFGW_OPS	SUTO	2021-07-21	<2
SFGW_OPS	SUTO	2021-07-27	2.8

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFGW_OPS	SUTO	2021-08-03	16.3
SFGW_OPS	SUTO	2021-08-10	6.46
SFGW_OPS	SUTO	2021-08-17	2.6
SFGW_OPS	SUTO	2021-08-24	3.04
SFGW_OPS	SUTO	2021-08-31	2.54
SFGW_OPS	SUTO	2021-09-07	2.87
SFGW_OPS	SUTO	2021-09-14	2.78
SFGW_OPS	SUTO	2021-09-21	10.4
SFGW_OPS	SUTO	2021-09-28	4.14
SFGW_OPS	SUTO	2021-10-05	4.43
SFGW_OPS	SUTO	2021-10-12	4.61
SFGW_OPS	SUTO	2021-10-19	3.36
SFGW_OPS	SUTO	2021-10-26	3.41
SFGW_OPS	SUTO	2021-11-02	3.12
SFGW_OPS	SUTO	2021-11-09	2.25
SFGW_OPS	SUTO	2021-11-16	2.63
SFGW_OPS	SUTO	2021-11-23	<2
SFGW_OPS	SUTO	2021-11-30	<2
SFGW_OPS	SUTO	2021-12-07	<2
SFGW_OPS	SUTO	2021-12-15	3.63
SFGW_OPS	SUTO	2021-12-21	2.04
SFGW_OPS	SUTO	2021-12-28	6.3
SFGW_RUNS	SSO#1_N	2019-06-17	2.59
SFGW_RUNS	SSO#1_N	2020-07-09	<2
SFGW_RUNS	SSO#2_S	2020-07-09	<2
SFGW_RUNS	SSO#1_N	2021-07-13	2.18
SFDS_RUNS	SSO#1_N	2017-06-27	<2
SFDS_RUNS	SSO#1_N	2017-07-04	2.74
SFDS_RUNS	SSO#1_N	2017-07-11	<2
SFDS_RUNS	SSO#1_N	2017-07-18	<2
SFDS_RUNS	SSO#1_N	2017-07-25	<2
SFDS_RUNS	SSO#1_N	2017-08-01	<2
SFDS_RUNS	SSO#1_N	2017-08-08	2.16
SFDS_RUNS	SSO#1_N	2017-08-15	<2
SFDS_RUNS	SSO#1_N	2017-08-22	<2
SFDS_RUNS	SSO#1_N	2017-08-29	<2
SFDS_RUNS	SSO#1_N	2017-09-05	<2
SFDS_RUNS	SSO#1_N	2017-09-12	2.04
SFDS_RUNS	SSO#1_N	2017-09-19	2.1
SFDS_RUNS	SSO#1_N	2017-09-26	2.3

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFDS_RUNS	SSO#1_N	2017-10-03	<2
SFDS_RUNS	SSO#1_N	2017-10-10	2.26
SFDS_RUNS	SSO#1_N	2017-10-17	2.8
SFDS_RUNS	SSO#1_N	2017-10-24	2.57
SFDS_RUNS	SSO#1_N	2017-10-31	3.07
SFDS_RUNS	SSO#1_N	2017-11-07	2.64
SFDS_RUNS	SSO#1_N	2017-11-14	2.5
SFDS_RUNS	SSO#1_N	2017-11-21	2.67
SFDS_RUNS	SSO#1_N	2017-11-28	3.21
SFDS_RUNS	SSO#1_N	2017-12-05	2.23
SFDS_RUNS	SSO#1_N	2017-12-12	3.14
SFDS_RUNS	SSO#1_N	2017-12-19	2.75
SFDS_RUNS	SSO#1_N	2017-12-26	3.83
SFDS_RUNS	SSO#1_N	2018-01-02	3.6
SFDS_RUNS	SSO#1_N	2018-01-09	4.03
SFDS_RUNS	SSO#1_N	2018-01-16	4.11
SFDS_RUNS	SSO#1_N	2018-01-23	3.84
SFDS_RUNS	SSO#1_N	2018-01-30	2.07
SFDS_RUNS	SSO#1_N	2018-02-06	3.47
SFDS_RUNS	SSO#1_N	2018-02-13	3.54
SFDS_RUNS	SSO#1_N	2018-02-20	2.67
SFDS_RUNS	SSO#1_N	2018-02-27	2.44
SFDS_RUNS	SSO#1_N	2018-03-06	3.07
SFDS_RUNS	SSO#1_N	2018-03-13	2.93
SFDS_RUNS	SSO#1_N	2018-03-20	2.61
SFDS_RUNS	SSO#1_N	2018-03-27	<2
SFDS_RUNS	SSO#1_N	2018-04-03	7.03
SFDS_RUNS	SSO#1_N	2018-04-10	<2
SFDS_RUNS	SSO#1_N	2018-04-17	2.21
SFDS_RUNS	SSO#1_N	2018-04-24	2.89
SFDS_RUNS	SSO#1_N	2018-05-01	2.76
SFDS_RUNS	SSO#1_N	2018-05-08	2.18
SFDS_RUNS	SSO#1_N	2018-05-15	2.35
SFDS_RUNS	SSO#1_N	2018-05-22	2.05
SFDS_RUNS	SSO#1_N	2018-05-29	<2
SFDS_RUNS	SSO#1_N	2018-06-05	<2
SFDS_RUNS	SSO#1_N	2018-06-12	<2
SFDS_RUNS	SSO#1_N	2018-06-19	<2
SFDS_RUNS	SSO#1_N	2018-06-26	<2
SFDS_RUNS	SSO#1_N	2018-07-03	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFDS_RUNS	SSO#1_N	2018-07-10	<2
SFDS_RUNS	SSO#1_N	2018-07-17	<2
SFDS_RUNS	SSO#2_S	2017-06-27	<2
SFDS_RUNS	SSO#2_S	2017-07-04	<2
SFDS_RUNS	SSO#2_S	2017-07-11	<2
SFDS_RUNS	SSO#2_S	2017-07-18	<2
SFDS_RUNS	SSO#2_S	2017-07-25	2.06
SFDS_RUNS	SSO#2_S	2017-08-01	<2
SFDS_RUNS	SSO#2_S	2017-08-08	<2
SFDS_RUNS	SSO#2_S	2017-08-15	<2
SFDS_RUNS	SSO#2_S	2017-08-22	<2
SFDS_RUNS	SSO#2_S	2017-08-29	<2
SFDS_RUNS	SSO#2_S	2017-09-05	<2
SFDS_RUNS	SSO#2_S	2017-09-12	<2
SFDS_RUNS	SSO#2_S	2017-09-19	<2
SFDS_RUNS	SSO#2_S	2017-09-26	2.11
SFDS_RUNS	SSO#2_S	2017-10-03	<2
SFDS_RUNS	SSO#2_S	2017-10-10	2.24
SFDS_RUNS	SSO#2_S	2017-10-17	2.38
SFDS_RUNS	SSO#2_S	2017-10-24	2.08
SFDS_RUNS	SSO#2_S	2017-10-31	2.71
SFDS_RUNS	SSO#2_S	2017-11-07	2.46
SFDS_RUNS	SSO#2_S	2017-11-14	2.4
SFDS_RUNS	SSO#2_S	2017-11-21	2.16
SFDS_RUNS	SSO#2_S	2017-11-28	2.12
SFDS_RUNS	SSO#2_S	2017-12-05	<2
SFDS_RUNS	SSO#2_S	2017-12-12	2.52
SFDS_RUNS	SSO#2_S	2017-12-19	2.76
SFDS_RUNS	SSO#2_S	2017-12-26	3.52
SFDS_RUNS	SSO#2_S	2018-01-02	3.23
SFDS_RUNS	SSO#2_S	2018-01-09	3.6
SFDS_RUNS	SSO#2_S	2018-01-16	3.9
SFDS_RUNS	SSO#2_S	2018-01-23	3.43
SFDS_RUNS	SSO#2_S	2018-01-30	2.24
SFDS_RUNS	SSO#2_S	2018-02-06	4.2
SFDS_RUNS	SSO#2_S	2018-02-13	3.12
SFDS_RUNS	SSO#2_S	2018-02-20	2.82
SFDS_RUNS	SSO#2_S	2018-02-27	2.57
SFDS_RUNS	SSO#2_S	2018-03-06	2.82
SFDS_RUNS	SSO#2_S	2018-03-13	2.56

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFDS_RUNS	SSO#2_S	2018-03-20	3.06
SFDS_RUNS	SSO#2_S	2018-03-27	<2
SFDS_RUNS	SSO#2_S	2018-04-03	<2
SFDS_RUNS	SSO#2_S	2018-04-10	<2
SFDS_RUNS	SSO#2_S	2018-04-17	<2
SFDS_RUNS	SSO#2_S	2018-04-24	2.35
SFDS_RUNS	SSO#2_S	2018-05-01	2.29
SFDS_RUNS	SSO#2_S	2018-05-08	<2
SFDS_RUNS	SSO#2_S	2018-05-15	2.09
SFDS_RUNS	SSO#2_S	2018-05-22	<2
SFDS_RUNS	SSO#2_S	2018-05-29	<2
SFDS_RUNS	SSO#2_S	2018-06-05	<2
SFDS_RUNS	SSO#2_S	2018-06-12	3.47
SFDS_RUNS	SSO#2_S	2018-06-19	<2
SFDS_RUNS	SSO#2_S	2018-06-26	<2
SFDS_RUNS	SSO#2_S	2018-07-03	<2
SFDS_RUNS	SSO#2_S	2018-07-10	<2
SFDS_RUNS	SSO#2_S	2018-07-17	<2
SFDS_RUNS	SUTO	2017-06-27	2.91
SFDS_RUNS	SUTO	2017-07-04	<2
SFDS_RUNS	SUTO	2017-07-11	2.84
SFDS_RUNS	SUTO	2017-07-18	<2
SFDS_RUNS	SUTO	2017-07-25	<2
SFDS_RUNS	SUTO	2017-08-01	<2
SFDS_RUNS	SUTO	2017-08-08	2.29
SFDS_RUNS	SUTO	2017-08-15	<2
SFDS_RUNS	SUTO	2017-08-22	2.14
SFDS_RUNS	SUTO	2017-08-29	2.18
SFDS_RUNS	SUTO	2017-09-05	<2
SFDS_RUNS	SUTO	2017-09-12	2.4
SFDS_RUNS	SUTO	2017-09-19	2.38
SFDS_RUNS	SUTO	2017-09-26	2.55
SFDS_RUNS	SUTO	2017-10-03	2.64
SFDS_RUNS	SUTO	2017-10-10	2.78
SFDS_RUNS	SUTO	2017-10-17	3.83
SFDS_RUNS	SUTO	2017-10-24	2.49
SFDS_RUNS	SUTO	2017-10-31	4.27
SFDS_RUNS	SUTO	2017-11-07	2.89
SFDS_RUNS	SUTO	2017-11-14	2.61
SFDS_RUNS	SUTO	2017-11-21	4.24

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
SFDS_RUNS	SUTO	2017-11-28	22.7
SFDS_RUNS	SUTO	2017-12-05	4.02
SFDS_RUNS	SUTO	2017-12-12	5.31
SFDS_RUNS	SUTO	2017-12-19	4.01
SFDS_RUNS	SUTO	2017-12-26	4.63
SFDS_RUNS	SUTO	2018-01-02	3.75
SFDS_RUNS	SUTO	2018-01-09	5.58
SFDS_RUNS	SUTO	2018-01-16	5.71
SFDS_RUNS	SUTO	2018-01-23	4.13
SFDS_RUNS	SUTO	2018-01-30	3.36
SFDS_RUNS	SUTO	2018-02-06	4.69
SFDS_RUNS	SUTO	2018-02-13	3.14
SFDS_RUNS	SUTO	2018-02-20	2.99
SFDS_RUNS	SUTO	2018-02-27	2.58
SFDS_RUNS	SUTO	2018-03-06	3.43
SFDS_RUNS	SUTO	2018-03-13	3.04
SFDS_RUNS	SUTO	2018-03-20	3.77
SFDS_RUNS	SUTO	2018-03-27	<2
SFDS_RUNS	SUTO	2018-04-03	<2
SFDS_RUNS	SUTO	2018-04-10	<2
SFDS_RUNS	SUTO	2018-04-17	2.69
SFDS_RUNS	SUTO	2018-04-24	2.23
SFDS_RUNS	SUTO	2018-05-01	2.04
SFDS_RUNS	SUTO	2018-05-08	<2
SFDS_RUNS	SUTO	2018-05-15	21.1
SFDS_RUNS	SUTO	2018-05-22	2.19
SFDS_RUNS	SUTO	2018-05-29	<2
SFDS_RUNS	SUTO	2018-06-05	<2
SFDS_RUNS	SUTO	2018-06-12	4.1
SFDS_RUNS	SUTO	2018-06-19	<2
SFDS_RUNS	SUTO	2018-06-26	<2
SFDS_RUNS	SUTO	2018-07-03	50.4
SFDS_RUNS	SUTO	2018-07-10	13.1
SFDS_RUNS	SUTO	2018-07-17	<2
EAST BAY SURFACE WATER FIRE MONITORING			
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2020-11-04	92
EBAY_RES_FIRE_MONITORING	Apperson Creek	2020-11-04	2.57
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2020-11-04	103
EBAY_RES_FIRE_MONITORING	CR-1	2020-11-04	6.28
EBAY_RES_FIRE_MONITORING	CR-4	2020-11-04	6.01

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
EBAY_RES_FIRE_MONITORING	Indian Creek - Upstream	2020-11-04	4.33
EBAY_RES_FIRE_MONITORING	San Antonio Creek - Upstream	2020-11-04	6.53
EBAY_RES_FIRE_MONITORING	SNT-1	2020-11-04	2.58
EBAY_RES_FIRE_MONITORING	SNT-4	2020-11-04	2.42
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2020-12-15	51
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2020-12-15	45.1
EBAY_RES_FIRE_MONITORING	CR-1	2020-12-15	57.7
EBAY_RES_FIRE_MONITORING	CR-4	2020-12-15	34.1
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2021-01-05	28.8
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2021-01-05	74.6
EBAY_RES_FIRE_MONITORING	CR-1	2021-01-05	33.2
EBAY_RES_FIRE_MONITORING	CR-4	2021-01-05	20.3
EBAY_RES_FIRE_MONITORING	Apperson Creek	2021-01-06	9.4
EBAY_RES_FIRE_MONITORING	Indian Creek - Upstream	2021-01-06	6.57
EBAY_RES_FIRE_MONITORING	San Antonio Creek - Upstream	2021-01-06	9.26
EBAY_RES_FIRE_MONITORING	SNT-1	2021-01-06	3.92
EBAY_RES_FIRE_MONITORING	SNT-4	2021-01-06	4.63
EBAY_RES_FIRE_MONITORING	Apperson Creek	2021-01-28	5.08
EBAY_RES_FIRE_MONITORING	Indian Creek - Upstream	2021-01-28	25.6
EBAY_RES_FIRE_MONITORING	San Antonio Creek - Upstream	2021-01-28	46.1
EBAY_RES_FIRE_MONITORING	SNT-1	2021-01-28	4.12
EBAY_RES_FIRE_MONITORING	SNT-4	2021-01-28	3.87
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2021-02-01	26
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2021-02-01	9.42
EBAY_RES_FIRE_MONITORING	CR-1	2021-02-01	11.4
EBAY_RES_FIRE_MONITORING	CR-4	2021-02-01	10.7
EBAY_RES_FIRE_MONITORING	Apperson Creek	2021-02-02	65.7
EBAY_RES_FIRE_MONITORING	Indian Creek - Upstream	2021-02-02	15
EBAY_RES_FIRE_MONITORING	San Antonio Creek - Upstream	2021-02-02	89
EBAY_RES_FIRE_MONITORING	SNT-1	2021-02-02	2.6
EBAY_RES_FIRE_MONITORING	SNT-4	2021-02-02	2.91
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2021-02-16	21.7
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2021-02-16	2.35
EBAY_RES_FIRE_MONITORING	CR-1	2021-02-16	7.09
EBAY_RES_FIRE_MONITORING	CR-4	2021-02-16	7.65
EBAY_RES_FIRE_MONITORING	Apperson Creek	2021-03-08	37.7
EBAY_RES_FIRE_MONITORING	Indian Creek - Upstream	2021-03-08	22.2
EBAY_RES_FIRE_MONITORING	San Antonio Creek - Upstream	2021-03-08	260
EBAY_RES_FIRE_MONITORING	SNT-1	2021-03-08	3.18
EBAY_RES_FIRE_MONITORING	SNT-4	2021-03-08	3.91

Rasprojectno_(Project_ID)	ClSampNo	Date	Manganese, Mn µg/L
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2021-03-09	25.9
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2021-03-09	8.45
EBAY_RES_FIRE_MONITORING	CR-1	2021-03-09	6.81
EBAY_RES_FIRE_MONITORING	CR-4	2021-03-09	7.28
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2021-03-17	23.5
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2021-03-17	2.95
EBAY_RES_FIRE_MONITORING	CR-1	2021-03-17	8.32
EBAY_RES_FIRE_MONITORING	CR-4	2021-03-17	8.13
EBAY_RES_FIRE_MONITORING	Apperson Creek	2021-03-23	18.6
EBAY_RES_FIRE_MONITORING	Indian Creek - Upstream	2021-03-23	91.8
EBAY_RES_FIRE_MONITORING	San Antonio Creek - Upstream	2021-03-23	49.8
EBAY_RES_FIRE_MONITORING	SNT-1	2021-03-23	3.34
EBAY_RES_FIRE_MONITORING	SNT-4	2021-03-23	4.78
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2021-03-24	36
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2021-03-24	2.6
EBAY_RES_FIRE_MONITORING	CR-1	2021-03-24	14
EBAY_RES_FIRE_MONITORING	CR-4	2021-03-24	12
EBAY_RES_FIRE_MONITORING	Apperson Creek	2021-04-19	7.48
EBAY_RES_FIRE_MONITORING	Indian Creek - Upstream	2021-04-19	13.9
EBAY_RES_FIRE_MONITORING	San Antonio Creek - Upstream	2021-04-19	16.5
EBAY_RES_FIRE_MONITORING	SNT-1	2021-04-19	3.63
EBAY_RES_FIRE_MONITORING	SNT-4	2021-04-19	5.63
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2021-04-20	77.2
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2021-04-20	10.5
EBAY_RES_FIRE_MONITORING	CR-1	2021-04-20	7.98
EBAY_RES_FIRE_MONITORING	CR-4	2021-04-20	11.6

Table 6-10. Results of Molybdenum T22 SFPUC Monitoring in 2016 and Special Sampling of Sunset Reservoir in 2020

Rasprojectno_(Project_ID)	ClSampNo	Date	Molybdenum, Mo µg/L
SURFACE WATER HETCH HETCHY			
T22_ANNUAL_RUNS	HHR	2016-06-15	<1
T22_ANNUAL_RUNS	MOC_RES	2016-06-15	<1
WQ_ENG_SPECIAL	SP4 MtnTnl@EarlyInt	2017-01-12	1.5
T22_ANNUAL_RUNS	LK_ELEANOR	2016-06-13	<1
T22_ANNUAL_RUNS	CHERRY_CREEK	2016-06-14	<1
T22_ANNUAL_RUNS	CHERRY_RES	2016-06-13	<1
T22_ANNUAL_RUNS	EI_RES	2016-06-14	<1
EAST BAY SURFACE WATER			
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2016-06-15	1.21
T22_ANNUAL_RUNS	CAL_SURF	2016-06-15	<1
T22_ANNUAL_RUNS	SANT_SURF	2016-06-15	<1
WEST BAY SURFACE WATER			
T22_ANNUAL_RUNS	LCS_SURF	2016-06-14	<1
T22_ANNUAL_RUNS	SA_SURF	2016-06-14	<1
T22_ANNUAL_RUNS	PIL_SURF	2016-06-14	1.09
T22_ANNUAL_RUNS	STONE_DAM_SURF	2016-06-14	1.22
GROUNDWATER SF CITY			
T22_ANNUAL_RUNS	LK_MERCED_S	2016-06-20	<1
T22_ANNUAL_RUNS	SF_ZOO_WELL_5	2016-06-14	<1
GROUNDWATER PENINSULA			
T22_ANNUAL_RUNS	SUNOL_FILTER	2016-06-14	2.22
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2016-06-14	1.04
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2016-06-14	<1
DRINKING WATER			
T22_ANNUAL_RUNS	MOC_TK	2016-06-15	<1
T22_ANNUAL_RUNS	OSH_TK	2016-06-15	<1
T22_ANNUAL_RUNS	EI_TK	2016-06-14	<1
T22_ANNUAL_RUNS	ALAMEDA_EAST	2016-06-14	<1
T22_ANNUAL_RUNS	SVWTP_EFF	2016-06-14	1.03
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	2016-06-14	<1
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2016-06-21	<1
T22_ANNUAL_RUNS	CS#2_BADEN	2016-06-14	<1
CRP	SSO#2_S	2020-02-23	<1
SPECIAL			
GW_EVAL	Forest Hill Station	2016-09-13	0.412
PRESIDIO_RUNS	LOBOS_CREEK	2016-01-12	<1
PRESIDIO_RUNS	QC_TRIP_BLANK	2016-01-12	<1

Rasprojectno_(Project_ID)	ClSampNo	Date	Molybdenum, Mo µg/L
BA_HILLSBOROUGH_SPECIAL	SPECIAL	2017-07-31	<1
WQ_ENG_SPECIAL	SPECIAL	2018-09-27	<1
WQ_ENG_SPECIAL	SPECIAL	2020-02-27	<1
WQ_ENG_SPECIAL	SPECIAL	2020-02-27	<1
WQ_ENG_SPECIAL	SPECIAL	2020-02-27	<1
WQ_ENG_SPECIAL	SPECIAL	2020-02-27	<1
WQ_ENG_SPECIAL	SPECIAL	2020-02-27	<1
WQ_ENG_SPECIAL	SPECIAL	2020-02-27	<1
WQ_ENG_SPECIAL	SPECIAL	2018-09-27	<1
WQ_ENG_SPECIAL	SPECIAL	2018-09-27	<1
WQ_ENG_SPECIAL	SPECIAL	2020-02-27	<1
WQ_ENG_SPECIAL	SS#01	2020-02-27	<1
WQ_ENG_SPECIAL	SS#03	2020-02-27	<1
WQ_ENG_SPECIAL	SS#05	2020-02-27	<1
WQ_ENG_SPECIAL	SS#06	2020-02-27	<1
WQ_ENG_SPECIAL	SS#07	2020-02-27	<1
WQ_ENG_SPECIAL	SS#08	2020-02-27	<1
WQ_ENG_SPECIAL	SS#09	2020-02-27	<1
WQ_ENG_SPECIAL	SS#10	2020-02-27	<1
WQ_ENG_SPECIAL	SS#11	2020-02-27	<1

Table 6-11. Strontium SFPUC Monitoring Results, 2016-2021

Rasprojectno_(Project_ID)	ClSampNo	Date	Strontium, Sr µg/L
Surface Water Hetch Hetchy			
T22_ANNUAL_RUNS	HHR	2016-06-15	7.36
T22_ANNUAL_RUNS	HHR	2017-06-19	8.61
T22_ANNUAL_RUNS	HHR	2018-06-18	8.88
T22_ANNUAL_RUNS	HHR	2019-06-18	7.87
T22_ANNUAL_RUNS	HHR	2020-06-16	8.42
T22_ANNUAL_RUNS	HHR	2021-07-14	10
T22_ANNUAL_RUNS	CHERRY_RES	2016-06-13	10.4
T22_ANNUAL_RUNS	CHERRY_RES	2017-06-26	8.36
T22_ANNUAL_RUNS	CHERRY_RES	2018-06-18	10.3
T22_ANNUAL_RUNS	CHERRY_RES	2019-06-18	10.9
T22_ANNUAL_RUNS	CHERRY_RES	2020-06-17	8.89
T22_ANNUAL_RUNS	CHERRY_RES	2021-07-01	9.06
T22_ANNUAL_RUNS	MOC_RES	2016-06-15	10.8
T22_ANNUAL_RUNS	MOC_RES	2017-07-19	7.89
T22_ANNUAL_RUNS	MOC_RES	2019-06-18	9.89
T22_ANNUAL_RUNS	MOC_RES	2020-06-15	11
T22_ANNUAL_RUNS	MOC_RES	2021-07-14	11
T22_ANNUAL_RUNS	LK_ELEANOR	2016-06-13	8.46
T22_ANNUAL_RUNS	LK_ELEANOR	2017-06-26	6.87
T22_ANNUAL_RUNS	LK_ELEANOR	2018-06-18	8.75
T22_ANNUAL_RUNS	LK_ELEANOR	2019-06-18	8.47
T22_ANNUAL_RUNS	LK_ELEANOR	2020-06-22	9.08
T22_ANNUAL_RUNS	LK_ELEANOR	2021-07-01	9.18
T22_ANNUAL_RUNS	EI_RES	2016-06-14	9.3
T22_ANNUAL_RUNS	EI_RES	2017-06-19	8.67
T22_ANNUAL_RUNS	EI_RES	2018-06-19	10.3
T22_ANNUAL_RUNS	EI_RES	2019-06-19	8.08
T22_ANNUAL_RUNS	EI_RES	2020-06-23	12.5
T22_ANNUAL_RUNS	EI_RES	2021-07-14	12.7
T22_ANNUAL_RUNS	MOC_TAILRACE	2017-06-20	9.3
T22_ANNUAL_RUNS	MOC_TAILRACE	2018-06-18	9.94
EAST BAY SURFACE WATER			
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2016-06-15	266
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2017-06-19	294
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2018-06-18	169
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2019-05-02	190
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2020-07-01	257
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2021-03-03	198

Rasprojectno_(Project_ID)	ClSampNo	Date	Strontium, Sr µg/L
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2018-06-18	623
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2019-06-17	589
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2020-07-01	586
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2021-03-03	615
T22_ANNUAL_RUNS	CAL_SURF	2016-06-15	391
T22_ANNUAL_RUNS	CAL_SURF	2017-06-19	416
T22_ANNUAL_RUNS	CAL_SURF	2018-06-18	510
T22_ANNUAL_RUNS	CAL_SURF	2019-06-17	388
T22_ANNUAL_RUNS	CAL_SURF	2020-07-20	413
T22_ANNUAL_RUNS	CAL_SURF	2021-06-28	398
T22_ANNUAL_RUNS	SANT_SURF	2016-06-15	223
T22_ANNUAL_RUNS	SANT_SURF	2017-06-19	249
T22_ANNUAL_RUNS	SANT_SURF	2018-06-18	238
T22_ANNUAL_RUNS	SANT_SURF	2019-06-17	231
T22_ANNUAL_RUNS	SANT_SURF	2020-06-24	200
T22_ANNUAL_RUNS	SANT_SURF	2021-06-11	185
WEST BAY SURFACE WATER			
T22_ANNUAL_RUNS	LCS_SURF	2016-06-14	73.4
T22_ANNUAL_RUNS	LCS_SURF	2017-06-19	94.7
T22_ANNUAL_RUNS	LCS_SURF	2018-06-18	77
T22_ANNUAL_RUNS	LCS_SURF	2019-06-17	83.1
T22_ANNUAL_RUNS	LCS_SURF	2020-07-28	52.6
T22_ANNUAL_RUNS	LCS_SURF	2021-06-14	41
T22_ANNUAL_RUNS	SA_SURF	2016-06-14	68.3
T22_ANNUAL_RUNS	SA_SURF	2017-06-19	82.1
T22_ANNUAL_RUNS	SA_SURF	2018-06-18	88.5
T22_ANNUAL_RUNS	SA_SURF	2019-06-17	81.7
T22_ANNUAL_RUNS	SA_SURF	2020-06-15	75.1
T22_ANNUAL_RUNS	SA_SURF	2021-06-16	53.2
T22_ANNUAL_RUNS	SA_SURF	2020-06-15	75.1
T22_ANNUAL_RUNS	SA_SURF	2021-06-16	53.2
T22_ANNUAL_RUNS	PIL_SURF	2016-06-14	54.3
T22_ANNUAL_RUNS	PIL_SURF	2017-06-19	46.5
T22_ANNUAL_RUNS	PIL_SURF	2018-06-18	54.2
T22_ANNUAL_RUNS	PIL_SURF	2019-06-17	52.8
T22_ANNUAL_RUNS	PIL_SURF	2020-07-21	57.5
T22_ANNUAL_RUNS	PIL_SURF	2021-06-22	61
T22_ANNUAL_RUNS	STONE_DAM_SURF	2016-06-14	67
T22_ANNUAL_RUNS	STONE_DAM_SURF	2017-06-19	73
T22_ANNUAL_RUNS	STONE_DAM_SURF	2018-06-18	65
T22_ANNUAL_RUNS	STONE_DAM_SURF	2019-06-17	69.9

Rasprojectno_(Project_ID)	ClSampNo	Date	Strontium, Sr µg/L
T22_ANNUAL_RUNS	STONE_DAM_SURF	2020-07-21	61.3
T22_ANNUAL_RUNS	STONE_DAM_SURF	2021-06-29	68.8
GROUNDWATER SF CITY			
T22_ANNUAL_RUNS	LK_MERCED_S	2016-06-20	250
T22_ANNUAL_RUNS	LK_MERCED_S	2017-06-19	235
T22_ANNUAL_RUNS	LK_MERCED_S	2020-07-14	232
T22_ANNUAL_RUNS	SF_ZOO_WELL_5	2016-06-14	165
T22_ANNUAL_RUNS	SF_ZOO_WELL_5	2017-06-19	176
T22_ANNUAL_RUNS	SF_ZOO_WELL_5	2020-06-17	191
SFGW_HISTORICAL	SFGW-LMW	2017-06-14	139
SFGW_1ST-YR	SFGW-LMW	2018-01-11	137
SFGW_1ST-YR	SFGW-GCW	2018-03-06	203
SFGW_1ST-YR	SFGW-SSW	2018-03-06	182
SFGW_1ST-YR	SFGW-WSW	2018-03-08	152
SFGW_HISTORICAL	SFGW-LMW	2018-04-17	134
SFGW_1ST-YR	SFGW-GCW	2018-06-12	236
SFGW_1ST-YR	SFGW-SSW	2018-06-12	197
SFGW_1ST-YR	SFGW-WSW	2018-06-12	163
SFGW_1ST-YR	SFGW-LMW	2018-07-17	137
SFGW_1ST-YR	SFGW-GCW	2018-09-18	201
SFGW_1ST-YR	SFGW-SSW	2018-09-18	180
SFGW_1ST-YR	SFGW-WSW	2018-09-18	154
SFGW_1ST-YR	SFGW-LMW	2018-10-17	130
SFGW_1ST-YR	SFGW-GCW	2018-12-11	220
SFGW_1ST-YR	SFGW-SSW	2018-12-11	203
SFGW_1ST-YR	SFGW-WSW	2018-12-11	159
SFGW_WRD	SFGW-SSW	2019-05-16	161
SFGW_RUNS	SFGW-GCW	2019-06-17	202
SFGW_RUNS	SFGW-LMW	2019-06-17	134
SFGW_RUNS	SFGW-SSW	2019-06-17	201
SFGW_RUNS	SFGW-WSW	2019-06-17	168
SFGW_RUNS	SFGW-LMW	2020-07-14	131
SFGW_RUNS	SFGW-SSW	2020-07-14	204
SFGW_RUNS	SFGW-GCW	2020-07-15	210
SFGW_RUNS	SFGW-WSW	2020-07-15	187
SFGW_1ST-YR	SFGW-NLW	2020-07-16	164
SFGW_1ST-YR	SFGW-SWW	2020-07-20	180
SFGW_1ST-YR	SFGW-NLW	2020-10-20	167
SFGW_1ST-YR	SFGW-SWW	2020-10-20	180
SFGW_1ST-YR	SFGW-NLW	2021-01-12	200
SFGW_1ST-YR	SFGW-SWW	2021-01-12	176

Rasprojectno_(Project_ID)	ClSampNo	Date	Strontium, Sr µg/L
SFGW_1ST-YR	SFGW-NLW	2021-04-13	215
SFGW_1ST-YR	SFGW-SWW	2021-04-13	174
SFGW_RUNS	SFGW-LMW	2021-07-13	127
SFGW_RUNS	SFGW-SSW	2021-07-13	206
SFGW_RUNS	SFGW-WSW	2021-07-13	185
SFGW_RUNS	SFGW-GCW	2021-07-20	203
SFGW_RUNS	SFGW-NLW	2021-07-20	168
SFGW_RUNS	SFGW-SWW	2021-07-20	175
GROUNDWATER PENINSULA			
GSR_PRE-COMP	GSR-HBW	2019-06-24	189
GSR_PRE-COMP	GSR-PDWLGWLGW	2019-06-24	135
GSR_PRE-COMP	GSR-SBW	2019-06-24	276
GSR_PRE-COMP	GSR-MSW	2019-06-25	316
GSR_PRE-COMP	GSR-MYW	2019-06-25	247
GSR_PRE-COMP	GSR-SDW	2019-06-25	401
GSR_PRE-COMP	GSR-BSW	2019-06-26	292
GSR_PRE-COMP	GSR-CBW	2019-06-26	255
GSR_PRE-COMP	GSR-FSW	2019-06-26	231
GSR_1ST-YR	GSR-HBW	2020-07-07	186
GSR_1ST-YR	GSR-PDW	2020-07-07	139
GSR_1ST-YR	GSR-CBW	2020-07-08	270
GSR_1ST-YR	GSR-FSW	2020-07-08	257
GSR_1ST-YR	GSR-MYW	2020-07-08	262
GSR_HISTORICAL	GSR-SDW	2020-08-05	460
GSR_PARTNER	GSR-BFW	2020-08-12	267
GSR_PARTNER	GSR-LPW	2020-08-26	252
GSR_1ST-YR	GSR-CBW	2020-10-21	259
GSR_1ST-YR	GSR-FSW	2020-10-21	258
GSR_1ST-YR	GSR-PDW	2020-10-21	138
GSR_1ST-YR	GSR-HBW	2020-10-22	187
GSR_1ST-YR	GSR-MYW	2020-10-22	253
GSR_1ST-YR	GSR-HBW	2021-01-06	184
GSR_1ST-YR	GSR-MYW	2021-01-06	253
GSR_1ST-YR	GSR-PDW	2021-01-07	134
GSR_1ST-YR	GSR-CBW	2021-01-13	261
GSR_1ST-YR	GSR-FSW	2021-01-13	247
GSR_1ST-YR	GSR-BSW	2021-04-07	310
GSR_1ST-YR	GSR-CBW	2021-04-07	279
GSR_1ST-YR	GSR-FSW	2021-04-07	253
GSR_1ST-YR	GSR-PDW	2021-04-07	133
GSR_1ST-YR	GSR-HBW	2021-04-08	187

Rasprojectno_(Project_ID)	ClSampNo	Date	Strontium, Sr µg/L
GSR_1ST-YR	GSR-MYW	2021-04-08	281
GSR_RUNS	GSR-MYW	2021-07-07	260
GSR_RUNS	GSR-HBW	2021-07-08	180
GSR_RUNS	GSR-PDW	2021-07-08	136
GSR_1ST-YR	GSR-BSW	2021-07-14	296
GSR_RUNS	GSR-CBW	2021-07-14	249
GSR_RUNS	GSR-FSW	2021-07-14	257
GSR_1ST-YR	GSR-SBW	2021-08-18	260
GSR_1ST-YR	GSR-BSW	2021-10-06	304
GSR_1ST-YR	GSR-SBW	2021-11-04	271
GSR_1ST-YR	GSR-MSW	2021-12-16	320
GROUNDWATER EAST BAY			
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2016-06-14	1340
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2016-06-14	1500
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2017-06-19	1690
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2017-06-19	1470
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2018-06-18	1440
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2018-06-18	1420
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2019-06-17	1480
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2019-06-26	1630
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2020-06-16	1690
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2020-06-16	1480
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2021-06-23	1400
T22_ANNUAL_RUNS	SUNOL_FILTER	2016-06-14	652
T22_ANNUAL_RUNS	SUNOL_FILTER	2017-06-19	224
T22_ANNUAL_RUNS	SUNOL_FILTER	2018-06-18	579
T22_ANNUAL_RUNS	SUNOL_FILTER	2019-06-17	558
T22_ANNUAL_RUNS	SUNOL_FILTER	2020-06-17	574
T22_ANNUAL_RUNS	SUNOL_FILTER	2021-06-23	435
DRINKING WATER			
T22_ANNUAL_RUNS	EI_TK	2016-06-14	10.3
T22_ANNUAL_RUNS	EI_TK	2017-06-19	9.44
T22_ANNUAL_RUNS	EI_TK	2018-06-19	9.58
T22_ANNUAL_RUNS	EI_TK	2020-06-23	9.6
T22_ANNUAL_RUNS	OSH_TK	2016-06-15	10.2
T22_ANNUAL_RUNS	OSH_TK	2017-06-19	8.9
T22_ANNUAL_RUNS	OSH_TK	2018-06-19	9.79
T22_ANNUAL_RUNS	OSH_TK	2020-06-16	9.67
T22_ANNUAL_RUNS	MOC_TK	2016-06-15	9.94
T22_ANNUAL_RUNS	MOC_TK	2017-06-20	9.23
T22_ANNUAL_RUNS	MOC_TK	2018-06-18	9.87

Rasprojectno_(Project_ID)	ClSampNo	Date	Strontium, Sr µg/L
T22_ANNUAL_RUNS	MOC_TK	2020-06-15	10.2
T22_ANNUAL_RUNS	SVWTP_EFF	2016-06-14	204
T22_ANNUAL_RUNS	SVWTP_EFF	2017-06-19	234
T22_ANNUAL_RUNS	SVWTP_EFF	2018-06-28	199
T22_ANNUAL_RUNS	SVWTP_EFF	2019-06-17	230
T22_ANNUAL_RUNS	SVWTP_EFF	2020-06-24	242
T22_ANNUAL_RUNS	SVWTP_TWR_EFF	2021-06-15	181
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	2016-06-14	17.5
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	2017-06-19	52
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2016-06-21	68.4
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2017-06-19	86.6
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2018-06-18	86.4
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2019-07-02	78.3
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2020-06-15	74.7
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2021-06-16	53.2
T22_ANNUAL_RUNS	CS#2_BADEN	2016-06-14	19.4
T22_ANNUAL_RUNS	CS#2_BADEN	2017-06-19	38.7
T22_ANNUAL_RUNS	CS#2_BADEN	2018-06-18	15
T22_ANNUAL_RUNS	CS#2_BADEN	2020-06-16	15.4
SFGW_RUNS	SSO#1_N	2019-06-17	49.3
SFGW_RUNS	SSO#1_N	2020-07-09	22
SFGW_RUNS	SSO#2_S	2020-07-09	27.7
CRP	SSO#2_S	2020-02-23	86.5
SPECIAL EMERGENCY SAMPLING			
WQ_ENG_SPECIAL	SS#01	2020-02-27	74.6
WQ_ENG_SPECIAL	SS#03	2020-02-27	64.4
WQ_ENG_SPECIAL	SS#04	2020-02-27	68.3
WQ_ENG_SPECIAL	SS#05	2020-02-27	78.4
WQ_ENG_SPECIAL	SS#06	2020-02-27	75.8
WQ_ENG_SPECIAL	SS#07	2020-02-27	76.8
WQ_ENG_SPECIAL	SS#08	2020-02-27	69.6
WQ_ENG_SPECIAL	SS#09	2020-02-27	80
WQ_ENG_SPECIAL	SS#10	2020-02-27	78.1
WQ_ENG_SPECIAL	SS#11	2020-02-27	69

Table 6-12. Vanadium Monitoring Results 2016-2021

Rasprojectno_(Project_ID)	ClSampNo	Date	Vanadium, V µg/L
Surface Water Hetch Hetchy			
T22_ANNUAL_RUNS	HHR	2016-06-15	<1
T22_ANNUAL_RUNS	HHR	2020-06-16	<1
T22_ANNUAL_RUNS	CHERRY_RES	2016-06-13	<1
T22_ANNUAL_RUNS	CHERRY_RES	2020-06-17	<1
T22_ANNUAL_RUNS	CHERRY_CREEK	2016-06-14	2.13
T22_ANNUAL_RUNS	CHERRY_CREEK	2020-06-24	<1
T22_ANNUAL_RUNS	MOC_RES	2016-06-15	<1
T22_ANNUAL_RUNS	MOC_RES	2020-06-15	<1
T22_ANNUAL_RUNS	LK_ELEANOR	2016-06-13	<1
T22_ANNUAL_RUNS	LK_ELEANOR	2020-06-22	<1
T22_ANNUAL_RUNS	EI_RES	2016-06-14	<1
T22_ANNUAL_RUNS	EI_RES	2020-06-23	<1
WQ_ENG_SPECIAL	SP1 MtnTnl@PriestRes	2017-01-12	7.13
WQ_ENG_SPECIAL	SP4 MtnTnl@EarlyInt	2017-01-12	<1
EAST BAY SURFACE WATER			
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2018-06-18	2.19
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2019-06-17	1.47
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2020-07-01	1.54
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2021-03-03	<1
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2016-06-15	1.16
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2018-06-18	4.07
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2020-07-01	1.16
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2021-03-03	2.87
T22_ANNUAL_RUNS	CAL_SURF	2016-06-15	1.03
T22_ANNUAL_RUNS	CAL_SURF	2018-06-18	2.02
T22_ANNUAL_RUNS	CAL_SURF	2020-07-20	<1
T22_ANNUAL_RUNS	SANT_SURF	2016-06-15	1.48
T22_ANNUAL_RUNS	SANT_SURF	2020-06-24	1.33
WEST BAY SURFACE WATER			
T22_ANNUAL_RUNS	SA_SURF	2016-06-14	<1
T22_ANNUAL_RUNS	SA_SURF	2020-06-15	<1
T22_ANNUAL_RUNS	LCS_SURF	2016-06-14	2.43
T22_ANNUAL_RUNS	LCS_SURF	2020-07-28	<1
T22_ANNUAL_RUNS	PIL_SURF	2016-06-14	<1
T22_ANNUAL_RUNS	PIL_SURF	2020-07-21	<1
T22_ANNUAL_RUNS	STONE_DAM_SURF	2016-06-14	1.51
T22_ANNUAL_RUNS	STONE_DAM_SURF	2020-07-21	<1

Rasprojectno_(Project_ID)	ClSampNo	Date	Vanadium, V µg/L
GROUNDWATER SF CITY			
T22_ANNUAL_RUNS	LK_MERCED_S	2016-06-20	1.67
T22_ANNUAL_RUNS	LK_MERCED_S	2020-07-14	2.76
SFGW_OPS	SFGW - WSW	2018-10-04	6.38
SFGW_RUNS	SFGW-LMW	2020-07-14	6.98
SFGW_RUNS	SFGW-SSW	2020-07-14	5.08
SFGW_RUNS	SFGW-GCW	2020-07-15	5.43
SFGW_RUNS	SFGW-WSW	2020-07-15	5.94
SFGW_1ST-YR	SFGW-NLW	2020-07-16	5.75
SFGW_1ST-YR	SFGW-SWW	2020-07-20	5.25
GROUNDWATER PENINSULA			
GSR_PARTNER	GSR-SMW	2016-02-17	5.12
GW_EVAL	Forest Hill Station	2016-09-13	2.12
GSR_PRE-COMP	GSR-HBW	2019-06-24	6.57
GSR_PRE-COMP	GSR-PDWLGWLGW	2019-06-24	6.17
GSR_PRE-COMP	GSR-SBW	2019-06-24	5.48
GSR_PRE-COMP	GSR-MSW	2019-06-25	6.51
GSR_PRE-COMP	GSR-MYW	2019-06-25	4.18
GSR_PRE-COMP	GSR-SDW	2019-06-25	<1
GSR_PRE-COMP	GSR-BSW	2019-06-26	4.73
GSR_PRE-COMP	GSR-CBW	2019-06-26	4.49
GSR_PRE-COMP	GSR-FSW	2019-06-26	5.35
GSR_1ST-YR	GSR-HBW	2020-07-07	6.95
GSR_1ST-YR	GSR-PDW	2020-07-07	6.67
GSR_1ST-YR	GSR-CBW	2020-07-08	4.66
GSR_1ST-YR	GSR-FSW	2020-07-08	5.39
GSR_1ST-YR	GSR-MYW	2020-07-08	4.65
GROUNDWATER EAST BAY			
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2016-06-14	3.26
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2017-06-19	1.93
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2018-06-18	3.7
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2019-06-26	2.6
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2020-06-16	2.59
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2016-06-14	2.22
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2017-06-19	2.01
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2018-06-18	3.19
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2019-06-17	2.5
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2020-06-16	2.55
T22_ANNUAL_RUNS	SUNOL_FILTER	2016-06-14	1.22
T22_ANNUAL_RUNS	SUNOL_FILTER	2020-06-17	<1

Rasprojectno_(Project_ID)	ClSampNo	Date	Vanadium, V µg/L
DRINKING WATER			
T22_ANNUAL_RUNS	MOC_TK	2016-06-15	<1
T22_ANNUAL_RUNS	OSH_TK	2016-06-15	<1
T22_ANNUAL_RUNS	EI_TK	2016-06-14	<1
T22_ANNUAL_RUNS	ALAMEDA_EAST	2016-06-14	<1
T22_ANNUAL_RUNS	ALAMEDA_EAST	2017-06-19	<1
T22_ANNUAL_RUNS	ALAMEDA_EAST	2018-06-18	<1
T22_ANNUAL_RUNS	ALAMEDA_EAST	2019-06-17	<1
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	2016-06-14	<1
T22_ANNUAL_RUNS	SVWTP_EFF	2016-06-14	<1
T22_ANNUAL_RUNS	SVWTP_EFF	2017-06-19	<1
T22_ANNUAL_RUNS	SVWTP_EFF	2018-06-28	<1
T22_ANNUAL_RUNS	SVWTP_EFF	2019-06-17	<1
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2016-06-21	<1
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2017-06-19	<1
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2018-06-18	<1
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2019-07-02	<1
T22_ANNUAL_RUNS	CS#2_BADEN	2016-06-14	<1
T22_ANNUAL_RUNS	CS#2_BADEN	2017-06-19	<1
T22_ANNUAL_RUNS	CS#2_BADEN	2018-06-18	<1
T22_ANNUAL_RUNS	CS#2_BADEN	2019-06-17	<1
CRP	SSO#2_S	2020-02-23	<1
SPECIAL -EMERGENCY SAMPLING			
WQ_ENG_SPECIAL	SS#01	2020-02-27	<1
WQ_ENG_SPECIAL	SS#03	2020-02-27	<1
WQ_ENG_SPECIAL	SS#04	2020-02-27	<1
WQ_ENG_SPECIAL	SS#05	2020-02-27	<1
WQ_ENG_SPECIAL	SS#06	2020-02-27	<1
WQ_ENG_SPECIAL	SS#07	2020-02-27	<1
WQ_ENG_SPECIAL	SS#08	2020-02-27	<1
WQ_ENG_SPECIAL	SS#09	2020-02-27	<1
WQ_ENG_SPECIAL	SS#10	2020-02-27	<1
WQ_ENG_SPECIAL	SS#11	2020-02-27	<1

Table 6-13. Zinc SFPUC Monitoring Results, 2016-2021

Rasprojectno_(Project_ID)	ClSampNo	Date	Zinc, Zn µg/L
SURFACE WATER HETCH HETCHY			
T22_ANNUAL_RUNS	HHR	2016-06-15	<2
T22_ANNUAL_RUNS	HHR	2017-06-19	<2
T22_ANNUAL_RUNS	HHR	2018-06-18	<2
T22_ANNUAL_RUNS	CHERRY_RES	2016-06-13	<2
T22_ANNUAL_RUNS	CHERRY_RES	2017-06-26	<2
T22_ANNUAL_RUNS	CHERRY_CREEK	2016-06-14	4.71
T22_ANNUAL_RUNS	CHERRY_CREEK	2017-06-26	3.5
T22_ANNUAL_RUNS	CHERRY_CREEK	2020-06-24	<2
T22_ANNUAL_RUNS	LK_ELEANOR	2016-06-13	<2
T22_ANNUAL_RUNS	LK_ELEANOR	2017-06-26	<2
T22_ANNUAL_RUNS	LK_ELEANOR	2020-06-22	<2
WQ_MOCCASIN_SPECIAL	OSH_BKPK_WELL	2016-03-02	<2
WQ_MOCCASIN_SPECIAL	OSH_BKPK_WELL	2016-03-23	<2
T22_ANNUAL_RUNS	MOC_RES	2016-06-15	<2
T22_ANNUAL_RUNS	MOC_RES	2017-07-19	<2
T22_ANNUAL_RUNS	MOC_TAILRACE	2017-06-20	<2
T22_ANNUAL_RUNS	MOC_TAILRACE	2018-06-18	2.71
T22_ANNUAL_RUNS	EI_RES	2016-06-14	<2
T22_ANNUAL_RUNS	EI_RES	2017-06-19	<2
T22_ANNUAL_RUNS	EI_RES	2020-06-23	<2
EAST BAY SURFACE WATER			
ALAMEDA_CR_RECAP	ALAMEDA_CR_P_F2EA	2016-05-18	<2
ALAMEDA_CR_RECAP	ALAMEDA_CR_P_F2EA	2016-03-16	<2
ALAMEDA_CR_RECAP	ALAMEDA_CR_P_F2EA	2016-06-15	<2
ALAMEDA_CR_RECAP	ALAMEDA_CR_P_F2EA	2016-04-20	<2
ALAMEDA_CR_RECAP	ALAMEDA_CR_P_F2EA	2016-07-20	<2
ALAMEDA_CR_RECAP	ALAMEDA_CR_P_F2EA	2016-02-17	<2
ALAMEDA_CR_RECAP	ALAMEDA_CR_P_F2EA	2016-01-20	<2
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F2EA	2018-06-18	<2
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2016-06-15	<2
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2017-06-19	<2
T22_ANNUAL_RUNS	ALAMEDA_CR_P_F3E	2018-06-18	<2
T22_ANNUAL_RUNS	CAL_SURF	2016-06-15	<2
T22_ANNUAL_RUNS	CAL_SURF	2017-06-19	<2
T22_ANNUAL_RUNS	CAL_SURF	2018-06-18	<2
T22_ANNUAL_RUNS	SANT_SURF	2016-06-15	2.24
T22_ANNUAL_RUNS	SANT_SURF	2017-06-19	<2
T22_ANNUAL_RUNS	SANT_SURF	2018-06-18	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Zinc, Zn µg/L
WEST BAY SURFACE WATER			
T22_ANNUAL_RUNS	LCS_SURF	2016-06-14	2.5
T22_ANNUAL_RUNS	LCS_SURF	2017-06-19	<2
T22_ANNUAL_RUNS	LCS_SURF	2019-06-17	<2
T22_ANNUAL_RUNS	LCS_SURF	2020-07-28	<2
T22_ANNUAL_RUNS	LCS_SURF	2021-06-14	<2
T22_ANNUAL_RUNS	SA_SURF	2016-06-14	<2
T22_ANNUAL_RUNS	SA_SURF	2017-06-19	5.89
T22_ANNUAL_RUNS	SA_SURF	2018-06-18	<2
T22_ANNUAL_RUNS	STONE_DAM_SURF	2016-06-14	<2
T22_ANNUAL_RUNS	STONE_DAM_SURF	2017-06-19	<2
T22_ANNUAL_RUNS	STONE_DAM_SURF	2018-06-18	2.47
T22_ANNUAL_RUNS	STONE_DAM_SURF	2019-06-17	<2
T22_ANNUAL_RUNS	STONE_DAM_SURF	2020-07-21	<2
T22_ANNUAL_RUNS	STONE_DAM_SURF	2021-06-29	<2
T22_ANNUAL_RUNS	PIL_SURF	2016-06-14	<2
T22_ANNUAL_RUNS	PIL_SURF	2017-06-19	<2
T22_ANNUAL_RUNS	PIL_SURF	2018-06-18	<2
T22_ANNUAL_RUNS	PIL_SURF	2019-06-17	3.02
T22_ANNUAL_RUNS	PIL_SURF	2020-07-21	<2
T22_ANNUAL_RUNS	PIL_SURF	2021-06-22	<2
GROUNDWATER SF CITY			
T22_ANNUAL_RUNS	LK_MERCED_S	2016-06-20	<2
T22_ANNUAL_RUNS	LK_MERCED_S	2017-06-19	<2
T22_ANNUAL_RUNS	LK_MERCED_S	2020-07-14	<2
T22_ANNUAL_RUNS	SF_ZOO_WELL_5	2016-06-14	8.06
T22_ANNUAL_RUNS	SF_ZOO_WELL_5	2017-06-19	30.6
SFGW_HISTORICAL	SFGW-LMW	2017-06-14	9
SFGW_1ST-YR	SFGW-LMW	2018-01-11	6.71
SFGW_1ST-YR	SFGW-GCW	2018-03-06	17.4
SFGW_1ST-YR	SFGW-SSW	2018-03-06	10.3
SFGW_1ST-YR	SFGW-WSW	2018-03-08	6.46
SFGW_1ST-YR	SFGW-SSW	2018-06-12	28.6
SFGW_1ST-YR	SFGW-GCW	2018-06-12	19
SFGW_1ST-YR	SFGW-WSW	2018-06-12	7.53
SFGW_1ST-YR	SFGW-SSW	2018-09-18	16.9
SFGW_1ST-YR	SFGW-WSW	2018-09-18	10.7
SFGW_1ST-YR	SFGW-GCW	2018-09-18	14.3
SFGW_1ST-YR	SFGW-SSW	2018-12-11	13.4
SFGW_1ST-YR	SFGW-GCW	2018-12-11	30.3
SFGW_1ST-YR	SFGW-WSW	2018-12-11	10.4

Rasprojectno_(Project_ID)	ClSampNo	Date	Zinc, Zn µg/L
SFGW_1ST-YR	SFGW-NLW	2020-07-16	18.7
SFGW_1ST-YR	SFGW-SWW	2020-07-20	27.4
GSR_1ST-YR	GSR-PDW	2020-07-07	<2
GSR_1ST-YR	GSR-HBW	2020-07-07	<2
GSR_1ST-YR	GSR-CBW	2020-07-08	<2
GSR_1ST-YR	GSR-MYW	2020-07-08	2.34
GSR_1ST-YR	GSR-FSW	2020-07-08	<2
GSR_1ST-YR	GSR-BSW	2021-07-14	<2
GSR_1ST-YR	GSR-SBW	2021-08-18	5.49
SFGW_RUNS	SFGW-SSW	2019-06-17	14.6
SFGW_RUNS	SFGW-LMW	2019-06-17	7.99
SFGW_RUNS	SFGW-WSW	2019-06-17	9.22
SFGW_RUNS	SFGW-GCW	2019-06-17	14.6
SFGW_RUNS	SFGW-SSW	2020-07-14	9.42
SFGW_RUNS	SFGW-LMW	2020-07-14	6.12
SFGW_RUNS	SFGW-WSW	2020-07-15	16
SFGW_RUNS	SFGW-GCW	2020-07-15	11.6
SFGW_RUNS	SFGW-WSW	2021-07-13	12.3
SFGW_RUNS	SFGW-SSW	2021-07-13	18
SFGW_RUNS	SFGW-LMW	2021-07-13	10.5
SFGW_RUNS	SFGW-GCW	2021-07-20	9.79
SFGW_RUNS	SFGW-NLW	2021-07-20	10.5
SFGW_RUNS	SFGW-SWW	2021-07-20	14.5
GROUNDWATER PENINSULA			
GSR_RUNS	GSR-MYCP	2021-07-07	<2
GSR_RUNS	GSR-MYW	2021-07-07	<2
GSR_RUNS	GSR-HBW	2021-07-08	2.08
GSR_RUNS	GSR-PDW	2021-07-08	<2
GSR_RUNS	GSR-FSW	2021-07-14	<2
GSR_RUNS	GSR-CBW	2021-07-14	<2
GSR_RUNS	GSR-FSCP	2021-08-12	<2
GSR_PRE-COMP	GSR-PDWLGWLGW	2019-06-24	<2
GSR_PRE-COMP	GSR-SBW	2019-06-24	2.41
GSR_PRE-COMP	GSR-HBW	2019-06-24	<2
GSR_PRE-COMP	GSR-MSW	2019-06-25	<2
GSR_PRE-COMP	GSR-MYW	2019-06-25	5.34
GSR_PRE-COMP	GSR-SDW	2019-06-25	2.9
GSR_PRE-COMP	GSR-CBW	2019-06-26	<2
GSR_PRE-COMP	GSR-FSW	2019-06-26	<2
GSR_PRE-COMP	GSR-BSW	2019-06-26	<2
GSR_PARTNER	GSR-SMW	2016-02-17	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Zinc, Zn µg/L
GSR_HISTORICAL	GSR-SDW	2020-08-05	4.45
GSR_PARTNER	GSR-BFW	2020-08-12	<2
GSR_PARTNER	GSR-LPW	2020-08-26	<2
GW_EVAL	Forest Hill Station	2016-09-13	<0.3
BA_HILLSBOROUGH_SPECIAL	SPECIAL	2017-07-31	30.9
BA_SFO_SPECIAL	SPECIAL	2018-05-31	18
BA_SFO_SPECIAL	SPECIAL	2018-05-31	20.2
BA_REDWOOD_C_SPECIAL	SPECIAL	2018-07-05	2.8
GROUNDWATER EAST BAY			
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2016-06-14	<2
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2016-06-14	<2
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2017-06-19	<2
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2017-06-19	<2
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2018-06-18	<2
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2018-06-18	<2
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2019-06-17	<2
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2019-06-26	<2
T22_ANNUAL_RUNS	PLEAS_W_F_A_(N)	2020-06-16	<2
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2020-06-16	<2
T22_ANNUAL_RUNS	PLEAS_W_F_B_(S)	2021-06-23	<2
T22_ANNUAL_RUNS	SUNOL_FILTER	2016-06-14	<2
T22_ANNUAL_RUNS	SUNOL_FILTER	2017-06-19	<2
T22_ANNUAL_RUNS	SUNOL_FILTER	2018-06-18	9.14
DRINKING WATER			
T22_ANNUAL_RUNS	OSH_TK	2016-06-15	8.74
T22_ANNUAL_RUNS	OSH_TK	2017-06-19	4.54
T22_ANNUAL_RUNS	OSH_TK	2018-06-19	4.9
T22_ANNUAL_RUNS	OSH_TK	2019-06-18	5.3
T22_ANNUAL_RUNS	OSH_TK	2020-06-16	7.53
T22_ANNUAL_RUNS	OSH_TK	2021-07-14	<2
T22_ANNUAL_RUNS	MOC_TK	2016-06-15	<2
T22_ANNUAL_RUNS	MOC_TK	2017-06-20	<2
T22_ANNUAL_RUNS	MOC_TK	2018-06-18	<2
T22_ANNUAL_RUNS	MOC_TK	2019-06-18	<2
T22_ANNUAL_RUNS	MOC_TK	2020-06-15	<2
T22_ANNUAL_RUNS	MOC_TK	2021-07-14	<2
T22_ANNUAL_RUNS	EI_TK	2016-06-14	2.16
T22_ANNUAL_RUNS	EI_TK	2017-06-19	<2
T22_ANNUAL_RUNS	EI_TK	2018-06-19	2.29
T22_ANNUAL_RUNS	EI_TK	2019-06-19	<2
T22_ANNUAL_RUNS	EI_TK	2020-06-23	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Zinc, Zn µg/L
T22_ANNUAL_RUNS	EI_TK	2021-07-14	<2
T22_ANNUAL_RUNS	ALAMEDA_EAST	2016-06-14	<2
T22_ANNUAL_RUNS	ALAMEDA_EAST	2017-06-19	<2
T22_ANNUAL_RUNS	ALAMEDA_EAST	2018-06-18	<2
T22_ANNUAL_RUNS	ALAMEDA_EAST	2019-06-17	<2
T22_ANNUAL_RUNS	ALAMEDA_EAST	2020-06-15	<2
T22_ANNUAL_RUNS	ALAMEDA_EAST	2021-06-22	<2
T22_ANNUAL_RUNS	SVWTP_EFF	2016-06-14	<2
T22_ANNUAL_RUNS	SVWTP_EFF	2017-06-19	<2
T22_ANNUAL_RUNS	SVWTP_EFF	2018-06-28	<2
T22_ANNUAL_RUNS	SVWTP_EFF	2019-06-17	<2
T22_ANNUAL_RUNS	SVWTP_EFF	2020-06-24	<2
T22_ANNUAL_RUNS	SVWTP_TWR_EFF	2021-06-15	<2
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	2016-06-14	<2
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	2017-06-19	<2
T22_ANNUAL_RUNS	SUNOL_FLOWER_ST	2021-06-22	<2
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2016-06-21	<2
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2017-06-19	<2
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2018-06-18	<2
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2019-07-02	<2
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2020-06-15	<2
T22_ANNUAL_RUNS	HTWTP_EFF_POST	2021-06-16	<2
T22_ANNUAL_RUNS	CS#2_BADEN	2016-06-14	<2
T22_ANNUAL_RUNS	CS#2_BADEN	2017-06-19	<2
T22_ANNUAL_RUNS	CS#2_BADEN	2018-06-18	<2
T22_ANNUAL_RUNS	CS#2_BADEN	2019-06-17	<2
T22_ANNUAL_RUNS	CS#2_BADEN	2020-06-16	<2
T22_ANNUAL_RUNS	CS#2_BADEN	2021-06-16	<2
DS_GW_CCM	CS#2_BADEN	2016-08-22	<2
DS_GW_CCM	CS#2_BADEN	2016-09-19	<2
DS_GW_CCM	CS#2_BADEN	2016-10-17	<2
DS_GW_CCM	CS#2_BADEN	2017-02-27	<2
DS_GW_CCM	SA#2_BADEN	2016-08-22	<2
DS_GW_CCM	SA#3_BADEN	2016-08-22	<2
DS_GW_CCM	SA#2_BADEN	2016-09-19	<2
DS_GW_CCM	SA#3_BADEN	2016-09-19	<2
DS_GW_CCM	SA#2_BADEN	2016-10-17	<2
DS_GW_CCM	SA#3_BADEN	2016-10-17	<2
DS_GW_CCM	SA#2_BADEN	2017-02-27	<2
DS_GW_CCM	SA#3_BADEN	2017-02-27	<2
DS_GW_CCM	SSL_BADEN	2016-08-22	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Zinc, Zn µg/L
DS_GW_CCM	SSL_BADEN	2016-09-19	<2
DS_GW_CCM	SSL_BADEN	2016-10-17	<2
DS_GW_CCM	SSL_BADEN	2017-02-27	<2
CRP	SSO#2_S	2020-02-23	<2
DS_GW_CCM	CHS#03	2016-08-22	<2
DS_GW_CCM	CHS#03	2016-09-19	<2
DS_GW_CCM	CHS#03	2016-10-17	<2
DS_GW_CCM	CHS#03	2017-02-27	<2
DS_GW_CCM	HPS	2016-08-22	<2
DS_GW_CCM	HPS	2016-09-19	<2
DS_GW_CCM	HPS	2016-10-17	<2
DS_GW_CCM	HPS	2017-02-27	<2
DS_GW_CCM	LS	2016-08-22	<2
DS_GW_CCM	LS	2016-09-19	<2
DS_GW_CCM	LS	2016-10-17	<2
DS_GW_CCM	LS	2017-02-27	<2
DS_GW_CCM	MCS#02	2016-08-22	<2
DS_GW_CCM	MCS#02	2016-09-19	<2
DS_GW_CCM	MCS#02	2016-10-17	<2
DS_GW_CCM	MCS#02	2017-02-27	<2
DS_GW_CCM	MMS#02	2016-08-22	<2
DS_GW_CCM	MMS#02	2016-09-19	<2
DS_GW_CCM	MMS#02	2016-10-17	<2
DS_GW_CCM	MMS#02	2017-02-27	<2
DS_GW_CCM	PHS	2016-08-22	<2
DS_GW_CCM	PHS	2016-09-19	<2
DS_GW_CCM	PHS	2016-10-17	<2
DS_GW_CCM	PHS	2017-02-27	<2
DS_GW_CCM	SHS#01	2016-08-22	<2
DS_GW_CCM	SS#05	2016-08-22	<2
DS_GW_CCM	SHS#01	2016-09-19	<2
DS_GW_CCM	SHS#01	2016-10-17	<2
DS_GW_CCM	SHS#01	2017-02-27	<2
DS_GW_CCM	SS#05	2016-09-19	<2
DS_GW_CCM	SS#05	2016-10-17	<2
DS_GW_CCM	SS#05	2017-02-27	<2
DS_GW_CCM	SSO#1_N	2016-08-22	<2
DS_GW_CCM	SSO#1_N	2016-09-19	<2
DS_GW_CCM	SSO#1_N	2016-10-17	<2
DS_GW_CCM	SSO#1_N	2017-02-27	<2
DS_GW_CCM	SSO#2_S	2016-08-22	<2

Rasprojectno_(Project_ID)	ClSampNo	Date	Zinc, Zn µg/L
DS_GW_CCM	SSO#2_S	2016-09-19	<2
DS_GW_CCM	SSO#2_S	2016-10-17	<2
DS_GW_CCM	SSO#2_S	2017-02-27	<2
DS_GW_CCM	SUMS	2016-08-22	<2
DS_GW_CCM	SUMS	2016-09-19	<2
DS_GW_CCM	SUMS	2016-10-17	<2
DS_GW_CCM	SUMS	2017-02-27	<2
DS_GW_CCM	SUTS#06	2016-08-22	<2
DS_GW_CCM	SUTS#06	2016-09-19	<2
DS_GW_CCM	SUTS#06	2016-10-17	<2
DS_GW_CCM	SUTS#06	2017-02-27	<2
DS_GW_CCM	UMS#04	2016-08-22	<2
DS_GW_CCM	UMS#04	2016-09-19	<2
DS_GW_CCM	UMS#04	2016-10-17	<2
DS_GW_CCM	UMS#04	2017-02-27	<2
SFGW_RUNS	SSO#1_N	2019-06-17	<2
SFGW_RUNS	SSO#1_N	2020-07-09	<2
SFGW_RUNS	SSO#2_S	2020-07-09	<2
SFGW_RUNS	SSO#1_N	2021-07-13	<2
EAST BAY SURFACE WATER FIRE MONITORING			
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2020-11-04	1.08
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2020-11-04	<0.368
EBAY_RES_FIRE_MONITORING	San Antonio Creek - Upstream	2020-11-04	<0.368
EBAY_RES_FIRE_MONITORING	Indian Creek - Upstream	2020-11-04	0.388
EBAY_RES_FIRE_MONITORING	SNT-1	2020-11-04	<0.368
EBAY_RES_FIRE_MONITORING	Apperson Creek	2020-11-04	0.374
EBAY_RES_FIRE_MONITORING	CR-4	2020-11-04	<0.368
EBAY_RES_FIRE_MONITORING	CR-1	2020-11-04	2.04
EBAY_RES_FIRE_MONITORING	SNT-4	2020-11-04	<0.368
EBAY_RES_FIRE_MONITORING	CR-1	2020-12-15	1.57
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2020-12-15	<0.368
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2020-12-15	1.18
EBAY_RES_FIRE_MONITORING	CR-4	2020-12-15	0.412
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2021-01-05	<0.368
EBAY_RES_FIRE_MONITORING	CR-4	2021-01-05	0.657
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2021-01-05	<0.368
EBAY_RES_FIRE_MONITORING	CR-1	2021-01-05	0.422
EBAY_RES_FIRE_MONITORING	SNT-4	2021-01-06	0.643
EBAY_RES_FIRE_MONITORING	Indian Creek - Upstream	2021-01-06	6.82
EBAY_RES_FIRE_MONITORING	Apperson Creek	2021-01-06	0.611
EBAY_RES_FIRE_MONITORING	SNT-1	2021-01-06	<0.368

Rasprojectno_(Project_ID)	ClSampNo	Date	Zinc, Zn µg/L
EBAY_RES_FIRE_MONITORING	San Antonio Creek - Upstream	2021-01-06	3.16
EBAY_RES_FIRE_MONITORING	SNT-1	2021-01-28	0.413
EBAY_RES_FIRE_MONITORING	San Antonio Creek - Upstream	2021-01-28	1.41
EBAY_RES_FIRE_MONITORING	Indian Creek - Upstream	2021-01-28	<0.368
EBAY_RES_FIRE_MONITORING	Apperson Creek	2021-01-28	<0.368
EBAY_RES_FIRE_MONITORING	SNT-4	2021-01-28	<0.368
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2021-02-01	1.49
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2021-02-01	2.69
EBAY_RES_FIRE_MONITORING	CR-1	2021-02-01	0.904
EBAY_RES_FIRE_MONITORING	CR-4	2021-02-01	0.37
EBAY_RES_FIRE_MONITORING	Indian Creek - Upstream	2021-02-02	1.55
EBAY_RES_FIRE_MONITORING	SNT-4	2021-02-02	<0.368
EBAY_RES_FIRE_MONITORING	Apperson Creek	2021-02-02	0.381
EBAY_RES_FIRE_MONITORING	SNT-1	2021-02-02	0.815
EBAY_RES_FIRE_MONITORING	San Antonio Creek - Upstream	2021-02-02	1.2
EBAY_RES_FIRE_MONITORING	CR-1	2021-02-16	<0.368
EBAY_RES_FIRE_MONITORING	CR-4	2021-02-16	<0.368
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2021-02-16	<0.368
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2021-02-16	0.422
EBAY_RES_FIRE_MONITORING	SNT-4	2021-03-08	0.489
EBAY_RES_FIRE_MONITORING	SNT-1	2021-03-08	<0.368
EBAY_RES_FIRE_MONITORING	San Antonio Creek - Upstream	2021-03-08	0.64
EBAY_RES_FIRE_MONITORING	Indian Creek - Upstream	2021-03-08	0.371
EBAY_RES_FIRE_MONITORING	Apperson Creek	2021-03-08	<0.368
EBAY_RES_FIRE_MONITORING	CR-4	2021-03-09	<0.368
EBAY_RES_FIRE_MONITORING	CR-1	2021-03-09	<0.368
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2021-03-09	<0.368
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2021-03-09	<0.368
EBAY_RES_FIRE_MONITORING	CR-1	2021-03-17	<0.368
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2021-03-17	<0.368
EBAY_RES_FIRE_MONITORING	CR-4	2021-03-17	<0.368
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2021-03-17	<0.368
EBAY_RES_FIRE_MONITORING	SNT-4	2021-03-23	<0.368
EBAY_RES_FIRE_MONITORING	SNT-1	2021-03-23	<0.368
EBAY_RES_FIRE_MONITORING	Indian Creek - Upstream	2021-03-23	<0.368
EBAY_RES_FIRE_MONITORING	Apperson Creek	2021-03-23	<0.368
EBAY_RES_FIRE_MONITORING	San Antonio Creek - Upstream	2021-03-23	<0.368
EBAY_RES_FIRE_MONITORING	CR-4	2021-03-24	<0.368
EBAY_RES_FIRE_MONITORING	CR-1	2021-03-24	<0.368
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2021-03-24	<0.368
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2021-03-24	0.489

Rasprojectno_(Project_ID)	ClSampNo	Date	Zinc, Zn µg/L
EBAY_RES_FIRE_MONITORING	SNT-1	2021-04-19	0.463
EBAY_RES_FIRE_MONITORING	Indian Creek - Upstream	2021-04-19	0.413
EBAY_RES_FIRE_MONITORING	SNT-4	2021-04-19	0.576
EBAY_RES_FIRE_MONITORING	San Antonio Creek - Upstream	2021-04-19	0.544
EBAY_RES_FIRE_MONITORING	Apperson Creek	2021-04-19	<0.368
EBAY_RES_FIRE_MONITORING	CR-4	2021-04-20	<0.368
EBAY_RES_FIRE_MONITORING	Calaveras Creek - Below Dam	2021-04-20	<0.368
EBAY_RES_FIRE_MONITORING	CR-1	2021-04-20	0.385
EBAY_RES_FIRE_MONITORING	Arroyo Hondo - Upstream	2021-04-20	0.595

Zinc, EPA 200.8 Method

Water Quality Division, Technical Review 2016-2021

Contaminants of Emerging Concern (CEC) in Drinking Water

Inorganics

Inorganics are naturally existing elements, which can be found in Earth's water and rock layers. Most water supplies will contain trace amounts of inorganics, can have adverse effects on human health when more than the recommended dietary amount is present in groundwater (Michigan Environmental Council, 2017). Taste and odor in drinking water can result from naturally occurring inorganics; from biological activity, either in the source, treatment process or distribution system; as a by-product of water treatment processes; or from chemical contamination at any point from source to tap (Australian Drinking Water Guidelines, 2021).

OCCURRENCE AND HEALTH EFFECTS

Utilities understand the influence inorganics can have on water quality. Depending on the specific contaminant, inorganics can increase risk to human health, cause unacceptable aesthetic issues, adversely affect treatment processes, and accumulate in distribution systems (Brandhuber, 2022).

Adverse health effects of overconsumption of specific inorganics may affect the liver, kidney, nervous system, circulatory system, blood, gastrointestinal system, bones, or skin depending upon the inorganic compound and level of exposure (Michigan Environmental Council, 2017). These contaminants are either unregulated in the United States, subject to changing regulation, or inadequately regulated. (Brandhuber, 2022). Inorganics, which have undergone regulatory evaluation are listed in Table 6-2 in Monitoring Review.

A brief description of each inorganics in given below:

Boron

Boron gets into drinking water from both naturally occurring and man-made sources. Some areas in the western United States (California, Nevada, Oregon) have high concentrations of boron in some of their soils (USEPA, 2014).

Health Effects of Boron Overdose

An acute overdose to infants has caused diarrhea, vomiting, signs of irritability, erythema in the diaper area, a mild red rash on the face and neck, a pus-like discharge or mild congestion of the eye, and possibly convulsive seizures. In adults, an acute overdose causes nausea, vomiting, redness of the skin, difficulty swallowing due to ulcers in the throat, and a non-bloody diarrhea (USEPA, 2014).

Cadmium

Cadmium is an element found naturally in the earth's crust and soil. It is used in batteries, paints, pigments, coatings and some types of inexpensive jewelry. A low level of cadmium is found naturally in surface and groundwater throughout the United States. Higher levels of cadmium in water can result from the use and disposal of items containing cadmium. For example, water draining from a landfill could have higher levels of cadmium. Low level exposure to cadmium decreases bone density and disrupts bone composition. Rapidly growing bones are the most sensitive to these effects, so children are at an increased risk. Cadmium does not easily leave our bodies and tends to build up in the kidney. As a result, both shorter, higher exposures and lifetime low level exposures to cadmium can cause kidney disease in older adults. Although cadmium can cause cancer when inhaled, there is little evidence to support that it can cause cancer when ingested (Minnesota DH, 2014).

Chromium (VI)

Chromium-6 can occur naturally in the environment from the erosion of chromium deposits. It also is produced through industrial processes and when used in electroplating, pigments manufacture, corrosion control and other manufacturing activities. Chromium-6 also can be produced when chromium-3 is oxidized into chromium-6 during disinfection at WTP. It is a known that when some forms of chromium-6 are inhaled, they can cause cancer (ACWA, 2017).

Cr (VI) is a Human Carcinogen by Inhalation

Hexavalent chromium is classified as a known human carcinogen by inhalation routes of exposure. Decades of epidemiological studies have shown that occupational exposure of workers in various industries (electroplating, chrome pigment, mining, leather tanning, and chrome alloy production) to airborne hexavalent chromium posed increased risks of lung cancer (WRF, Brandhuber, 2017a).

A study analyzed two national datasets and extensive data from California found that total chromium is distributed around the U.S., with the highest concentrations found in the southwestern U.S. The study also found no significant difference in total chromium distribution in groundwaters versus surface waters, and that most total chromium in groundwater is hexavalent chromium (WRF, Brandhuber, 2017a).

No MCL for Cr (VI)

Sources of chromium within the distribution system are of interest to utilities. Understanding the fate of chromium, particularly in the distribution system, is critical to the decision of where to regulate Cr(VI): at the entry point or at some point in the distribution system. Water leaving a treatment plant may be in compliance with USEPA regulations regarding total chromium or likely future California's regulation regarding Cr(VI) but can corrosion of distribution system components release sufficient chromium into solution to significantly impact the level of chromium, and in particular Cr(VI), in water at the tap (WRF, Woods-Chabane, 2016a).

Cobalt

Cobalt is a natural element found throughout the environment; the general population may be exposed to cobalt in the air, drinking water, and food. Cobalt is used to make superalloys (alloys that maintain their strength at high temperatures approaching their melting points) and in pigment manufacture. Acute (short-term) exposure to high levels of cobalt by inhalation in humans and animals results in respiratory effects, such as a significant decrease in ventilatory function, congestion, edema, and hemorrhage of the lung. Respiratory effects are also the major effects noted from chronic (long-term) exposure to cobalt by inhalation, with respiratory irritation, wheezing, asthma, pneumonia, and fibrosis noted. Cardiac effects, congestion of the liver, kidneys, and conjunctiva, and immunological effects have also been noted in chronically exposed humans. Cobalt is an essential element in humans, as a constituent of vitamin B 12 (USEPA, 2016).

Human studies are inconclusive regarding inhalation exposure to cobalt and cancer, and the one available oral study did not report a correlation between cobalt in the drinking water and cancer deaths. EPA has not classified cobalt for carcinogenicity (USEPA, 2016).

Germanium

Germanium is a rare element but is present in trace quantities in most rock types because of its affinity for iron- and organic-bearing materials. Germanium is a semiconducting metalloid with electrical properties between those of a metal and an insulator (USGS, 2015).

Germanium is an essentially nontoxic element, with the exception of only a few compounds. However, if dissolved concentrations in drinking water are as high as 1 mg/L chronic diseases may occur (USGS, 2015). Germanium can cause harm to the kidney, liver, peripheral nervous system, cause anemia, muscle weakness (EWG, 2021).

The major use of germanium worldwide is for fiber-optic systems. The leading domestic use of germanium is for the production of infrared optical lenses and windows. Infrared imaging devices are used extensively by the military and law enforcement agencies for surveillance, reconnaissance, and target acquisition applications (USGS, 2015).

Lithium

Lithium is an alkali metal that occurs naturally in some groundwater where that groundwater interacts with lithium-containing minerals or saline water. Although useful for treating mental health disorders, pharmaceutical use of lithium at all therapeutic dosages can cause adverse health effects—primarily impaired thyroid and kidney function (USGS, 2021b).

Health Based Screening Level for Lithium

The USGS, in collaboration with the EPA, calculated a nonregulatory Health-Based Screening Level (HBSL) for drinking water of 10 micrograms per liter (µg/L) to provide context for evaluating lithium concentrations in groundwater. It is assumed that the only source of lithium exposure is from drinking water (other sources of lithium include eggs, dairy products, and beverages such as soft drinks and beer). USGS study reports that about 45% of public-supply wells and about 37% of U.S. domestic supply wells have concentrations of lithium that could present a potential human-health risk (USGS, 2021b).

Manganese (Mn)

Manganese is widely present and whose undesirable effects are still becoming understood. Manganese in drinking water is not a new challenge. Manganese often co-occurs with iron but could discolor water even when iron is not present. Recent research has demonstrated that manganese can have many adverse consequences on lead corrosion, including the following (Brandhuber, 2022):

- Manganese promotes formation of less stable and more amorphous lead scales.
- Manganese oxides can scavenge and transport lead associated with particulate manganese.

- Manganese can promote the release of soluble lead.
- Sequestrants used to prevent manganese discoloration of water can destabilize lead scales.
- Taken together, systems with lead service lines or other lead sources will find it more difficult to manage lead concentrations at the tap when elevated levels of manganese are present.

Health vs Aesthetic Effect of Manganese

Mn that has accumulated within distribution systems, can cause a number of problems for water utilities and their customers. Historically, Mn has been perceived as a nuisance contaminant because of its tendency to degrade aesthetic water quality when concentrations exceed 0.015–0.02 mg/L. Many utilities' perception of whether they have a "Mn problem" is based on customer complaints about color, staining, and/or taste. The perception that Mn is purely an aesthetic issue is consistent with the USEPA 2003 determination that the "regulation of Mn in drinking water does not present a meaningful opportunity for health risk reduction." In other words, the presence of Mn at levels typically present in drinking water is not a health concern. Emerging research suggests that Mn exposure from drinking water can cause adverse health effects (WRF, Brandhuber, 2015b).

A utility survey results indicated over half of the participating utilities had experienced discolored water episodes in their distribution systems, ranging from 1 to 45 episodes per year. Approximately, one quarter of these discolored water episodes occur in the parts of the distribution system that are more vulnerable to Mn accumulation and/or release.

Flushing the distribution system pipelines near the discolored episode location appears to be the most accepted response plan for the utilities (WRF, Brandhuber, 2015b).

Possible Adverse Neurological Effects of Manganese in Children

In the 2000s, a series of epidemiological studies of North American populations exposed to plausible levels of manganese in drinking water observed adverse neurological effects in school-aged children. These effects include the following (Brandhuber, 2022):

- Increased hyperactivity.
- Impaired intellectual development.
- Decreased memory and motor function.

Molybdenum

While low levels of molybdenum are required to maintain health, high levels may cause health effects. Studies in research animals have shown that eating or drinking high levels of molybdenum can damage the kidneys and liver and affect reproduction and development. Studies have also shown that breathing air with high levels of molybdenum can damage the inside of the nose and cause lung cancer. There are no federal or state drinking water standards for molybdenum (Wisconsin, DHS, 2021). There is USEPA DWEL of 0.2 mg/L for Molybdenum.

Molybdenum is a naturally occurring metal that is essential for life. It is found in small amounts in soil rocks, and water. Molybdenum is used to make cast iron, stainless steel, biofuels, solar panels, catalysts, lubricants, and pigments (Wisconsin, DHS, 2021).

Strontium

Strontium occurs naturally in some minerals, including calcium carbonate. If strontium-containing minerals are present in soils, sediments, and rocks, strontium is released to groundwater as those minerals dissolve. Elevated levels of strontium in groundwater were found primarily in samples of untreated groundwater from drinking-water wells that tap carbonate-rock aquifers, such as in southern Florida and central Texas (USGS, 2021c).

Strontium is under consideration by the U.S. Environmental Protection Agency for regulation; currently it has a non-regulatory Health-Based Screening Level of 4,000 µg/L. Elevated strontium concentrations can adversely affect bone development and mineralization. A new USGS study reports that about 2.3 percent of drinking-water wells in the U.S. have concentrations of strontium at levels that present a potential human health risk. These wells provide water for an estimated 2.3 million people (USGS, 2021c).

Tungsten

Tungsten is a naturally occurring element that exists in the form of minerals, but typically not as a pure metal. Tungsten in the form of finely divided powder is highly flammable and may ignite spontaneously on contact with air. Powdered tungsten may also cause fire or explosion on contact with oxidants. Tungsten-based products have been used in a wide range of applications ranging from common household products to highly specialized components of science and technology. Tungsten may be present in the environment as a result of mining, weathering of rocks, burning of coal and municipal solid waste, land application of fertilizers or industrial applications. Studies indicate that an elevated pH in soil may increase the solubility of tungsten and cause it to leach more readily into the groundwater table (USEPA, 2017).

Symptoms of tungsten exposure can include irritation of the eyes, skin and respiratory system, diffuse pulmonary fibrosis, loss of appetite, nausea, cough and blood changes. Recent studies found evidence for bioaccumulation of tungsten in plants from soil, implying the potential for trophic transfer into the terrestrial food web (USEPA, 2017).

There is not enough information to determine whether inhalation, oral, or dermal exposure to tungsten or tungsten compounds can cause cancer in humans. Tungsten has not been classified for carcinogenic effects by the Department of Health and Human Services (DHHS), the International Agency for Research on Cancer (IARC), or the EPA (ATSDR, 2014).

Vanadium

Vanadium is a naturally occurring element and is widely distributed in the earth's crust. Vanadium is naturally released into water and soil as a result of weathering of rock and soil erosion (HDOH, 2014). Vanadium is used in producing rust-resistant, spring, and high-speed tool steels. It is an important carbide stabilizer in making steels (ATSDR, 2012). The general population is exposed to vanadium in food, drinking water, and vitamins. Higher levels of vanadium can be found in seafood such as oysters, wild mushrooms and some nutritional food supplements. It is also found in coal and crude oil and in lower amounts in some types of fertilizers (HDOH, 2014).

According to the Agency for Toxic Substances and Disease Registry (ATSDR), "exposure to the levels of vanadium naturally present in food and water are not considered to be harmful." Studies in humans who have been exposed to large amounts of vanadium reported minor complaints such as stomach cramps (HDOH, 2014).

White Phosphorus

White phosphorus is used mainly for producing phosphoric acid and other chemicals. These chemicals are used to make fertilizers, additives in foods and drinks, cleaning compounds, and other products. In the military, white phosphorus is used in ammunitions such as mortar and artillery shells, and grenades. White phosphorus enters the environment when industries make it or use it to make other chemicals and when the military uses it as ammunition. It also enters the environment from spills during storage and transport. Rainwater washout from these sites may contaminate nearby waterways and their bottom deposits. Hazardous waste sites that contain white phosphorus are also potential sources of exposure to people. Breathing in white phosphorus can cause cough or a condition known as phossy jaw that involves poor wound healing in the mouth and a breakdown of the jawbone. Ingesting a small amount of white phosphorus (less than one teaspoon), may cause stomach cramps, vomiting, liver, heart, or kidney damage; drowsiness or even death (CDC, 2014).

Zinc

Zinc is a metal emitted to the environment from a variety of natural and anthropogenic sources. In urban runoff, zinc levels are commonly elevated resulting in zinc impairments in California water bodies (SWRCB, 2019).

While zinc concentrations in urban runoff do not generally, pose a threat to human health, concentrations above established water quality objectives can be toxic to aquatic organisms (SWRCB, 2019).

Others

Exotic trace elements used in new high-tech applications, such as Gadolinium (Gd), are emerging contaminants in San Francisco Bay and that anthropogenic Gd concentrations increased substantially over a 20- year period. As emerging contaminants, there is still relatively little knowledge of the biogeochemical or anthropogenic cycles of Rare Earth Elements (REE), including Gd, in the environment (Hatje et.al., 2016).

A 2005 study (Lee and Helsel) evaluated nationwide data on potable groundwater aquifers. For unregulated metals included in the study (cobalt, molybdenum, and zinc), 95th percentile concentrations were 1.0, 11, and 206 ug/L, respectively. Guideline values available for molybdenum (200 ug/L USEPA DWEL) and zinc (2,000 ug/L USEPA HAL) are much higher. Similarly, occurrence data for strontium indicate levels typically much lower than the USEPA HAL (4,000 ug/L) (Eaton, 2013). For regulated metals, concentrations were nearly always below MCLs, except for arsenic (which has a 7% chance of exceeding the MCL in groundwater). Together these data indicate for most metals in US potable groundwaters do not pose a significant health risk.

A second groundwater survey published in 2011 found that concentrations of trace elements in groundwater, including unregulated metals are highly variable in the United States, primarily due to varying geological composition (Ayotte, 2011). For unregulated metals, the 90th percentile concentrations observed were 220 µg/L (boron), 1.1 µg/L (cobalt), 360 µg/L (manganese), 8.0 µg/L (molybdenum), 1,700 µg/L (strontium) and 27 µg/L (vanadium). Again, guideline values for these metals are much higher.

Detection Methods

Reliable analytical methods are available for several unregulated inorganics, and can be found at USEPA website: https://www.epa.gov/dwanalyticalmethods/approved-drinking-water-analytical-methods.

REGULATORY DEVELOPMENTS

As regulations continue to evolve, water utilities throughout North America are devoting more planning resources to satisfy regulations and customer expectations associated with many of the inorganic contaminants. Some of the most common reasons are as follows (Shimabuku et.al., 2019):

- There's an ever-increasing need to use sources with more marginal water quality because of population growth, overconsumption of finite groundwater resources, prolonged droughts, and water supply extremes associated with climate change.
- Water systems that rely on groundwater can face an assortment of co-occurring contaminants, which can complicate treatment and increase its cost.
- Aquifer storage and recovery has led to the unintentional contamination of water pumped into some aquifers by contaminants such as arsenic.

There are several heavy metals found in United States drinking water that are naturally occurring and, human activities can increase the concentrations. The USEPA currently only regulates ten heavy metals in public water systems, while numerous metals remain unregulated, including cobalt, molybdenum, strontium, and vanadium (Thompson et.al., 2021). A federal drinking water standard has not been established for tungsten. Three states have standards for tungsten. Indiana is the only state that has soil and groundwater screening levels (IDEM 2016). North Carolina has preliminary soil remediation goals for tungsten. Texas has soil and groundwater protective concentration levels for sodium tungstate dihydride (USEPA, 2017)

California Notification Levels (SWRCB, 2021a):

- Boron – 1 mg/L
- Manganese – 0.5 mg/L
- Vanadium – 0.05 mg/L

Cr (VI) MCL of 10 µg/L was rescinded by SWRCB in 2017 after the court ruling. Hence, California does not have MCL for Cr (VI) yet, but the MCL for total Chromium is 50 µg/L, lower than USEPA's MCL at 100 µg/L. Regulation for Cr (VI) MCL is underway (SWRCB, 2021b).

Cadmium is listed on the proposed priority for regulatory development by SWRCB. The current cadmium MCL and DLR are 5 µg/L and 1 µg/L, respectively. OEHHA has issued a PHG of 0.04 µg/L, based on kidney toxicity. U.S. EPA's MCLG for cadmium is 5 µg/L (SWRCB, 2022).

Boron, Cobalt, Lithium, Manganese, Tungsten, Vanadium are listed in draft CCL5 (USEPA, 2021b). Lithium is also listed in UCMR5 (USEPA, 2022)

In 2019, Health Canada established a maximum acceptable concentration (the Canadian equivalent of the USEPA MCL) for manganese of 0.12 mg/L to protect children. Subsequently, the World Health Organization has proposed a health-based treatment objective for manganese of 0.08 mg/L (Brandhuber, 2022).

Health Canada has established MAC for Boron at 5 mg/L and for Strontium at 7 mg/L (Health Canada, 2017).

EU has established parametric values for the inorganics and metals in their directive 98/83/EC - the legal framework to protect human health from the adverse effects of any contamination of water intended for human consumption by ensuring that it is wholesome and clean. The parametric values can be found in Annex I (Part B and Part C) of their directive (EU, 2020).

Several metals, without MCLs, have Drinking Water Equivalent Levels (DWELs). For example, Boron has a DWEL of 7000 ug/L and Manganese has a DWEL of 1600 ug/L. Vanadium does not have a DWEL. Zinc has a USEPA Health Advisory Level (HAL) of 2,000 ug/L (Lee and Helsel, 2005) and strontium has a HAL 4,000 µg/L (Wisconsin DHS, 2011). The list of metals with MCLs and USEPA DWELs are presented in Table 6-2.

EPA requires industry to report spills of white phosphorus of more than 1 pound. White phosphorus levels in workplace air are regulated by the Occupational Safety and Health Administration (OSHA), and recommendations for safe levels have been made by the National Institute for Occupational Safety and Health (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH) (CDC, 2014).

TREATMENT

There are several treatment technologies to treat inorganics and metals.

Treatment of Chromium (VI)

There are numerous potential control points at which Cr(VI) could be effectively removedto reduce consumer exposure, including: 1) in-situ source water treatment to remove Cr(VI) from the influent water, 2) engineered treatment processes to remove Cr(III) and Cr(VI), 3) operation and maintenance of the water distribution system including secondary disinfectant residual type and dose, and 4) point of use devices. Ultimately, the effectiveness of each strategy and relative cost/benefits will be dependent on the source water chemistry, pre-existing treatment processes and facilities, chromium concentrations, water scarcity, residuals handling concerns, and the origins of the Cr(VI). The ultimate point of compliance for any Cr(VI) MCL (i.e., at the entry point to the distribution system vs. within the distribution network or at the tap) will also influence the treatment strategies. For example, if Cr(VI) at the tap was due to oxidation of Cr(III) in the distribution system, a treatment process to remove Cr(III) would have to be implemented (WRF, Brandhuber et.al., 2017a).

There has been considerable success applying "in situ" treatments to remove Cr(VI) in groundwater via injection of reducing agents to the aquifer, even in waters contaminated at the mg/L level. The added Fe(II) salts or reduced sulfur species, in conjunction with detention times on the order of days to years, can completely convert Cr(VI) to Cr(III). However, it is important to note that sufficient reductant must be added to account for other oxidants and that all other oxidants must also be scavenged by the Fe(II) to assure that the Cr(III) is not re-oxidized. Excess Fe(II) must also be controlled to avoid subsequent precipitation in finished water and plugging of pores by precipitated Fe(III). With levels of Cr(VI) over 100 µg/L, removal of the newly formed Cr(III) during subsequent treatment will also be of concern (WRF, Brandhuber et.al., 2017a).

Most work regarding Cr(VI) removal via engineered treatment processes has been conducted at California utilities. Studies have confirmed that treatment via reductive coagulation can easily obtain very low levels (< 5 µg/L) of Cr(VI) in water leaving the treatment plant. Other techniques, including membranes, weak base anion (WBA) exchange and strong base anion (SBA) exchange are also effective (WRF, Brandhuber, 2017a). WBA offers relatively simple, once-through treatment with a very high Cr(VI) capacity. SBA can be applied either as single-pass media or with periodic regeneration using salt brine solution. Regenerable SBA applicability is limited by the availability of brine disposal in many locations and may require trucking the brine waste offsite. SBA offers much lower throughput before replacement is needed, compared to WBA resin (one to two orders of magnitude), but does not require pH adjustment. Although not the best available technology, adsorptive media showed promise in Cr(VI) removal. Iron-based adsorptive media (sulfur-modified iron) had a higher capacity than SBA resins and other adsorptive media (WRF, Blute et.al., 2015a).

The WBA and SBA exchange processes are significantly simpler to implement and easier to operate for small systems that treat 2 MD or fewer compared to the other processes (WRF, Park et.al., 2017b).

Strong base anion exchange or reduction coagulation oxidation filtration for removal of Cr (VI) (Shimabuku et.al., 2019).

A study demonstrated effective use of Stannous Chloride to reduce Cr (VI) to trivalent Chromium followed by filtration (Kennedy et.al., 2018).

Treatment of Mn using Biofiltration

Drinking water biofiltration for manganese removal has been practiced in Europe intentionally for many years, though U.S. experience has been largely incidental. Indeed, biofiltration may be an effective strategy for Mn control that also achieves additional water treatment benefits through the simultaneous destruction of other contaminants, including disinfection byproduct formation potential (DBPFP), emerging contaminants, tastes and odors, and biological regrowth potential (WRF, Lauderdale et.al., 2016b).

Free chlorine residual in the filter influent promotes manganese (Mn) oxidation and precipitation on filter media. Although a portion of Mn precipitate is removed during filter backwash, a large fraction remains attached to the media. Biofiltration is gaining attention as an alternative filtration for the removal of Mn. The purpose of this process is to provide long-term water quality improvements in terms of taste and odor removal, disinfection, and effluent biostability. The potential of biofiltration as a sustainable Mn treatment process necessitates the development of a feasible method for the conversion of conventional chlorinated filters to biological filters with minimal impacts to treatment performance or finished water quality (WRF, Lauderdale et.al., 2016b).

The identification of such a strategy may (WRF, Lauderdale et.al., 2016b):

- Improve water quality.
- Reduce the conversion costs (i.e., avoid media replacement).
- Reduce disinfection by-products through reduced free chlorine usage and the biological removal of disinfection byproduct precursors.
- Provide utilities with a “green” treatment technology reliant on the natural processes responsible for Mn cycling.

The biofilters have limitations at temperature below 15 deg C, during which the removal of Mn decreases. When operating below 15 deg C, biofilters with granular activated carbon media, higher biofilter influent pH (i.e., 7.5 to 8.0), continuous operation (i.e., without shutdowns), and/or longer Empty Bed Contact Time (EBCT), greater than 8 minutes, removed more Mn. It is recommended that utilities operating or considering biofiltration frequently monitor Mn concentrations across all treatment processes, and if Mn is observed in the filter influent, to evaluate upstream control strategies and/or biofilter design and operating strategies to improve Mn control (WRF, Evans et.al., 2020).

The most commonly method used is oxidation followed by filtration for Mn (Shimabuku et.al., 2019).

WRF Recommendations to Utilities on Mn Management (WRF, Brandhuber et.al., 2015b)

Best management practices that can minimize Mn accumulation and reduce the potential for release episodes should be undertaken by a utility whether it has a legacy Mn problem or not. Therefore, as long as a utility has good treatment and distribution system operation and maintenance practices in place, the likelihood of significant Mn release episodes should be minimized. There are a variety of BMPs utilities can implement on a system-specific basis pertaining to main cleaning, source water and treatment optimization, distribution system monitoring, and hydraulic and pressure management.

A utility's goal should be to achieve the following (WRF, Brandhuber et.al., 2015b):

- Minimize Mn inventory in the distribution system.
- Minimize sources of Mn entering the distribution system.
- Minimize changes to distribution system water chemistry, particularly with respect to pH and ORP.
- Minimize physical and hydraulic disruptions to the distribution system.

Strontium and Tungsten Treatment

Conventional water treatment processes, such as coagulation/filtration, are largely ineffective at removing strontium from drinking water. However, water-softening treatments such as lime-soda ash or cation-exchange water softeners designed to reduce calcium concentrations also can decrease strontium concentrations (USGS, 2021c). Strontium can be effectively removed using chemical precipitation and cation exchange resins (WRF, Najm, 2016).

Treatment methods for tungsten in environmental media are currently under development. Methods under investigation include electrokinetic soil remediation and phytoremediation (USEPA, 2017).

Recommendations

- Continue groundwater monitoring for Cr (VI) and Mn.
- Continue blended water monitoring for Cr (VI) and Mn in San Francisco.
- Evaluate/implement treatment for Cr (VI) and Mn in Regional Wells.
- Continue the Chemical Quality Control Program (October 2010) at water treatment plants to minimize impurities in treatment chemicals (e.g. metals).
- Monitor inorganics listed in UCMR5 and draft CCL5 (Lithium).
- Continue to maintain source water protection and optimized multibarrier water treatment and distribution system operation.
- Track information on any Federal and State regulatory developments, especially for Cr (VI) in groundwater.

Table 6-14. Health Advisories for Inorganics (USEPA, 2018)

Chemicals	**CASRN Number**	**Standards**			**Status HA Document**	**Health Advisories**						**Cancer Descriptor**
		Status Reg.	**MCLG (mg/L)**	**MCL (mg/L)**		**10-kg Child**						
						One-day (mg/L)	**Ten-day (mg/L)**	**RfD (mg/kg/day)**	**DWEL (mg/L)**	**Life-time (mg/L)**	**mg/L at 10^{-4} Cancer Risk**	
					INORGANICS							
Ammonia	7664-41-7	-	-	-	D ‘92	-	-	-	-	30	-	D
Antimony	7440-36-0	F	0.006	0.006	F ‘92	0.01	0.01	0.0004	0.01	0.006	-	D
Arsenic	7440-38-2	F	zero	0.01	-	-	-	**0.0003**	0.01	-	**0.002**	A
Asbestos (fibers/l >10Fm length)	1332-21-4	F	7 MFL[1]	7 MFL	-	-	-	-	-	-	700-MFL	A[2]
Barium	7440-39-3	F	2	2	D ‘93	0.7	0.7	**0.2**	7	-	-	**N**
Beryllium	7440-41-7	F	0.004	0.004	F ‘92	30	30	**0.002**	0.07	-	-	-
Boron	7440-42-8	-	-	-	F ‘08	3	3	**0.2**	7	6	-	**I**
Bromate	7789-38-0	F	zero	0.01	D ‘98	0.2	-	**0.004**	0.14	-	0.005	B2
Cadmium	7440-43-9	F	0.005	0.005	F ’87	0.04	0.04	0.0005	0.02	0.005	-	D
Chloramine[3]	10599-90-3	F	4[4]	4[4]	D ‘95	-	-	0.1	3.5	3.0	-	-
Chlorine	7782-50-5	F	4[4]	4[4]	D ‘95	3	3	0.1	5	4	-	D
Chlorine dioxide	10049-04-4	F	0.8[4]	0.8[4]	D ‘98	0.8	0.8	0.03	1	0.8	-	D
Chlorite	7758-19-2	F	0.8	1	D ‘98	0.8	0.8	0.03	1	0.8	-	D
Chromium (total)	7440-47-3	F	0.1	0.1	F ‘87	1	1	**0.003**[5]	0.1	-	-	D
Copper (at tap)	7440-50-8	F	1.3	TT[6]	D ‘98	-	-	-	-	-	-	D
Cyanide	143-33-9	F	0.2	0.2	F ‘87	0.2	0.2	**0.0006**[7]	-	-	-	**I**
Fluoride	7681-49-4	F	4	4	-	-[8]	-	**0.06**[9]	-	-	-	-
Lead (at tap)	7439-92-1	F	zero	TT[6]	-	-	-	-	-	-	-	B2
Manganese	7439-96-5	-	-	-	F”04	1	1	0.14[10]	1.6	0.3	-	D
Mercury (inorganic)	7487-94-7	F	0.002	0.002	F ‘87	0.002	0.002	**0.0003**	0.01	0.002	-	D
Molybdenum	7439-98-7	-	-	-	D ‘93	0.08	0.08	0.005	0.2	0.04	-	D
Nickel	7440-02-0	F	-	-	F ‘95	1	1	0.02	0.7	0.1	-	-

[1] MFL = million fibers per liter.

[2] Carcinogenicity based on inhalation exposure.

[3] Monochloramine; measured as free chlorine.

[4] 1998 Final Rule for Disinfectants and Disinfection By-products: MRDLG=Maximum Residual Disinfection Level Goal; and MRDL=Maximum Residual Disinfection Level.

[5] IRIS value for chromium VI.

[6] Copper action level 1.3 mg/L; lead action level 0.015 mg/L.

[7] This RfD is for hydrogen cyanide.

[8] In case of overfeed of the fluoridation chemical see CDC Guidelines in Engineering and Administrative Recommendations on Water Fluoridation www.cdc.gov/mmwr/preview/mmwrhtml/00039178.htm. Elevated F levels ≥ 10mg/L require action by the water system operator.

[9] Based on dental fluorosis in children, a cosmetic effect. MCLG based on skeletal fluorosis.

[10] Dietary manganese. The lifetime health advisory includes a 3 fold modifying factor to account for increased bioavailability from drinking water.

Chemicals	CASRN Number	Standards			Status HA Document	Health Advisories						Cancer Descriptor
						10-kg Child						
		Status Reg.	MCLG (mg/L)	MCL (mg/L)		One-day (mg/L)	Ten-day (mg/L)	RfD (mg/kg/day)	DWEL (mg/L)	Life- time (mg/L)	mg/L at 10^{-4} Cancer Risk	
Nitrate (as N)	14797-55-8	F	10	10	D '93	10[1]	10[1]	1.6	-	-	-	-
Nitrite (as N)	14797-65-0	F	1	1	D '93	1[1]	1[1]	0.16	-	-	-	-
Nitrate + Nitrite (both as N)		F	10	10	D '93	-	-	-	-	-	-	-
Perchlorate[2]	14797-73-0	-	-	-	I '08	-	-	0.007	0.025	0.015	-	L/N
Selenium	7782-49-2	F	0.05	0.05	-	-	-	0.005	0.2	0.05	-	D
Silver	7440-22-4	-	-	-	F '92	0.2	0.2	0.005[3]	0.2	0.1[3]	-	D
Strontium	7440-24-6	-	-	-	D '93	25	25	**0.6**	20	4	-	D
Thallium	7440-28-0	F	0.0005	0.002	F '92	0.007	0.007	-	-	-	-	**I**
White phosphorous	7723-14-0	-	-	-	F '90	-	-	0.00002	0.0005	0.0001		D
Zinc	7440-66-6	-	-	-	D '93	6	6	0.3	10	2	-	**I**
RADIONUCLIDES												
Beta particle and photon activity (formerly man-made radionuclides)		F	zero	4 mrem/yr	-	-	-	-	-		4 mrem/yr	A
Gross alpha particle activity		F	zero	15 pCi/L	-	-	-	-	-	-	15 pCi/L	A
Combined Radium 226 & 228	7440-14-4	F	zero	5 pCi/L	-	-	-	-	-	-	-	A
Radon	10043-92-2	P	zero	300 pCi/L AMCL[4] 4000 pCi/L	-	-	-	-	-	-	150 pCi/L	A
Uranium	7440-61-1	F	zero	0.03	-	-	-	0.0006[5]	0.02	-	-	A

[1] These values are calculated for a 4-kg infant and are protective for all age groups.

[2] Subchronic value for pregnant women.

[3] Based on a cosmetic effect.

[4] AMCL = Alternative Maximum Contaminant Level.

[5] Soluble uranium salts. Radionuclide Rule.

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7. Unregulated Organic Contaminants

The term “organics” means compounds that have the element carbon as a principal constituent. Organic chemicals can be of many types and have many origins. Some chemicals in drinking water are caused by the decay of naturally occurring vegetation. A much larger group of organic contaminants are manmade organic chemicals, which are commonly grouped into two classes: Synthetic Organic Compounds (SOC) and Volatile Organic Compounds (VOC).

MEDIUM PRIORITY FOR SFPUC

SFPUC monitors regulated SOCs and VOCs in surface water, groundwater, and drinking water. Monitoring results of SOCs were below the detection limits. Monitoring results of VOCs for most analytes were below the detection limits, with the exception of tetrachloroethylene and carbon tetrachloride in some of City’s groundwater wells. These wells are not in operation. However, SWRCB has approved blending as a treatment for carbon tetrachloride and tetrachloroethylene. Monitoring results of unregulated pesticides and chemicals were below the detection limit with the exception of Fluoranthene and Quinoline in drinking water. Unregulated Industrial Chemical – Quinoline was found in drinking waters. It is suspected to be caused by coal tar lining in transmission pipelines (SFPUC, 2019). Fluoranthene, another unregulated chemical with no guideline value, was found on one occasion in drinking water close to its detection limit.

This section presents: (1) Screening Evaluation Table, (2) SFPUC Monitoring Review 2016-2021, and (3) Technical Review 2016-2021 of available scientific studies.

Table 7-1. Screening Evaluation Table for Unregulated Organic Contaminants

GENERAL INFORMATION ON CEC	
Instructions	This Screening Evaluation may be applied to a CEC group or an individual CEC. The purpose of this section of the Evaluation is to develop background information on the CEC or CEC group.
CEC Name	**Unregulated Organic Contaminants**
CEC Description Is CEC a group? If individual CEC, which group is CEC part of?	The term "organics" means compounds that have the element carbon as a principal constituent. Organic compounds can be of many types and have many origins. Some organics in drinking water are caused by the decay of naturally occurring vegetation. A much larger group of organic contaminants are manmade organic chemicals, which are commonly grouped into two classes: Synthetic Organic Compounds (SOC) and Volatile Organic Compounds (VOC). A few examples of unregulated organic contaminants are (DES, NH, 2020): 1. Industrial solvents, such as Hexane, n-butylbenzene. 2. Hydrocarbons, such as anthracene, Benzo(b)fluoranthene. 3. Pesticides, such as Alpha Hexachlorocyclohexane (alpha-HCH), Chlorpyrifos. 4. Herbicides, such as metolachlor and propanil. 5. VOCs and SOCs leaching from pipe lining materials, gaskets etc. These chemicals get into drinking water sources from human activities. Examples include (VDH, 2021): • Pesticides sprayed too close to a well or other water supply [agricultural runoff, air deposition, seepage into soil and groundwater]. • Accidental chemical spill. • Improper disposal of chemicals down storm drains, household drains, or down the toilet. • From old manufacturing sites where chemicals were improperly disposed of.
CEC Grouping What is the basis for grouping? *(Grouping factors are: common health effects, treatment, and analytical method, and/or compound co-occurrence)*	Organics are a group comprising hundreds of compounds with different chemical structures. Chemical classes include organochlorine compounds, carbamates, organophosphates, and chlorophenoxy compounds. Some organics are regulated, and some are unregulated. Unregulated organics are the focus of this CEC Screening Evaluation. A detailed list of unregulated CECs under consideration is presented in Table 7-2 of Monitoring Review. The principal basis for the grouping is common sources, since these contaminants are more likely to occur in watersheds that have industrial zones and/or wastewater discharges. However, specific sources may vary (e.g., fuel from vehicles; solvents from select manufacturing operations).

Examples and Indicators If group, what are notable examples? Are there possible indicator constituents? *(A suitable indicator occurs at quantifiable levels and may co-occur with other CEC, exhibit similar treatment and fate in environment)*	Examples of unregulated organics are listed in Table 7-2 in Monitoring Review. However, common or high use of pesticides in a geographical area may be a good indicator of the presence of pesticides in drinking water for that area. SOC and VOC analysis has been used by the SFPUC in the past to test leaching from new pipe linings.
Health Advisories Does CEC have a USEPA Health Advisory (e.g., Drinking Water Equivalent Level [DWEL]) or California Notification Level?	There are organics with Drinking Water Equivalent Levels (DWELs) that do not have MCLs (e.g., diazinon). California Notification Levels exist for organics: diazinon - 1.2 ug/L; propachlor - 90 ug/L, 1,4 -Dioxane – 14 mg/L, Ethylene Glycol – 14 mg/L, RDX – 0.0003 mg/L (SWRCB, 2021b). List of organics with USEPA DWELs, CA NLs is presented in SFPUC Monitoring Review in Table 7-2.
Regulatory Development Status Is CEC on USEPA Candidate Contaminant List (CCL), Unregulated Contaminant Monitoring Rule (UCMR) list, or California Public Health Goal (PHG) list?	There are several organics including pesticides and industrial chemicals included on the CCL4, UCMR4 and on Draft CCL5. The list is provided in Table 7-2 of Monitoring Review. Pesticides are regulated with 24 primary MCLs and some currently unregulated pesticides are targeted for future regulations. Eleven (11) pesticides were part of UCMR2, and 45 pesticides were on the CCL3, 42 pesticides on CCL4, and 42 pesticides on draft CCL5. There were 34 industrial chemicals on CCL4, 6 on UCMR4, and 14 on draft CCL5.

CONTEXT OF CEC EVALUATION AT SFPUC	
Instructions	The purpose of this section is to report SFPUC experience with the CEC or CEC Group, including occurrence data for each source water if available.
Purpose Why is evaluation undertaken? What is new about the issue that is considered 'emerging' (e.g., new chemical, new effect)?	From a national perspective, organics in general comprise a highly toxic group with widespread environmental contamination. Due to regulatory requirements and continued development of chemicals, SFPUC has years of monitoring data for organics. Although SFPUC watersheds are not impacted by agricultural or urban runoff, the group should be reviewed due to the overall importance of this class of contaminants and the possibility of impacts from isolated organics use and/or air deposition. A data review should confirm that organic levels are very low or non-detectable. Concern about potential leachate from linings is not a new issue but depends on the lining materials developed by manufacturers and used by SFPUC, and on the analytical range of VOCs/SOCs and other contaminants tested, soak tests may identify unexpected regulated or unregulated contaminants.
Customer Interaction Widespread public concerns? Media coverage?	There are no widespread concerns about organics in SFPUC's drinking water system. However, trace organics detection could raise concerns even if trace levels are not a health concern.
Expected Outcomes What are the likely benefits of the investigation to SFPUC and its customers?	Information collected as part of this investigation will be valuable to understand occurrence, temporal patterns, potential health impacts (if any in SFPUC system) and sources for trace levels of organics. This will provide documentation of drinking water quality with respect to organic contaminants and inform potential actions.

Occurrence Data (US and SFPUC) What occurrence information is available? Have detections, if any, been confirmed by follow-up sampling and/or QA/QC review?	Reliable analytical methods are available. Newer methods continue to be developed for newly studied organics. SFPUC has significant monitoring data for pesticides and industrial chemicals showing years of non-detects. Also, some DBP groups such as HAA and NDMA have been reported to increase in association with synthetic linings or gaskets. SFPUC monitors for both regulated and unregulated organics as listed in Tables 7-3 to 7-8 in Monitoring Review, which provides evidence on the potential occurrence of unregulated organics. **Sanitary Surveys Review.** The NPS monitors water quality at several locations in the watershed during the tourist season as part of a core task under the Watershed Protection MOA. The Hetch Hetchy sanitary survey implements integrated vegetation management, by using herbicides per Pest Control Advisor (PCA) recommendation, following the label instructions, and use properly trained applicators. HHWP uses Integrated Vegetation Management (IVM) to reduce fuel loading. (SFPUC 2020) **UCMR4.** Pesticide monitoring in 2018-2019 as a part of UCMR4 indicate all results were below the detection limits (see Table 7-3). Industrial chemicals monitored in 2018-2019 as a part of UCMR4 found detects of the unregulated contaminant quinoline in drinking water samples. It is assumed to be caused by coal tar lining in transmission pipelines (SFPUC, 2019). No other contaminants were detected (See Table 7-3). **Soak Tests.** Soak tests were not conducted during the 2016 – 2021 reporting period. **Summary.** Data for regulated and select unregulated organics listed in Tables 7-2 to 7-8 of Monitoring Review, confirm that SFPUC source waters are pristine, i.e., organics are not detected in source waters and drinking water with very few exceptions described in Monitoring Review. This is to be expected due to the minimal agricultural and urban runoff impact in SFPUC watersheds. It should be noted that detection limits are not low enough to assess trace air deposition and patterns.
Supporting Information List key references.	DES, New Hampshire, 2020. Organics in drinking water. https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/2020-01/dwgb-3-10.pdf Council of the European Commission (1998) Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption, p. 32. SFPUC 2020, Annual Sanitary Survey Update Report for the Hetch Hetchy Water Supply. SFPUC WQD, NRLMD, April 2021. SFPUC 2021a, 2020 Watershed Sanitary Survey Update for the Alameda Watershed prepared by Stantec Consulting Services.

	SFPUC 2021b, 2020 Watershed Sanitary Survey Update for the Peninsula Watershed prepared by Stantec Consulting Services. SWRCB, 2021a. MCLs, DLRs, PHGs, for Regulated Drinking Water Contaminants. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/mclreview/mcls_dlrs_phgs.pdf SWRCB, 2021b. Drinking Water Notification Levels and Response Levels: An Overview. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/notificationlevels/notification_levels_response_levels_overview.pdf USGS, 2021. Assessing Pesticide Use, stream concentrations, and health criteria. https://www.usgs.gov/news/potential-toxicity-pesticides-aquatic-life-us-rivers-widespread Vermont Department of Health (VDH), 2021. Pesticides, petrochemicals and other organic chemicals in drinking water. https://www.healthvermont.gov/health-environment/drinking-water/volatile-organic-compounds

DIAGNOSTIC QUESTIONS TO SUPPORT CEC PRIORITIZATION	
Instructions	The purpose of the Diagnostic Questions is to determine whether the CEC or CECs Group are significant to SFPUC drinking water and whether they merit further evaluation and/or action. All answers require explanation except those clearly not applicable. The Diagnostic Questions are divided into Health, Occurrence, and Treatment sections. The more questions are answered with a "Yes", the higher the probability that the CEC is a high priority or that a proactive approach should be taken.
HEALTH EFFECTS FROM SCIENTIFIC STUDIES	

Question	Answer	Explanation and Comments
Is scientific knowledge on CEC health effects well developed?	**Yes**	The degree of scientific knowledge of health risk varies by contaminant. Acute effects from high exposures are well understood and documented. Organic chemicals (VOCs, SOCs, and non-volatile organics) comprise the predominant CEC. Some industrial chemicals have adequate health information (e.g., 1,4-dioxane, 1,2,3-TCP). Typical endpoints are cancer or endocrine disruption. NSF developed a program to evaluate the leaching potential of different materials to certify that they do not pose a chemical health risk for use in drinking water systems. Drinking water that contains VOCs can increase risk for a variety of health issues. Some VOCs have been proven to cause cancer after prolonged exposure, while others are considered possible cancer risks. For example, consuming drinking water with high levels of Perchloroethylene (PCE) or Trichloroethylene (TCE) over many years may increase the risk for liver problems and cancer. People who drink water that contains high levels of atrazine over many years may be at greater risk for cardiovascular disease and reproductive difficulties. Some people who drink water containing bis 2-ethylhexyl)phthalate (DEHP) at more than the MCL over many years may be at greater risk for liver disease, reproductive difficulties and cancer (VDH, 2021).

Question	Answer	Explanation and Comments
Based on current scientific understanding, does the CEC pose potential health risk at the levels typically found in drinking water in the US?	No	The levels of unregulated organics in drinking water appear to be much lower than the MCLs for other regulated organics. On this basis, it is unlikely that unregulated organics pose potential health risk at the levels typically found in US drinking water. The rate of leaching of organic compounds from pipe linings etc. typically decreases exponentially over time, and studies investigating VOCs leaching from polymers agree that the VOC release decreases to below detectable levels or to concentrations that do not pose a risk (WRF 2010b). In the case of SFPUC, approved materials are used and the impacts of CECs, if any, are at trace levels, localized, and transitory. Most contaminants analyzed in the past for few pipe linings were not detected.
Adverse health impacts observed in other drinking water systems? Are public health studies documenting human health impacts (disease or outbreaks) available?	No	There have been no known adverse health impacts in other drinking water systems due to unregulated organics.
Existing regulations or guidelines outside of US (e.g., WHO, EU)?	Yes	WHO has derived guidelines for several pesticides, the majority of which are organochlorine compounds. Examples of pesticides unregulated in the US but with WHO guidelines include: aldrin, chloropyrifos, isoproturon, pendimethalin and trifluralin (Villanueva, 2014, WHO 2017). Rather than regulate individual chemicals, the EU directive on water quality for human consumption limits the maximum permissible concentration of pesticides in drinking water to 0.5 ug/L (total) and 0.1 ug/L for any single pesticide (Council of European Commission, 1998).
Existing US health advisories or CA notification levels?	Yes	CA MCL, CA Notification Levels, PHGs and USEPA DWELs of organics are listed in SFPUC Monitoring Review in Table 7-2.

Question	Answer	Explanation and Comments
Likely US regulation in the next 10 years? Is CEC on a regulatory development list, such as CCL? Is there a pending regulation or California PHG?	**Possible** **On Draft CCL5**	Eleven (11) pesticides were part of UCMR2, and 45 pesticides were on the CCL3, 42 pesticides on CCL4, and 42 pesticides on draft CCL5. There were 34 industrial chemicals on CCL4, 6 on UCMR4, and 14 on draft CCL5.
SUMMARY – SIGNIFICANT TO PUBLIC HEALTH IN GENERAL? *(Based on above answers)*	**Yes**	Given general scientific recognition of organics health risk, available WHO, European, and California guidelines or notification levels for select unregulated organics, and the large number of organics on the USEPA CCL3, CCL4, and Draft CCL5 indicate that unregulated organics are significant to public health in general. However, the concentrations found in most US drinking waters are unlikely to pose a significant health risk, based on limited information available. CEC potentially leaking from linings is not an issue of significant public health concern at SFPUC.
OCCURRENCE		
Is scientific knowledge on CEC sources/formation well developed?	**Yes**	In general, organics may reach drinking water sources from agricultural runoff, urban runoff, improper disposal or spill, and leaching due to pipeline lining material. Commercial chemicals may also be derived from municipal wastewater (e.g., use of consumer products). Air deposition can also contribute to trace levels of industrial contaminants to a watershed (PCBs).
CEC presence reported in other water supplies? Are occurrence studies available?	**Yes**	A USGS study published in 2021 of pesticides in U.S. rivers and streams reported that, on average, 17 pesticides were detected at least once at the 74 river and stream sites sampled 12 to 24 times per year during 2013–2017. Herbicides were detected much more frequently than insecticides and fungicides (USGS 2021). Results of soak tests by other utilities are not widely available or published. It is likely that results like at SFPUC would be observed.

Question	Answer	Explanation and Comments
CEC present in SFPUC watersheds and/or surface waters? Are there complex issues involved in managing CEC; e.g., point vs. non-point sources?	Yes	SFPUC source waters are in protected watersheds. These watersheds are not impacted by wastewater discharges, industrial pollution, or agricultural runoff. Data presented in Monitoring Review in Tables 7-5, 7-6, 7-7 and 7-8 indicate the regulated and unregulated synthetic organic chemicals and volatile organic chemicals are not detected. Although SPUC's protected watersheds are not impacted, there is use of organics in the service and transmission area. Alameda County and Santa Clara County apply herbicides to manage the public right-of-way. Herbicides are also used by the SFPUC and EBRPD for invasive species control. Potential contaminants associated with commercial nursery (in the secondary watershed along Calaveras, Andrade, and Niles Canyon Roads) operations include herbicides and pesticides. Marijuana growing operations are another illegal activity in the watershed are the potential source of pollutants which include fertilizers, herbicides and pesticides. In 2016, the EBRPD began phasing out use of the herbicide Roundup, which contains glyphosate. (SFPUC 2021a) Herbicides, fungicides, and pesticides are used within the Peninsula Watershed on SFPUC-owned land, on public road ROWs, and potentially on private land. Minimal amounts of pesticides and herbicides are used by the SFPUC to control invasive species. Herbicides and pesticides are also used by Caltrans and San Mateo County for road maintenance, the Crystal Springs Golf Course for turf maintenance, and the Filoli Estate for landscaping and turf maintenance. (SFPUC 2021b)
Is the CEC a potential groundwater contaminant?	Yes **but Not Present**	Pesticides and industrial chemicals from runoff can seep into soil and potentially contaminate groundwater. Available groundwater monitoring data indicate no detection of regulated SOC (Table 7-5), unregulated pesticides (Table 7-7), unregulated industrial chemicals (Table 7-8). A few regulated VOC were detected in Golden Gate Park Wells that are not in operation. Carbon tetrachloride (CCl_4) and tetrachloroethylene (PCE) were detected in SF – groundwater wells above their MCL (see Table 7-6). CCl_4 exceedances were mainly found at South Sunset Well (SSW) and on one occasion at West Sunset Well (WSW). SSW is not in operation since September 2018. The detections of CCl_4 were during monitoring when the concerned wells were not in operation. Monitoring was conducted to track contaminants in case the wells need to be put into drinking water production. SWRCB has approved blending as a treatment for CCl_4. The groundwater wells exceeding the CA MCL for PCE and CCl_4 are not in service or not a source of drinking water.

Question	Answer	Explanation and Comments
If the CEC is a potential groundwater contaminant, is it highly mobile in the subsurface? *Is* the CEC low-sorbing and resistant to microbial degradation?	**Yes**	Mobility of organics varies as there is a range of physico-chemical properties between compounds of this group. Some organics are highly mobile in the subsurface, others tend to sink and pool and only mobilize when groundwater is extracted
Precursor present in SFPUC source waters? *(Including surface waters and groundwaters)*	**No**	There are no organic precursors.
Formed or added during current SFPUC treatment? If so, describe whether the formation or addition of CEC can be controlled.	**No**	Organics are not formed or added during SFPUC treatment.
Formed or added within SFPUC storage or distribution? If so, describe whether the formation or addition of CEC can be controlled.	**Yes**	New linings and gaskets within a water treatment or distribution system, even if NSF 61-approved, could contribute trace levels of contaminants that do not have established risk assessments or health limits. However, these levels are initially very low and will decrease immediately following installation due to dilution and a decrease in leaching over time. SFPUC monitoring has detected some leached contaminants during soak tests, but the vast majority are undetected.

Question	Answer	Explanation and Comments
Detected in SFPUC drinking water?	No	Please refer to the SFPUC Monitoring Review for results in drinking water - UCMR4 monitoring for pesticides and industrial chemicals in drinking water conducted in 2018 – 2019 presented in Tables 7-3 and 7-4. Detects of unregulated contaminant – quinoline was found in drinking water samples. It is assumed to be caused by coal tar lining in transmission pipelines (SFPUC, 2019). All other contaminants were not detected (See Table 7-3). Regulated SOC and VOC (see Tables 7-5 and 7-6) were all below the method detection limits. Unregulated pesticides and industrial chemicals monitored during 2016 – 2021 are presented in Tables 7-7 and 7-8. All results were below the method detection limit.
SUMMARY – OCCURRENCE IN SOURCE AND DRINKING WATER? *(OR SIGNIFICANT POTENTIAL TO OCCUR)* *(Based on above answers)*	No	Organics are not expected because SFPUC watersheds are not impacted by significant agricultural or urban runoff. Air deposition may cause trace levels of industrial chemicals within the watersheds (e.g., PAHs). As seen from Table 7-5 to 7-8, the SOCs and VOCs (both regulated and unregulated) are not detected with an exception of carbon tetrachloride and tetrachloroethylene in some Golden Gate Park Wells that are not in operation.
TREATMENT		
Is scientific knowledge on CEC treatment/removal well developed?	**Yes**	Treatment efficacy varies by contaminant. In general, removal of a broad range of organic chemicals is likely to be more effective using treatment such as activated carbon adsorption or reverse osmosis, which are not part of conventional drinking water treatment. Pre-oxidation with ozone removes most organics.
Likely to pass through current treatment for Hetch Hetchy Supply? Describe any complex issues involved with the treatment/removal of CEC.	No	Tesla Water Treatment Facility provides treatment via primary disinfection using chlorine and UV (no filtration). Though some organic contaminants (i.e., industrial/commercial CECs) may be transformed or removed by chlorine or UV treatment, many would likely pass through, if the CEC occurred in the source water. Results of monitoring at Hetch Hetchy Reservoir (source) and drinking water provide evidence that organic CEC are not expected to occur in Hetch Hetchy drinking water.

Question	Answer	Explanation and Comments
Likely to pass through current treatment at SVWTP? Describe any complex issues involved with the treatment/removal of CEC.	**No**	Ozonation is in pre-design phase at SVWTP. Results of monitoring at Calaveras and San Antonio Reservoirs (source) and SVWTP drinking water provide evidence that organic CEC are not expected to occur in SVWTP drinking water.
Likely to pass through current treatment at HTWTP? Describe any complex issues involved with the treatment/removal of CEC.	**No**	HTWTP uses ozone, which in many cases is effective at oxidizing trace concentrations of organic CEC. Results of monitoring at San Andreas Reservoir (source) and HTWTP drinking water provide evidence that organic CEC are not expected to occur in HTWTP drinking water.
Likely to pass through current treatment for groundwater? Describe any complex issues involved with the treatment/removal of CEC.	**Possible** **But Not Present**	As seen from Tables 7-3 to 7-8, the SOC and VOC (both regulated and unregulated) have not been detected during multi-year extensive monitoring except for carbon tetrachloride, tetrachloroethylene in two groundwater wells in Golden Gate Park. Quinoline was detected in drinking water during UCMR4 monitoring (see discussion above).
SUMMARY – LIKELY TO PASS (NOT REMOVED BY) CURRENT TREATMENT? *(Based on above answers)*	**Yes/No** **Not Present**	Organic CEC are not expected to occur in SFPUC drinking water provided watershed protection is maintained and groundwater will not be affected by reclaimed water or seepage form the surface.

CEC PRIORITIZATION – CURRENT ASSESSMENT	
Instructions	This section prioritizes the CEC based upon the information developed in the above Diagnostic Questions as well as in the background information. For high and medium priorities, develop monitoring and/or mitigation measures as appropriate. For low priorities, maintain current measures, track regulatory developments, health/technical studies and reevaluate priority when needed.
Could CEC occur in SFPUC drinking water at levels of possible health significance? *(Based on above Diagnostic Questions)*	**POSSIBLE** Organics (regulated or unregulated) are not expected to occur in SFPUC finished drinking water at levels of possible health significance. SFPUC watersheds are not impacted by significant agricultural or urban runoff. Groundwater that is impacted by contamination will either be treated or those wells removed from service.
CEC Prioritization for SFPUC High, Medium, or Low. Provide explanation. *(A high number of "Yes" answers to the Diagnostic Questions indicates a higher priority, and "No" or very few "Yes" answers indicates a lower priority.)*	**MEDIUM PRIORITY FOR SFPUC** Data presented in Monitoring Review in Tables 7-3 to 7-8 indicate the regulated and unregulated SOC and VOC are not detected. UCMR4 monitoring for industrial chemicals and pesticides in drinking water conducted in 2018 – 2019 is presented in Tables 7-3 and 7-4. Unregulated contaminant – quinoline was found in drinking water samples. It is assumed to be caused by coal tar lining in transmission pipelines (SFPUC, 2019). All other contaminants were not detected (See Table 7-3). Monitoring conducted for regulated SOCs and VOCs is presented in Tables 7-5 and 7-6 (all results not detected). Monitoring for regulated pesticides and industrial chemicals during 2016 – 2018 is presented in Tables 7-7 and 7-8 (all results not detection detected). Groundwater is not impacted by contamination.
Implemented Actions Indicate the progress and results of any action items, above, such as implemented in previous cycles of CEC review. Evaluate whether changes to the action plan are required.	• Maintained source water protection. • Performed UCMR4 monitoring in 2018 – 2019 for industrial chemicals and pesticides in drinking water (Tables 7-3 and 7-4) • Conducted extensive system wide monitoring as shown in Tables 7-2, 7-5, 7-6, 7-7, and 7-8 from 2016 – 2020 to monitor organics in surface water, groundwater and drinking water at select locations. • Assessed strategies to ensure CCl4 levels in new groundwater wells are carefully monitored and that acceptable treatment techniques are available. • Design phase for ozonation at SVWTP.

Recommended Actions Does the situation merit investing additional resources or has the information gathered so far fulfilled due diligence? Actions could include monitoring and other measures (specified by source water, if necessary).	• Track federal and state regulatory developments. • Track health/technical studies. • Implement ozonation at SVWTP. • Maintain source water protection and optimized multibarrier water treatment and distribution system operation. Continue to minimize and track pesticide use in the watersheds. • Continue monitoring programs in source and drinking water. • Continue monitoring programs in groundwater as wells are placed in service and operate long-term. • Require contracts to specify NSF 61 materials for the interiors of tanks, pipelines, and other facilities. Audit construction projects. • Conduct periodic soak tests as needed to ensure that materials are installed properly.

This evaluation was prepared based on available information (peer-reviewed literature and occurrence data) with the purpose of prioritizing work and informing the public on unregulated CEC. This evaluation will be updated every 6 years or when significant new research or occurrence data on CEC become available that may warrant changing priority and recommendations.

Water Quality Division, SFPUC Monitoring Review 2016 – 2021

Contaminants of Emerging Concern (CEC) in Drinking Water

Unregulated Organics

SFPUC has been monitoring some unregulated organics listed in previous Federal lists UCMR4, CCL3, CCL4 and draft CCL5. The list of unregulated organics is presented in Table 7-2 (and a few regulated organics that are on CCL4 or draft CCL5), including published Federal and California MCL, SMCL, PHG, and guidance values DWEL, NL. These unregulated organics have been monitored occasionally as a special sampling event and the results are briefly enumerated in Table 7-2.

The following Tables 7-3 to 7-8 present all available data for unregulated UCMR4, industrial chemicals (Table 7-3), pesticides (Table 7-4), summary of monitoring results for regulated SOC (Table 7-5), VOC (Table 7-6), summary of monitoring for unregulated pesticides (Table 7-7), and industrial chemicals (Table 7-8).

SFPUC has excellent water quality with respect to organics. The entirety of reviewed organic datasets in years 2016 – 2021 for pesticides and industrial chemicals, both regulated and unregulated reviewed individually and by water sources and in drinking water, indicate that SFPUC's approved water sources and drinking water are of excellent quality with respect to organic contaminants, below limits of analytical detection.

The following few exceptions are:

- **Fluoranthene (industrial chemical) unregulated, not on any regulatory development list, no guideline values, one detect at 0.102 µg/L close to DL in drinking water (outlet SSO2_S).**
- **Quinoline (industrial chemical) unregulated, on UCMR4 and draft CCL5, several detects in drinking water (see Table 7-3) in UCMR4 sampling.**
- **Carbon tetrachloride (regulated VOC), above MCL of 0.5 µg/L at South Sunset Well, which is not in operation.**
- **Tetrachloroethylene (regulated VOC), above MCL of 5 µg/L (at Westside Basin).**
- **Xylene (regulated VOC), one sample close to DL 1.07 µg/L, more than 1000 times below MCL.**

Individual sample data organized by contaminant, water source, location, and sample dates are available electronically.

SFPUC has conducted monitoring as a part of the following programs from 2016 – 2021:

- As mentioned above SFPUC has conducted special sampling of unregulated organic chemicals in surface water, groundwater, and drinking water. The results are listed in Table 7-2, Table 7-7, and Table 7-8. Unregulated industrial chemicals and pesticides were monitored during special sampling events between 2016 – 2020. The results were below USEPA DWEL, and CA NL. Fluoranthene and Quinoline were detected in drinking water close to DL.
- Industrial chemicals and pesticides were monitored as a part of UCMR4 from 2018 - 2019. The results were presented in 2019 CEC update report as well as in this Report in Table 7-3 and Table 7-4. All results were below detection limits besides quinoline. Quinoline was detected during UCMR4 (2018) in Sunset Supply Line at Baden Valve Lot, Lake Merced Pump Station, and Sunset Reservoir and is assumed to be caused by coal tar lining in transmission pipelines (CEC, 2019). In December 2019, a special sampling was conducted to monitor quinoline in drinking water and was detected close to DL on two occasions. Any stagnant water along with deteriorating coal tar lining may give a quinolone hit. Coal tar still exists near Lake Merced Pump Station, which causes detects during shutdown. Operationally, coal tar leaching can be prevented the water is flowing through the transmission lines, or discharge after a lengthy shutdown.
- SFPUC also monitors regulated Synthetic Organic Chemicals (SOCs) and Volatile Organic Chemicals (VOCs) as a part of Title 22 requirement. A monitoring summary statistic of SOCs and VOCs in surface water, groundwater, and drinking water from 2016 – 2021 are presented in Table 7-5 and Table 7-6. Monitoring results of SOCs were below the detection limits. Monitoring results of VOCs for most analytes were below the detection limits, with the exception of tetrachloroethylene and carbon tetrachloride in City's groundwater wells. Tetrachloroethylene was found to have 21 occurrences exceeding the CA MCL of 5 µg/L between 2016 - 2021, whereas carbon tetrachloride was found to be above CA MCL of 0.5 µg/L on 26 occurrences between 2018 – 2021. Carbon tetrachloride and tetrachloroethylene were detected in SF – groundwater wells above their MCLS. Carbon tetrachloride exceedances were mainly found at South Sunset Well (SSW) and on one occasion at West Sunset Well (WSW). SSW is not in operation since September 2018. The purpose of monitoring these non-operational wells was to track the presence of these contaminants, if these wells were required to be placed in operation to supply drinking water. However, SWRCB has approved blending as a treatment for carbon tetrachloride and tetrachloroethylene. Golden Gate Central Well is used for GGP irrigation only since Fall 2018. North Lake Well/South Windmill Well are used for GGP irrigation only until completion of the Westside Recycled Water Project.

However, concentration of these organics in drinking water were well below the CA NL as reflected in summary Table 7-6.

- Unregulated SOCs and VOCs were also monitored between 2016 - 2021 are presented in Tables 7-5 and 7-6. All results were below the method detection limit.

Styrene

Styrene is among one of the candidates for proposed priorities for regulatory development. It is an organic chemical that is widely used to make rubber and plastics. The current styrene MCL and DLR are 100 µg/L and 0.5 µg/L, respectively. OEHHA has issued a PHG of 0.5 µg/L, based on carcinogenicity, and identified a noncancer health protective value of 4 µg/L. U.S. EPA's MCLG for styrene is 100 µg/L (SWRCB, 2022). SFPUC has been monitoring Styrene in surface water, groundwater, and drinking water. All the results are below the DLR (<0.5 µg/L). The results are presented in Table 7-6.

Older Soak Tests Results, 2005 – 2010

Between 2005 and 2010, seven SOC soak test analyses were performed on six tanks and one pipeline. For CECs without any health advisories (CA NLs or DWELs), benzo[b]fluoranthene was detected twice at 0.02 and 0.03 ug/L(or ppb), fluoranthene was detected once at 0.5 ppb, phenanthrene was detected all seven times between 0.1 and 1.9 ppb, and pyrene was detected once at 0.3 ppb. These compounds are polycyclic aromatic hydrocarbons (PAHs).The types of linings tested included new concrete flooring and Endura-Flex polyurethane spray-applied lining. The soak test is a worst-case scenario as it is conducted immediately after the curing of the lining, covers a 5-day period, and usually tests a higher-than-normal surface area to volume ratio.

A review of 16 soak tests from 2005 to 2010 found that no MCLs, CA Notification Levels, or DWELs have been exceeded. No corrective actions were necessary, and all facilities were placed in service. All soak test detects of constituents with MCLs have been very low, approximately 1% of the corresponding MCL (with the exceptions of DEHP which was 17% of the MCL after 1 test and benzo(a)pyrene which was 10% of the MCL after 1 test). It is also unlikely that lining detections would persist beyond the soak test period.

No soak tests were performed during the 2016 – 2021 reporting period.

Table 7-2. Published Guideline Values and Monitoring Summary of Unregulated Organics, SFPUC 2016-2021

ORGANICS	**USEPA**		**CA STATE**			**Comments**	**Results**
	MCL	**DWEL**	**MCL**	**CA NL**	**PHG**		
	mg/L	**mg/L**	**mg/L**	**mg/L**	**mg/L**		
PESTICIDES							
2-Hydroxyatrizine						DRAFT CCL5	Not Monitored
3-Hydroxycarbofuran						on CCL4	Not Monitored
Acephate						CCL4, DRAFT CCL5	Not Monitored
Acetaldehyde						on CCL4	Not Monitored
Acetochlor						on CCL4	One sample groundwater Peninsula <0.1 µg/L. Refer to Table 7-7.
Acetochlor ethanesulfonic acid (ESA)						on CCL4	Not Monitored
Acetochlor oxanilic acid (OA)						on CCL4	Not Monitored
Acrolein						CCL4, DRAFT CCL5	Not Monitored
Alachlor ethanesulfonic acid (ESA)						on CCL4	Not Monitored
Alachlor oxanilic acid (OA)						on CCL4	Not Monitored
Alchlor						on CCL4	Not Monitored
Alpha Hexachlorocyclohexane (alpha-HCH)						CCL4, UCMR4, DRAFT CCL5	UCMR4 (2018) - Results below detection limits. Refer to Table 7-4
Bensulide						CCL4, DRAFT CCL5	Not Monitored
Bromoxynil						DRAFT CCL5	Not Monitored
Captan						on CCL4	Not Monitored
Carbaryl		0.4				DRAFT CCL5	Not Monitored
Carbendazim (MBC)						DRAFT CCL5	Not Monitored
Carbofuran	0.04	-	0.018		0.0007	on CCL4, CA T22	Regulated – Federal and State MCL. Refer to Table 7-5.
Chlordecone						DRAFT CCL5	Not Monitored
Chlorpyrifos		0.01				UCMR4, DRAFT CCL5	UCMR4 - Results below detection limits. Refer to Table 7-4.
Clethodim						on CCL4	Not Monitored
Desisopropyl atrazine						DRAFT CCL5	Not Monitored
Diazinon		0.007		0.0012		DRAFT CCL5, CA T22	Monitored in 2020. Results below detection limits (<0.1 µg/L). Refer to Table 7-7
Dicrotophos						on CCL4	Not Monitored

ORGANICS	USEPA		CA STATE			Comments	Results
	MCL	DWEL	MCL	CA NL	PHG		
	mg/L	mg/L	mg/L	mg/L	mg/L		
Dicrotopos						DRAFT CCL5	Not Monitored
Dieldrin		0.002				DRAFT CCL5	2016 - OSHK_WELL, NA. Results below detection limits (<0.2 µg/L). Refer to Table 7-7.
Diethylatrazine						DRAFT CCL5	Not Monitored
Dimethipin						CCL4, UCMR4	UCMR4 - Results below detection limits. Refer to Table 7-4.
Dimethoate						DRAFT CCL5	2016 - OSHK_WELL, NA. Results below detection limits (<0.1 µg/L). Refer to Table 7-7.
Disulfoton		0.004				on CCL4	Not Monitored
Diuron		0.1				CCL4, DRAFT CCL5	Not Monitored
Ethalfluralin						DRAFT CCL5	Not Monitored
Ethoprop						CCL4, UCMR4, DRAFT CCL5	UCMR4 (2018) - Results below detection limits. Refer to Table 7-4.
Ethylene oxide						on CCL4	Not Monitored
Ethylene thiourea		0.007				on CCL4	Not Monitored
Fenamiphos		0.004				on CCL4	Not Monitored
Fibronil						DRAFT CCL5	Not Monitored
Flufenacet						DRAFT CCL5	Not Monitored
Fluometuron		0.5				DRAFT CCL5	Not Monitored
Iprodione						DRAFT CCL5	Not Monitored
Malathion		2				DRAFT CCL5	Not Monitored
Methamidophos						on CCL4	Not Monitored
Methomyl		0.9				DRAFT CCL5	Not Monitored
Metolachlor		3.5				on CCL4	Not Monitored
Metolachlor ethanesulfonic acid (ESA)						on CCL4	Not Monitored
Metolachlor oxanilic acid (OA)						on CCL4	Not Monitored
Molinate			0.02		0.001	on CCL4, CA T22	Regulated – State MCL. Refer to Table 7-5.
Norflurazon						DRAFT CCL5	Not Monitored
Oxirane, methyl-						on CCL4	Not Monitored
Oxydemeton-methyl						on CCL4	Not Monitored

ORGANICS	**USEPA**		**CA STATE**			**Comments**	**Results**
	MCL	**DWEL**	**MCL**	**CA NL**	**PHG**		
	mg/L	**mg/L**	**mg/L**	**mg/L**	**mg/L**		
Oxyfluorfen						CCL4, UCMR4, DRAFT CCL5	UCMR4 (2018) - Results below detection limits. Refer to Table 7-4.
Permethrin						CCL4, DRAFT CCL5	2016 - OSHK_WELL, NA. Results below detection limits (<0.1 µg/L). Refer to Table 7-7.
Phorate						DRAFT CCL5	Not Monitored
Phosmet						DRAFT CCL5	Not Monitored
Phostebupirim						DRAFT CCL5	Not Monitored
Profenofos						CCL4, UCMR4, DRAFT CCL5	UCMR4 - Results below detection limits. Refer to Table 7-4.
Propachlor		2		0.09		DRAFT CCL5	OSH WELL, AL CRK P, SFGW, GSR, Ground water EAST BAY. Results below 0.05 µg/L. Refer to Table 7-7.
Propanil						DRAFT CCL5	Not Monitored
Propargite						DRAFT CCL5	Not Monitored
Propazine		0.7				DRAFT CCL5	Covered under PPCP
Propoxur						DRAFT CCL5	Not Monitored
Tebuconazole						CCL4, UCMR4, DRAFT CCL5	UCMR4 (2018) - Results below detection limits. Refer to Table 7-4.
Tebufenozide						on CCL4	Not Monitored
Terbufos		0.002				DRAFT CCL5	Not Monitored
Thiamethoxan						DRAFT CCL5	Not Monitored
Thiodicarb						on CCL4	Not Monitored
Thiophanate-methyl						on CCL4	Not Monitored
Total permethrin (cis- & trans-)						UCMR4	UCMR4 - Results below detection limits. Refer to Table 7-4.
Tri-allate						DRAFT CCL5	Not Monitored
Tribufos						CCL4, UCMR4, DRAFT CCL5	UCMR4 - Results below detection limits. Refer to Table 7-4.
Triphenyltin hydroxide (TPTH)						on CCL4	Not Monitored
Vinclozolin						on CCL4	Not Monitored
Ziram						on CCL4	Not Monitored

ORGANICS	**USEPA**		**CA STATE**			**Comments**	**Results**
	MCL	**DWEL**	**MCL**	**CA NL**	**PHG**		
	mg/L	**mg/L**	**mg/L**	**mg/L**	**mg/L**		
INDUSTRIAL CHEMICALS							
	USEPA		**CA STATE**				
	MCL	**DWEL**	**MCL**	**CA NL**	**PHG**	**Comment**	
	mg/L	**mg/L**	**mg/L**	**mg/L**	**mg/L**		
1,1,1,2- Tetrachloroethane		1				on CCL4	Special Sampling at select locations from 2016 - 2019. Results below detection limits (<1 µg/L). Refer to Table 7-8.
1,1-Dichloroethane			0.005		0.003	on CCL4, CA T22	Regulated – State MCL. Refer to Table 7-3.
1,2,3-Trichloropropane		0.1	0.000005		0.0000007	CCL4, DRAFT CCL5, CA T22	Regulated – State MCL. Refer to Table 7-5.
1,3-Butadiene						on CCL4	Not Monitored
1,4-Dioxane				0.001		CCL4, DRAFT CCL5, CA T22	Monitored in 2020. Results below detection limits (<1 µg/L). Refer to Table 7-8.
1-butanol						UCMR4, CCL4	Results below detection limit. Refer to Table 7-3.
2,4,6-Trinitrotoluene (TNT)		0.02		0.001		CA T22	Special sampling at groundwater locations. T22 at East Bay at couple locations. Results below detection limits (<0.0004 µg/L). Refer to Table 7-8.
2,4-Dinitrophenol						DRAFT CCL5	Special sampling from 2016-2020. Results below detection limits (<50 µg/L). Refer to Table 7-8.
2-Aminotoluene						DRAFT CCL5	Not Monitored
2-Chlorotoluene				0.14			Special sampling from 2016-2020. Results below detection limits (<1 µg/L). Refer to Table 7-8.
2-methoxyethanol						UCMR4	Results below detection limits. Refer to Table 7-3.
2-propen-1-ol						UCMR4	Results below detection limits. Refer to Table 7-3.
4,4'-Methylenedianiline						on CCL4	Not Monitored
4-Chlorotoluene				0.14			Special sampling from 2016-2020. Results below detection limits (<1 µg/L). Refer to Table 7-8.
4-Nonylphenol (all isomers)						DRAFT CCL5	Not Monitored
6-Chloro-1,3,5-triazine-2,4-diamine						DRAFT CCL5	Not Monitored
Acetaldehyde						on CCL4	Not Monitored
Acetamide						on CCL4	Not Monitored

ORGANICS	USEPA		CA STATE			Comments	Results
	MCL	DWEL	MCL	CA NL	PHG		
	mg/L	mg/L	mg/L	mg/L	mg/L		
Aniline						on CCL4	Not Monitored
Anthracene		10					Special sampling from 2016-2020, East Bay Fire Monitoring 2020-2021. Results below detection limits (<10 µg/L). Refer to Table 7-8.
Benzo(b)fluoranthene							Special sampling from 2016-2020, East Bay Fire Monitoring 2020-2021. Results below detection limits (<10 µg/L). Refer to Table 7-8.
Benzyl chloride						on CCL4	Not Monitored
Bisphenol A						DRAFT CCL5	Part of PPCP, monitoring data covered under PPCP
butylated hydroxyanisole						UCMR4, DRFAT CCL5	Results below detection limits. Refer to Table 7-3.
Butylbenzyphthalate		7					Special sampling between 2016 - 2020. Results below detection limits (<0.5 µg/L). Refer to Table 7-8.
Carbondisulfide				0.16			Special sampling at groundwater locations. T22 at East Bay at couple locations. Results below detection limits (<0.5 µg/L). Refer to Table 7-8.
Chloromethane (Methyl chloride)						on CCL4	Not Monitored
Cumene hydroperoxide						on CCL4	Not Monitored
Dichlorodifluoromethane (Freon 12)				1			Special sampling at groundwater locations. T22 at a couple locations in East Bay. Results below detection limits (<1 µg/L). Refer to Table 7-8.
Ethylene glycol		70		14		on CCL4	Special sampling at groundwater locations. T22 at a couple locations in East Bay. Results below detection limits (<5000 µg/L). Refer to Table 7-8.
Ethylene thiourea		0.007				on CCL4	Not Monitored
Fluoranthene							Special sampling from 2016-2020, East Bay Fire Monitoring 2020-2021. Results below detection limits (<10 µg/L). One detect 0.102 µg/L close to DL in drinking water. Refer to Table 7-8.
Fluorene		1					Special sampling from 2016-2020, East Bay Fire Monitoring 2020-2021. Results below detection limits (<10 µ/L). Refer to Table 7-8.
Formaldehyde				0.1		on CCL4	Special sampling at groundwater locations. T22 at a couple locations in East Bay. Results below detection limits (<5 µg/L). Refer to Table 7-8.
Halon 1011 (bromochloromethane)		0.5				on CCL4	Special sampling from 2016 - 2020. Results below detection limits (<1 µg/L). Refer to Table 7-8.
HCFC-22						on CCL4	Not Monitored
Hexane						on CCL4	Not Monitored

ORGANICS	USEPA		CA STATE			Comments	Results
	MCL	DWEL	MCL	CA NL	PHG		
	mg/L	mg/L	mg/L	mg/L	mg/L		
HMX				0.35			Special sampling at groundwater locations between 2019 - 2020. T22 at couple locations in East Bay in 2018 and 2020. Results below detection limits (0.4 µg/L). Refer to Table 7-8.
Hydrazine						on CCL4	Not Monitored
Isophorone		7					Special sampling between 2016 - 2020. Results below detection limits (<0.5 µg/L). Refer to Table 7-8.
isopropylbenzene				0.77			Special sampling at drinking water and groundwater locations between 2016 - 2021. T22 at couple locations in East Bay in 2018 and 2020. Results below detection limits (<1 µg/L). Refer to Table 7-8.
Methanol						on CCL4	Not Monitored
Methyl isobutyl ketone				0.12			Not Monitored
Methyl tert-butyl ether (MTBE)			0.013		0.013	CCL4, DRAFT CCL5, CA T22	Regulated – State MCL. Refer to Table 7-6.
Methylmercury						DRAFT CCL5	Not Monitored
Naphthalene		0.7		0.017		T22	T22 sampling in surface water, groundwater in 2020 - 2021. Special sampling at surface water and groundwater from 2016-2020. East Bay Fire Monitoring 2020 - 2021. Results below detection limits (<0.5 µg/L). Refer to Table 7-8.
n-butylbenzene				0.26			Special sampling at surface water and groundwater locations from 2016 - 2020. T22 at couple locations in East Bay in 2018 and 2020. Results below detection limits (<1 µg/L). Refer to Table 7-8.
Nitrobenzene						on CCL4	Not Monitored
Nitroglycerin						on CCL4	Not Monitored
N-Methyl-2-pyrrolidone						on CCL4	Not Monitored
Nonylphenol						on CCL4	Part of PPCP, monitoring data covered under PPCP
n-Propylbenzene				0.26		on CCL4	Special sampling at surface water and groundwater locations from 2016 - 2020. T22 at couple locations in East Bay in 2018 and 2020. Results below detection limits (<1 µg/L). Refer to Table 7-8.
o-toluidine						UCMR4, CCL4	Results below detection limits. Refer to Table 7-3.
Oxirane, methyl-						on CCL4	Not Monitored
Phenanthrene							Special sampling in surface water and drinking water from 2016 - 2020. East Bay Fire Monitoring in 2020-2021. Results below detection limits (<10 µg/L). Refer to Table 7-8.

ORGANICS	**USEPA**		**CA STATE**			**Comments**	**Results**
	MCL	**DWEL**	**MCL**	**CA NL**	**PHG**		
	mg/L	**mg/L**	**mg/L**	**mg/L**	**mg/L**		
Pyrene							Special sampling in surface water and drinking water from 2016 - 2020. East Bay Fire Monitoring in 2020-2021. Results below detection limits (<10 µg/L). Refer to Table 7-8.
Quinoline						UCMR4, DRAFT CCL5	Special drinking water sampling in 2019 besides UCMR4. Refer Table 7-3. Also, covered under PCPP in 2020 - 2021. Two detects in drinking water – 0.17 µg/L and 0.2 µg/L. Several detects in UCMR4.
RDX (Hexahydro-1,3,5)- RDX (Hexahydro-1,3,5-trinitro-1,3,5-triazine)		0.1		0.0003		on CCL4	Special groundwater sampling in 2019 and 2020. T22 at couple locations in East Bay in 2018 and 2020. Results below detection limits (<0.4 µg/L). Refer to Table 7-8.
sec-Butylbenzene				0.26		CCL4	Special surface water, groundwater and drinking water sampling between 2016-220. T22 at couple locations in East Bay in 2018 and 2020. Results below detection limits (<1 µg/L). Refer to Table 7-8.
tert-Butylbenzene				0.26			Special surface water, groundwater and drinking water sampling between 2016-220. T22 at couple locations in East Bay in 2018 and 2020. Results below detection limits (<1 µg/L). Refer to Table 7-8.
Tertiary butyl alcohol (TBA)				0.012			Special surface water, groundwater and drinking water sampling between 2016-220. T22 at couple locations in East Bay in 2018 and 2020. Results below detection limits (<10 µg/L). Refer to Table 7-8.
Toluene diisocyanate						on CCL4	Not Monitored
Tributyl phosphate						DRAFT CCL5	Not Monitored
Triethylamine						on CCL4	Not Monitored
Trimethylbenzene (1,2,4-)				0.33		DRAFT CCL5	Not Monitored
Trimethylbenzene (1,2,5-)				0.33			Not Monitored
Tris(2-chloroethyl) phosphate (TCEP)						DRAFT CCL5	Part of PPCP, monitoring data covered under PPCP
Urethane						on CCL4	Not Monitored

Table 7-3. UCMR4 Monitoring Results for Industrial Chemicals, SFPUC 2018-2019

Rasprojectno_(Project_ID)	ClSampNo	Date	1-butanol	2-methoxyethanol	2-propen-1-ol	butylated hydroxyanisole	o-toluidine	quinoline
			µg/L					
UCMR4	SSL_BADEN	22-Jan-18	<2	<0.4	<0.5	<0.03	<0.007	0.029
UCMR4	SSL_BADEN	23-Apr-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
UCMR4	SSL_BADEN	23-Jul-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
UCMR4	SSL_BADEN	22-Oct-18	<2	<0.4	<0.5			
UCMR4	SSL_BADEN	26-Nov-18				<0.03	<0.007	<0.02
UCMR4	SA#2_BADEN	22-Jan-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
UCMR4	SA#2_BADEN	23-Apr-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
UCMR4	SA#2_BADEN	23-Jul-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
UCMR4	SA#2_BADEN	22-Oct-18	<2	<0.4	<0.5			
UCMR4	SA#2_BADEN	26-Nov-18				<0.03	<0.007	<0.02
UCMR4	LMPS_SUTRO_DISCH	22-Jan-18	<2	<0.4	<0.5	<0.03	<0.007	0.024
UCMR4	LMPS_SUTRO_DISCH	23-Apr-18	<2	<0.4	<0.5			
UCMR4	LMPS_SUTRO_DISCH	7-Jun-18				<0.03	<0.007	<0.02
UCMR4	LMPS_SUTRO_DISCH	19-Sep-18	<2	<0.4	<0.5	<0.03	<0.007	1.5
UCMR4	LMPS_SUTRO_DISCH	11-Dec-18	<2	<0.4	<0.5			
UCMR4	LMPS_SUTRO_DISCH	15-Jan-19				<0.03	<0.007	0.44
UCMR4	LMPS_SUNSET_DISCH	22-Jan-18	<2	<0.4	<0.5	<0.03	<0.007	0.027
UCMR4	LMPS_SUNSET_DISCH	23-Apr-18	<2	<0.4	<0.5			
UCMR4	LMPS_SUNSET_DISCH	7-Jun-18				<0.03	<0.007	<0.02
UCMR4	LMPS_SUNSET_DISCH	19-Sep-18	<2	<0.4	<0.5	<0.03	<0.007	0.025
UCMR4	LMPS_SUNSET_DISCH	11-Dec-18	<2	<0.4	<0.5	<0.03	<0.007	0.022
UCMR4	SSO#1_N	22-Jan-18	<2	<0.4	<0.5	<0.03	<0.007	0.023
UCMR4	SSO#1_N	23-Apr-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
UCMR4	SSO#1_N	30-Aug-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
UCMR4	SSO#1_N	11-Dec-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
UCMR4	SSO#2_S	22-Jan-18	<2	<0.4	<0.5	<0.03	<0.007	0.026
UCMR4	SSO#2_S	23-Apr-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
UCMR4	SSO#2_S	30-Aug-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
BA_SAN_BRUNO_UCMR4	Entry Point to Dist System	12-Feb-18	<2	<0.4	<0.5			

Rasprojectno_(Project_ID)	ClSampNo	Date	1-butanol	2-methoxyethanol	2-propen-1-ol	butylated hydroxyanisole	o-toluidine	quinoline
			µg/L					
BA_SAN_BRUNO_UCMR4	Entry Point to Dist System	26-Feb-18				<0.03	<0.007	<0.02
BA_SAN_BRUNO_UCMR4	Entry Point to Dist System	7-May-18	<2	<0.4	<0.5			
BA_SAN_BRUNO_UCMR4	Entry Point to Dist System	18-Jul-18				<0.03	<0.007	<0.02
BA_SAN_BRUNO_UCMR4	Entry Point to Dist System	6-Aug-18				<0.03	<0.007	<0.02
BA_SAN_BRUNO_UCMR4	Entry Point to Dist System	8-Aug-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
BA_SAN_BRUNO_UCMR4	Entry Point to Dist System	5-Nov-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
BA_SAN_BRUNO_UCMR4	EP#11 Well 16-Treated	12-Feb-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
BA_SAN_BRUNO_UCMR4	EP#11-Well 16 Treated	6-Dec-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
BA_SAN_BRUNO_UCMR4	EP#12 Well 17-Treated	12-Feb-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
BA_SAN_BRUNO_UCMR4	EP#12-Well 17 Treated	9-Aug-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
BA_SAN_BRUNO_UCMR4	EP#13-Well 18 Treated	9-Apr-18				<0.03	<0.0071	<0.02
BA_SAN_BRUNO_UCMR4	EP#13-Well 18 Treated	21-Jun-18	<2	<0.4	<0.5			
BA_SAN_BRUNO_UCMR4	EP#13-Well 18 Treated	10-Sep-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
BA_SAN_BRUNO_UCMR4	EP# 15-Well 20 Treated	21-Jun-18	<2	<0.4	<0.5			
BA_SAN_BRUNO_UCMR4	EP# 15-Well 20 Treated	26-Jun-18				<0.0300	<0.0200	<0.00700
BA_SAN_BRUNO_UCMR4	EP# 15-Well 20 Treated	10-Sep-18	<2	<0.4	<0.5			
BA_SAN_BRUNO_UCMR4	EP# 15-Well 20 Treated	28-Nov-18				<0.03	<0.007	<0.02
BA_BURLINGAME_UCMR4	Magnolia/Trousdale Turnout	11-Sep-18	<2	<0.4	<0.5			
BA_BURLINGAME_UCMR4	Magnolia/Trousdale Turnout	24-Sep-18				<0.03	<0.007	<0.02
BA_BURLINGAME_UCMR4	Magnolia/Trousdale Turnout	10-Dec-18	<2	<0.4	<0.5	<0.03	<0.007	<0.02
BA_BURLINGAME_UCMR4	Magnolia/Trousdale Turnout	11-Mar-19	<2	<0.4	<0.5	<0.03	<0.007	<0.02
BA_BURLINGAME_UCMR4	Magnolia/Trousdale Turnout	10-Jun-19	<2	<0.4	<0.5	<0.03	<0.007	<0.02
BA_SFO_UCMR4	SouthField Turnout Tap	7-Jan-19	<2	<0.4	<0.5	<0.03	<0.007	0.022
BA_SFO_UCMR4	SouthField Turnout Tap	1-Apr-19	<2	<0.4	<0.5	<0.03	<0.007	0.022
BA_SFO_UCMR4	SouthField Turnout Tap	8-Jul-19	<2	<0.4	<0.5	<0.03	<0.007	<0.02
BA_SFO_UCMR4	SouthField Turnout Tap	7-Oct-19	<2	<0.4	<0.5	<0.03	<0.007	<0.02

Table 7-4. UCMR4 Monitoring Results for Pesticides, SFPUC 2018 – 2019

Rasprojectno_(Project_ID)	ClSampNo	Sample_Date	Dimethipin	Ethoprop	Total Permethrin (cis- & trans-)	Tribufos	Tebuconazole	Chlorpyrifos	Oxyfluorfen	Profenofos	alpha-BHC (alpha-HCH)
			µg/L								
BA_BURLINGAME_UCMR4	Magnolia/Trousdale Turnout	11-Sep-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_BURLINGAME_UCMR4	Magnolia/Trousdale Turnout	10-Dec-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_BURLINGAME_UCMR4	Magnolia/Trousdale Turnout	11-Mar-19	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_BURLINGAME_UCMR4	Magnolia/Trousdale Turnout	10-Jun-19	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SAN_BRUNO_UCMR4	Entry Point to Dist System	12-Feb-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SAN_BRUNO_UCMR4	EP#11 Well 16-Treated	12-Feb-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SAN_BRUNO_UCMR4	EP#12 Well 17-Treated	12-Feb-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SAN_BRUNO_UCMR4	EP# 15-Well 20 Treated	13-Mar-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SAN_BRUNO_UCMR4	EP#13-Well 18 Treated	13-Mar-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SAN_BRUNO_UCMR4	Entry Point to Dist System	7-May-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SAN_BRUNO_UCMR4	Entry Point to Dist System	8-Aug-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SAN_BRUNO_UCMR4	EP#12-Well 17 Treated	9-Aug-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SAN_BRUNO_UCMR4	EP# 15-Well 20 Treated	10-Sep-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SAN_BRUNO_UCMR4	EP#13-Well 18 Treated	10-Sep-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SAN_BRUNO_UCMR4	Entry Point to Dist System	5-Nov-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SAN_BRUNO_UCMR4	EP#11-Well 16 Treated	6-Dec-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SFO_UCMR4	SouthField Turnout Tap	20-Feb-19	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SFO_UCMR4	SouthField Turnout Tap	1-May-19	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SFO_UCMR4	SouthField Turnout Tap	8-Jul-19	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
BA_SFO_UCMR4	SouthField Turnout Tap	7-Oct-19	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	LMPS_SUNSET_DISCH	22-Jan-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	LMPS_SUNSET_DISCH	23-Apr-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	LMPS_SUNSET_DISCH	9-Oct-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	LMPS_SUNSET_DISCH	11-Dec-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	LMPS_SUTRO_DISCH	22-Jan-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	LMPS_SUTRO_DISCH	23-Apr-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	LMPS_SUTRO_DISCH	9-Oct-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	LMPS_SUTRO_DISCH	23-Jan-19	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	SA#2_BADEN	22-Jan-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01

Rasprojectno_(Project_ID)	ClSampNo	Sample_Date	Dimethipin	Ethoprop	Total Permethrin (cis- & trans-)	Tribufos	Tebuconazole	Chlorpyrifos	Oxyfluorfen	Profenofos	alpha-BHC (alpha-HCH)
			µg/L								
UCMR4	SA#2_BADEN	23-Apr-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	SA#2_BADEN	23-Jul-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	SA#2_BADEN	22-Oct-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	SSL_BADEN	22-Jan-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	SSL_BADEN	23-Apr-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	SSL_BADEN	21-Aug-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	SSL_BADEN	22-Oct-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	SSO#1_N	22-Jan-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	SSO#1_N	23-Apr-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	SSO#1_N	30-Aug-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	SSO#1_N	11-Dec-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	SSO#2_S	22-Jan-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	SSO#2_S	23-Apr-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01
UCMR4	SSO#2_S	30-Aug-18	<0.2	<0.03	<0.04	<0.07	<0.2	<0.03	<0.05	<0.3	<0.01

Table 7-5. Summary of Regulated Synthetic Organic Chemicals Monitoring Results, SFPUC 2016 – 2021.

Regulated Synthetic Organic Chemical	**CA MCL µg/L**	**SURFACE WATER HETCH HETCHY**		**SF CITY SURFACE WATER**		**EAST BAY SURFACE WATER**		**WEST BAY SURFACE WATER**		**GROUNDWATER SF CITY**		**GROUNDWATER PENINSULA**		**GROUNDWATER EAST BAY**		**DRINKING WATER**	
		# Samples	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**
1,2,3-Trichloropropane	0.005	50	<0.005 (n=46), <5 (n=4)	3	<0.005	32	<0.005	32	<0.005	71	<0.005 (n=36), <0.5 (n=35)	38	<0.005	24	<0.005	14	<0.005 (n=10), <0.5 (n=4)
2,3,7,8-Tetrachlorodibenzo-p-dioxin	0.00003	8	<0.000005	1	<0.0000039	6	<0.000005	4	<0.000005	29	<0.000005 (n=29)	39	<0.000005 (n=39)	3	<0.000005		
2,4,5-TP (Silvex)	50	8	<0.2	1	<0.2	6	<0.2	4	<0.2	29	<0.2	38	<0.2	3	<0.2		
2,4-D	70	8	<0.1	1	<0.1	6	<0.1	4	<0.1	29	<0.1	38	<0.1	3	<0.1		
Alachlor	2	11	<0.05 (n= 3), <0.1 (n=8)	1	<0.1	6	<0.1	4	<0.1	33	<0.1	38	<0.1	3	<0.1	14	<0.1
Atrazine	1	10	<0.05	1	<0.05	6	<0.05	5	<0.05	33	<0.05 (n=27), <0.5 (n=6)	38	<0.05 (n=36), <0.5 (n=2)	3	<0.05	21	<0.05 (n=7), <0.1 (n=14)
Bentazon (Basagran)	18	8	<0.5	1	<0.5	6	<0.5	4	<0.5	29	<0.5	38	<0.5	3	<0.5		
Benzo[a]pyrene	2	12	<0.02 (n=10), <10 (n=2)	1	<0.02	6	<0.02	4	<0.02	33	<0.02 (n=27), <0.1 (n=6)	38	<0.02 (n=36), <0.1 (n=2)	3	<0.02	24	<0.1
Bis-(2-ethylhexyl)-adipate	400	10	<0.6	1	<0.6	6	<0.6	5	<0.6	33	<0.6 (n=27), <5 (n=6)	38	<0.6 (n=36), <5 (n=2)	3	<0.6	14	<5
Bis-(2-ethylhexyl)-phthalate	4	12	<0.6 (n=10), <10 (n=2)	1	<0.6	6	<0.6	4	<0.6	33	<0.6 (n=26), <3 (n=7)	38	<0.6 (n=36), <3 (n=2)	3	<0.6	24	<0.1 (n=10), <3 (n=14)
Carbofuran	18	8	<0.5	1	<0.5	6	<0.5	4	<0.5	29	<0.5	38	<0.5	3	<0.5		
Chlordane	1	8	<0.1	1	<0.1	6	<0.1	4	<0.1	33	<0.1	38	<0.1	3	<0.1	14	<0.1 (n=10), <0.5 (n=4)
Dalapon	200	8	<1	1	<1	6	<1	4	<1	29	<1	38	<1	3	<1		
Dibromochloropropane (DBCP)	2	8	<0.01	1	<0.01	6	<0.01	4	<0.01	29	<0.01	38	<0.01	3	<0.01		

Regulated Synthetic Organic Chemical	CA MCL µg/L	SURFACE WATER HETCH HETCHY		SF CITY SURFACE WATER		EAST BAY SURFACE WATER		WEST BAY SURFACE WATER		GROUNDWATER SF CITY		GROUNDWATER PENINSULA		GROUNDWATER EAST BAY		DRINKING WATER	
		# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L
Dinoseb	7	8	<0.2	1	<0.2	6	<0.2	4	<0.2	29	<0.2	38	<0.2	3	<0.2		
Diquat	20	8	<0.4	1	<0.37	6	<0.4	4	<0.4	29	<0.4	38	<0.4	3	<0.4		
Endothall	100	8	<5 (n=7), <20 (n=1)	1	<5	6	<5	4	<5	29	<5 (n=24), <20 (n=5)	38	<5 (n=21), <20 (n=17)	3	<20		
Endrin	2	10	<0.01 (n=8), 0.2 (n=2)	1	<0.01	6	<0.01	4	<0.01	33	<0.01	38	<0.01	3	<0.01	14	<0.01
Ethylene dibromide	0.05	8	<0.01	1	<0.01	6	<0.01	4	<0.01	29	<0.01	38	<0.01	3	<0.01		
gamma-BHC (gamma-HCH, Lindane)	0.2	10	<0.01	1	<0.01	6	<0.01	4	<0.01	29	<0.01	38	<0.01	3	<0.01		
Glyphosate	700	8	<6	1	<6	6	<6	4	<6	29	<6	38	<6	3	<6		
Heptachlor	0.01	10	<0.01 (n=8), <0.03 (n=2)	1	<0.01	6	<0.01	4	<0.01	33	<0.01	38	<0.01	3	<0.01	14	<0.01
Heptachlor epoxide	0.01	10	<0.01 (n=8), <0.05 (n=2)	1	<0.01	6	<0.01	4	<0.01	33	<0.01	38	<0.01	4	<0.01	15	<0.01
Hexachlorobenzene	1	12	<0.05 (n=10), <10 (n=2)	1	<0.05	6	<0.05	5	<0.05	33	<0.05 (n=31), <0.5 (n=2)	38	<0.05 (n=36), <0.5 (n=2)	4	<0.05	23	<0.05 (n=14), <0.25 (n=9)
Hexachlorocyclopentadiene	50	12	<0.05	1	<0.05	6	<0.05	5	<0.05	33	<0.05 (n=31), <1 (n=2)	38	<0.05 (n=36), <1 (n=2)	3	<0.05	24	<0.05 (n=14), <0.1 (n=10)
Methoxychlor	30	10	<0.05	1	<0.05	6	<0.05	4	<0.05	33	<0.05 (n=29), <0.1 (n=2)	38	<0.05	3	<0.05	14	<0.01
Molinate	20	10	<0.1	1	<0.1	6	<0.1	5	<0.1	33	<0.1 (n=31), <2 (n=2)	38	<0.1 (n=36), <2 (n=2)	3	<0.1	14	<0.1
Oxamyl (Vydate)	50	8	<0.5	1	<0.5	6	<0.5	4	<0.5	29	<0.5	38	<0.5	3	<0.5		
Pentachlorophenol	1	12	<0.04 (n=10), <10 (n=2)	1	<0.04	6	<0.04	4	<0.04	29	<0.04	38	<0.04	3	<0.04	10	<0.25
Picloram	500	8	<0.1	1	<0.1	6	<0.1	4	<0.1	29	<0.1	38	<0.1	3	<0.1		

Regulated Synthetic Organic Chemical	**CA MCL µg/L**	**SURFACE WATER HETCH HETCHY**		**SF CITY SURFACE WATER**		**EAST BAY SURFACE WATER**		**WEST BAY SURFACE WATER**		**GROUNDWATER SF CITY**		**GROUNDWATER PENINSULA**		**GROUNDWATER EAST BAY**		**DRINKING WATER**	
		# Samples	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**
Simazine	4	10	<0.05	1	<0.05	6	<0.05	5	<0.05	33	<0.05 (n=27), <1 (n=6)	38	<0.05 (n=36), <1 (n=2)	3	<0.05	21	<0.05 (n=7), <0.1 (n=14)
Thiobencarb	70	10	<0.2	1	<0.2	6	<0.2	5	<0.2	34	<0.2 (n=28), <1 (n=6)	40	<0.2 (n=38), <1 (n=2)	3	<0.2	15	<0.1
Total PCB	0.5	8	<0.1	1	<0.1	5	<0.1	3	<0.1	33	<0.1 (n=29), <0.5 (n=4)	38	<0.1	3	<0.1	14	<0.5 (n=10), <2.5 (n=4)
Toxaphene	3	8	<0.5	1	<0.5	6	<0.5	4	<0.5	33	<0.5 (n=29), <1 (n=4)	38	<0.5	3	<0.5	14	<1(n=9), <5 (n=5)

Table 7-6. Summary of Regulated Volatile Organic Chemicals Monitoring Results, SFPUC 2016 – 2021

Regulated Volatile Organic Chemical	CA MCL µg/L	SURFACE WATER HETCH HETCHY		EAST BAY SURFACE WATER		WEST BAY SURFACE WATER		SF CITY SURFACE WATER		GROUNDWATER SF CITY*		GROUNDWATER PENINSULA		GROUNDWATER EAST BAY		DRINKING WATER	
		# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L
1,1,1,2-Tetrachloroethane		4	<1							35	<0.5					3	<0.5
1,1,1-Trichloroethane	200	46	<0.5 (n=42), <1 (n=4)	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	18	<0.5	27	<0.5
1,1,2,2-Tetrachloroethane	1	46	<0.5 (n=42), <1 (n=4)	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	27	<0.5
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113)	1200	45	<0.5 (n=41), <10 (n=4)	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	25	<0.5
1,1,2-Trichloroethane	5	46	<0.5 (n=42), <1 (n=4)	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	27	<0.5
1,1-Dichloroethane	5	46	<0.5 (n=42), <1 (n=4)	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	27	<0.5
1,1-Dichloroethylene	6	46	<0.5 (n=42), <1 (n=4)	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	27	<0.5
1,2,4-Trichlorobenzene	5	48	<0.5 (n=44), <1 (n=4)	22	<0.5	24	<0.5	3	<0.5	157	<0.5	43	<0.5	17	<0.5	37	<0.5
1,2-Dichlorobenzene	600	50	<0.5 (n=42), <10 (n=8)	22	<0.5	24	<0.5	3	<0.5	158	<0.5	44	<0.5	17	<0.5	37	<0.5
1,2-Dichloroethane	0.5	46	<0.5	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	27	<0.5
1,2-Dichloropropane	5	50	<0.5 (n=42), <1 (n=8)	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	27	<0.5
1,3-dichloropropene	0.5	41	<0.5	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	29	<0.5
trans-1,3-dichloropropene		41	<0.5	21	<0.5	23	<0.5	3	<0.5	148	<0.5	43	<0.5	17	<0.5	26	<0.5
1,4-Dichlorobenzene	5	50	<0.5 (n=42), <10 (n=8)	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	37	<0.5
Benzene	1	46	<0.5	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	27	<0.5
Carbon tetrachloride	0.5	46	<0.5	22	<0.5	24	<0.5	3	<0.5	188	<0.5(n=166), >0.5 (n=26)**	44	<0.5	17	<0.5	27	<0.5
cis-1,2-dichloroethylene	6	45	<0.5 (n=41), <1(n=4)	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	30	<0.5
dichloromethane (methylene chloride)	5	46	<0.5 (n=42), <10 (n=4)	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5 (n=43), 1.9 (n=1)	17	<0.5	27	<0.5
Ethylbenzene	300	46	<0.5 (n=42), <1 (n=4)	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	27	<0.5
Methyl t-butyl ether	13	48	<0.5 (n= 16), <3 (n=32)	22	<0.5 (n=5), <3 (n=23)	19	<0.5 (n=4), <3 (n=15)	3	<3	158	<0.5 (n=43), <3 (n=115)	46	<0.5 (n=15), <3 (n=31)	17	<0.5 (n=5), <3 (n=12)	29	<0.5 (n=9), <3 (n=20)
Monochlorobenzene (chlorobenzene)	70	46	<0.5 (n=42), <1 (n=4)	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	27	<0.5
Styrene	100	45	<0.5 (n=41), <1(n=4)	21	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	27	<0.5
Tetrachloroethylene	5	46	<0.5 (n=42), <1 (n=4)	22	<0.5	24	<0.5	3	<0.5	205	<5 (n=185), >5 (n=21)**	44	<0.5	17	<0.5	39	<0.5

Regulated Volatile Organic Chemical	**CA MCL µg/L**	**SURFACE WATER HETCH HETCHY**		**EAST BAY SURFACE WATER**		**WEST BAY SURFACE WATER**		**SF CITY SURFACE WATER**		**GROUNDWATER SF CITY***		**GROUNDWATER PENINSULA**		**GROUNDWATER EAST BAY**		**DRINKING WATER**	
		# Samples	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**
Toluene	150	46	<0.5 (n=42), <1(n=4)	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	27	<0.5
trans-1,2-dichloroethylene	10	45	<0.5 (n=41), <1(n=4)	22	<0.5	25	<0.5	3	<0.5	156	<0.5	44	<0.5	17	<0.5	27	<0.5
Trichloroethylene	5	45	<0.5 (n=41), <1(n=4)	22	<0.5	24	<0.5	3	<0.5	156	<0.5 (n=148), <5 (n=18)	44	<0.5	17	<0.5	25	<0.5
Trichlorofluoromethane (F-11)	150	46	<0.5 (n=42), <10 (n=4)	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	24	<0.5
Vinyl chloride	0.5	46	<0.5	22	<0.5	24	<0.5	3	<0.5	157	<0.5	44	<0.5	17	<0.5	27	<0.5
Xylene (total: p, m, o)	1750	41	<0.5	22	<0.5	24	<0.5	3	<0.5	157	<0.5 (n=156), 1.07 (n=1)	44	<0.5	17	<0.5	27	<0.5

*Lake Merced emergency water supply

** Carbon tetrachloroethylene and trichloroethylene above CA MCL in SF groundwater wells, which are not in operation. Xylene detected at concentrations close to DL, but below CA MCL.

Table 7-7. Summary of Monitoring Results of Unregulated Pesticides, SFPUC 2016 - 2021

Unregulated Pesticide	USEPA DWEL µg/L	CA NL µg/L	SURFACE WATER HETCH HETCHY		SURFACE WATER EAST BAY		SURFACE WATER WEST BAY		SURFACE WATER SF CITY (LAKE MERCED)		GROUNDWATER SF CITY		GROUNDWATER PENINSULA		GROUNDWATER EAST BAY		DRINKING WATER	
			# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L
Acetochlor													1	<0.1				
Diazinon	7	1.2	5	<0.1	5	<0.1	2	<0.1	1	<0.1	4	<0.1	12	<0.1	2	<0.1	1	<0.1
Dieldrin	2		2	<0.2														
Dimethoate			2	<0.1														
Permetrin			2	<0.1														
Propachlor	2000	90	2	<0.05	1	<0.05					6	<0.05	15	<0.05	2	<0.05		

Table 7-8. Summary of Monitoring Results of Unregulated Industrial Chemicals, SFPUC, 2016 – 2021

Unregulated Chemical	USEPA DWEL µg/L	CA NL µg/L	SURFACE WATER HETCH HETCHY		SURFACE WATER EAST BAY		SURFACE WATER WEST BAY		GROUNDWATER SF CITY		GROUNDWATER PENINSULA		GROUNDWATER EAST BAY		DRINKING WATER	
			# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results µg/L	# Samples	Results, µg/L
1,1,1,2- Tetrachloroethane	1000		4	<1					35	<0.5					3	<0.5
1,4-Dioxane		1	6	<1	5	<1	4	<1	9	<1	14	<1	3	<1		
1-butanol																
2,4,6-Trinitrotoluene (TNT)	20	1			1	<0.0001			5	<0.0001	14	<0.0004 (n=9), <0.0001 (n=6)	2	<0.0001		
2,4-Dinitrophenol			2	<50											11	<1.16
2-Chlorotoluene		140	4	<1	1	<0.5			41	<0.5	15	<0.5	2	<0.5	7	<0.5
2-methoxyethanol																
2-propen-1-ol																
4-Chlorotoluene		140	4	<1	1	<0.5			41	<0.5	15	<0.5	2	<0.5	7	<0.5
Anthracene	10,000		4	<10 (n=2), <0.02 (n=2)											10	<0.13
Benzo(b)fluoranthene			4	<10 (n=2), <0.02 (n=2)											11	<0.11
Butylbenzyphthalate	7,000		4	<10 (n=2), <0.5 (n=2)											11	<0.28
Carbondisulfide		160			1	<0.5			21	<0.5	15	<0.5	2	<0.5		
Dichlorodifluoromethane (Freon 12)		1000	6	<1 (n=4), <0.128 (n=2)	1	<0.5			41	<0.5	15	<0.5	2	<0.5	2	<0.5
Ethylene glycol	70,000	14,000			1	<5000			6	<5000	14	<5000 (n=5), <4000 (n=9)	2	<5000		
Fluoranthene			4	<10 (n=2), <0.1 (n=2)											11	<0.04 (n=10), 0.102 (n=1)*
Fluorene	1000		4	<10 (n=2), 0.05 (n=2)											11	<0.3
Formaldehyde		100			1	<5			6	<5	14	<5	2	<5		
Halon 1011 (bromochloromethane)	500		4	<1					35	<0.5					6	<0.5
HMX		350			1	<0.1			6	<0.1	14	<0.1 (n=5), <0.4 (n=9)	2	<0.1		

Unregulated Chemical	**USEPA DWEL µg/L**	**CA NL µg/L**	**SURFACE WATER HETCH HETCHY**		**SURFACE WATER EAST BAY**		**SURFACE WATER WEST BAY**		**GROUNDWATER SF CITY**		**GROUNDWATER PENINSULA**		**GROUNDWATER EAST BAY**		**DRINKING WATER**	
			# Samples	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results µg/L**	**# Samples**	**Results, µg/L**
Isophorone	7000		4	<10 (n=2), <0.5 (n=2)											11	<0.3
isopropylbenzene		770	4	<1	1	<0.5			41	<0.5	15	<0.5	2	<0.5	6	<0.5
Naphthalene	700	17	16	<10 (n=2), <0.5 (n=2)	5	<0.5	4	<0.5	41	<0.5	15	<0.5	3	<0.5	16	<6.4 (n=2), <0.5 (n=14)
n-butylbenzene		260	4	<1	1	<0.5			41	<0.5	15	<0.5	2	<0.5	7	<0.5
Nonylphenol (PPCP)																
n-Propylbenzene		260	4	<1	1	<0.5			41	<0.5	15	<0.5	2	<0.5	6	<0.5
o-toluidine																
Phenanthrene			1	<0.04 (n=2), <10 (n=1)											11	<0.16
Pyrene			1	<0.05 (n=2), <10 (n=1)											11	<0.02
Quinoline															42	<0.02 (n=40), 0.17 (n=1), 0.20 (n=1)*
RDX (Hexahydro-1,3,5)- RDX (Hexahydro-1,3,5-trinitro-1,3,5-triazine)	100	3			1	<0.1			6	<0.1	14	<0.4 (n=9), <0.1 (n=5)	2	<0.1		
sec-Butylbenzene		260	4	<1	1	<0.5			41	<0.5	15	<0.5	2	<0.5	6	<0.5
tert-Butylbenzene		260	4	<1	1	<0.5			41	<0.5	15	<0.5	2	<0.5	6	<0.5
Tertiary butyl alcohol (TBA)		12	4	<10	1	<2			25	<2	15	<2	2	<2	6	<2
Tris(2-chloroethyl) phosphate (TCEP) (PPCP)																

*Fluoranthene (unregulated) detected at low concentrations in drinking water. Quinoline (unregulated) detected above DL in drinking water, possibly from leaching of coal tar in transmission lines.

Water Quality Division, Technical Review 2016 – 2021

Contaminants of Emerging Concern (CEC) in Drinking Water

Unregulated Organics

Most emerging organic contaminants currently lack water quality standards in natural and engineered systems despite known environmental impacts ranging from persistence, bioaccumulation, toxicity, endocrine disrupting potential on sensitive non-target organisms, and antibiotic resistance. Their widespread occurrence in aquatic ecosystems is affected by proximity to human, agricultural, and industrial wastewater sources. Furthermore, organic contaminants exhibit temporal variations associated with seasonal and demographic factors influencing consumer use and disposal patterns (Kibuye et.al., 2019).

Common Uses of Organic Chemicals

SOCs are manmade, organic (carbon-based) chemicals that are less volatile than VOC. They are used as pesticides, defoliants, fuel additives and as ingredients for other organic contaminants. Some of the more well-known SOCs are Atrazine, 2,4-D, Dioxin and Polychlorinated Biphenyls (PCBs) (Oklahoma, DEQ, 2019).

VOC encompass hundreds of high production volume chemicals that have been used in a wide range of household and industrial products. Widespread use of products that contain VOC resulted in their ubiquitous occurrence in the environment, with elevated concentrations frequently found in indoor environments. Human exposure to VOC is pervasive and has been a topic of concern, due to the mutagenic, neurotoxic, genotoxic, and carcinogenic potentials of these chemicals (Li et.al., 2021).

Several VOC are synthetic, high production volume chemicals and have been used in household and industrial products, including paints, wood preservatives, aerosol sprays, disinfectants, moth repellents, pesticides, building materials and furnishings, office equipment (e.g., copiers, printers, markers and correction fluids), hobby supplies, craft materials, and in the production of synthetic rubber, resin and polymers. Tobacco smoke and vehicle exhaust contain hundreds of VOC. Heat processing of foods and biomass burning can emit an array of VOC. The USEPA classified some VOC as hazardous air pollutants; examples are acrolein, acrylamide, acrylonitrile, vinyl chloride, ethylene oxide, (ethyl)benzene, 1-bromopropane, 1,3-butadiene, carbon disulfide, propylene oxide, styrene, tetrachloroethylene, toluene, trichloroethylene and xylene. Human exposure to VOC can occur through inhalation, ingestion and dermal contact (Li et.al., 2021).

Many agricultural practices can be harmful to humans and surrounding ecosystems and their potential benefits must be balanced against these harms. One widely adopted agricultural practice that is known to have harmful impacts to humans and the environment is the use of pesticides. While many pesticides are efficacious against agricultural pests and widely used to prevent crop damage, the harms to non-target species and humans can be widespread and severe. In addition to being the world's largest agricultural producers and exporters, the EU, Brazil, USA, and China are some of the world's largest pesticide users – each using 827 million, 831 million, 1.2 billion, and 3.9 billion pounds of pesticides in 2016, respectively (Donley, 2019).

Increased food availability, the unpreventable ubiquity of agrochemicals throughout the environment has resulted in pollution and has negatively impacted the ecosystem and human health. However, in contrast to the global awareness of the environmental footprint related to fertilizers, the global repercussions of pesticide dispersion in the environment remain largely unknown due to the lack of a comprehensive geographic quantification of active ingredient (AI) use and residues. Studies addressing pesticide threats mostly remain site-specific, and only a minority have targeted regional and global extents to assess the risks associated with a specific pesticide class (for example, insecticides or organochlorine pesticides) or within a certain environmental compartment (Tang et.al., 2021).

Pipe Linings

With respect to pipe linings, about 50% of North American water mains are unlined cast iron. Aging pipelines maybe rehabilitated by lining, which improves performance and water quality. However, there is concern about potential leaching of metals and organic chemicals from lining materials. In the US, cement-mortar lining is the most common lining used. However, studies have indicated that in soft waters, cement-mortar lining may corrode and adversely affect water quality. Alternatives to cement-mortar lining are epoxy or polyurethane lining (polymers). The National Sanitation Foundation (NSF) has provided approval certification (NSF-61) for use of epoxy and polyurethane (SFPUC, CEC, 2016).

Studies conducting soak tests for lining materials have indicated increases in pH, alkalinity, and total dissolved solids (TDS) (from cement-mortar lining) or organic carbon and disinfection byproducts (DBPs) (from polyurethane and epoxy lining). DBPs do not leach from the materials but are formed from the reaction of the residual disinfectant in the water (chlorine or monochloramine) with the polymer lining. Water quality impacts from leachate can be reduced by minimizing the hydraulic residence time (contact time between the materials and water) (WRF, Deb, 2010a; WRF, Ellison, 2010b).

With respect to impacts on water quality from cement-mortar lining, studies have observed increases in pH, alkalinity, calcium, metals, and TDS in the water in contact with the lining (WRF, Deb, 2010a; Whelton, 2012). These parameters are either regulated, and therefore outside the scope of this evaluation focused on unregulated CEC, or are not considered significant with respect to public health.

For epoxy lining, studies report an increase in the measurable total organic carbon (TOC, a bulk parameter that sums organic carbon-containing compounds) and DBPs. TOC is unregulated and non-specific. Water exposed to epoxy shows increases in the regulated DBPs trihalomethanes and haloacetic acids (WRF, Deb, 2010a) and likely other DBPs. Leaching of solvents and plasticizers, including bisphenol-A (BPA), phthalates and nonylphenol, from epoxy linings has also been observed (WRF, Deb, 2010a, b, Whelton, 2012). Recommended indicator compounds for leaching from epoxy are (WRF, Ellison, 2010b):

- Benzene (MCL = 5 ug/L)
- Toluene (MCL = 1,000 ug/L)
- Xylene (MCL = 10,000 ug/L)
- Methyl-isobutyl ketone (MIBK) (CA NL = 120 ug/L)

For polyurethane lining, studies report a reduction in pH and increase in the concentration of HAAs (regulatedDBPs) (WRF 2010a). Like epoxy, VOCs may also be released from polyurethane lining, but the curing time isgenerally faster than epoxies (WRF, Ellison, 2010b).

Other examples of compounds that may leach from polymers (i.e., epoxy or polyurethane linings) include the following constituents, which were detected by SFPUC between 2005 and 2010 during soak tests and are not regulated (i.e., do not have California Maximum Contaminant Levels [MCLs]).

- Naphthalene (CA NL = 17 ug/L, Drinking Water Equivalent Level [DWEL] = 700 ug/L)
- Anthracene (DWEL = 10,000 ug/L)
- Butylbenzylphthalate (DWEL = 7,000 ug/L)
- Fluorene (DWEL = 1,000 ug/L)
- Isophorone (DWEL = 7,000 ug/L)
- Benzo[b]fluoranthene (no CA NL or DWEL)
- Fluoranthene (no CA NL or DWEL)
- Phenanthrene (no CA NL or DWEL)

- Pyrene (no CA NL or DWEL)

Additionally, ethylbenzene and xylene are two examples where taste and odor are likely to be detected prior to any significant health risk from long-term exposure (WRF, Ellison 2010b).

For rubber gaskets and seals, studies have shown the nitrosamine NDMA may leach from the rubber sealing rings in newly constructed pipelines resulting in NDMA levels as high as 100 ng/L or more (Morran, 2011).

Additionally, chloramine induced degradation of gaskets and seals may release additives present in the elastomeric materials, including VOCs as well as vulcanizing agents and accelerants, such as benzisothiazole, (Nagisetty, 2014).

OCCURENCE AND HEALTH EFFECTS

The term pesticide is used to include herbicides, insecticides, and fungicides. They can enter watersheds and source waters for drinking water (i.e., surface and ground waters) by several routes, including from agricultural runoff, urban runoff and air deposition. Pesticides used in agriculture or in urban areas can wash away from the application site and reach surface water or can seep into the soil and reach groundwaters (SFPUC, 2016).

Once released to the environment, pesticides are subject to biological or chemical degradation processes that may transform the pesticide into a different chemical, and sometimes these degradation products (degradates) can also pose health or environmental risks, like the parent compounds. The environmental fate and potential health risks of pesticides and their degradates are areas of active research, including potential impacts to drinking water. Pesticides and degradates that are more water soluble are more likely to be found in drinking water. However, volatile pesticides/degradates can move in air from the application site and then be deposited in surface waters (Sinclair et al., 2006; NPTN, 2000).

Pesticides from Air Deposition near San Joaquin Valley (SFPUC, 2016)

Pesticide runoff into SFPUC source waters is unlikely due to SFPUC's protected watersheds. However, regional air deposition (at trace levels) is possible due to the adjacent agricultural lands in the San Joaquin Valley.

Based on a study of remote lakes in Kings Canyon National Park and Sequoia National Park (the closest agricultural lands are in the San Joaquin Valley, between 46 to 83 km away), 4 pesticides were frequently detected in lake water near or below 1 ng/L, listed below (Bradford et al., 2010). These lakes are not SFPUC source waters, but the detected pesticides could potentially be used as local indicators for pesticides deposited by air in the region. Simazine is regulated with a primary MCL. The other 3 pesticides are not regulated.

- Endosulfan
- Propargite
- Dacthal
- Simazine

SFPUC conducted UCMR4 monitoring in 2018-2019 (see Table 7-3 in Monitoring Review), which included 9 pesticides and 6 industrial chemicals. The results were below the method detection limits. Unregulated contaminant quinoline, which was detected in several samples of drinking water near detection limit

Special sampling of unregulated organics was conducted between 2016 – 2020 at select locations in surface water, groundwater, and drinking water. The results were below the method detection limits (See Table 7-4 and Table 7-7 for unregulated pesticides and Table 7-8 for unregulated industrial chemicals).

Pesticide monitoring in the U.S. has shown detectable concentrations in > 95% of sampled surface waters and approximately 50% of sampled groundwaters (AwwaRF, 2008; Gillom, 2006) though these are not necessarily all source waters for drinking. A 2006-2007 study detected trace concentrations of 3 of 11 pesticides (others were non-detects) in a survey of 19 US source waters, including unregulated pesticides (Benotti et al, 2009).

The unregulated pesticide metolachlor was the second most frequently detected pesticide (after atrazine) in a nationwide survey of streams and groundwater with 95th percentile concentrations often exceeding 0.5 μg/L (Gillom, 2006). Median total pesticide degradate concentrations have been reported in a recent survey at 0.62 μg/L in groundwater and 0.33 μg/L in surface waters; however, concentrations of individual degradates were typically less than 0.1 μg/L (Reemtsma, 2013).

Occurrence of VOC (regulated and unregulated) in Groundwater and Drinking Water Supply

Few studies have reported VOC concentrations in water. In 2006, the U.S. Geological Survey determined 55 VOCs in nation's ground water (n = 3500) and drinking-water supply wells (n = 3500) and found that 20% of samples contained one or more of the 55 VOCs analyzed; 90% of the VOC concentrations in samples were <1 µg/L. The concentrations of 15 most frequently detected VOCs were in the range of 0.002–350 µg/L. Gasoline hydrocarbons, BTEX, were widely detected in aquifers (0.58–17.9%) (Li et.al., 2021).

Several VOCs are mutagenic, genotoxic, neurotoxic, and carcinogenic. Studies have shown that exposure to VOCs increases the risks of developing respiratory illnesses, leukemia, birth defects, neurocognitive impairment, and cancer in humans. 1,3-butadiene is classified as known carcinogens by the International Agency for Research on Cancer (IARC). Acrylamide, acrylonitrile, N,N-dimethylformamide, isoprene and propylene oxide are classified as probable/possible IARC carcinogens. Acrolein, crotonaldehyde have been classified as group 3 carcinogens (i.e., inadequate evidence) (Li et.al., 2021).

Exogenous VOCs are a measure of exposure to harmful compounds in the environment. Exposure to VOCs affects central nervous system as well as immune and reproductive systems in humans. Exposure to 1,3-butadiene, widely present in tobacco smoke, increased the risk of lung cancer. Acrylamide exposure was linked to central and peripheral nervous system damage, and breast cancer. Prenatal VOC exposure was associated with elevated risk of neural tube defects, congenital male genital abnormalities and wheezing/asthma in infants. Although several studies have reported adverse health effects from exposure to VOCs, assessment of internal body burdens has been a challenge, due to the lack of appropriate analytical methods (Li et.al., 2021). It should be noted that San Francisco's Hetch Hetchy supply is much more protected than most of the supplies in the surveys discussed.

REGULATIONS

The USA, EU, China, and Brazil each have separate and distinct pesticide regulatory systems designed to protect, to varying degrees, humans and the environment. The EU, consisting of 27 member states, currently has the most comprehensive and protective pesticide regulations of any major agricultural producer. The European Commission oversees pesticide approval, restriction and cancellation in the EU in accordance with Regulations 1107/2009 and 396/2005, which are designed to "…ensure that industry demonstrates that substances or products produced or placed on the market do not have any harmful effect on human or animal health or any unacceptable effects on the environment" and place the burden of proof on the pesticide industry to demonstrate that its product can be used in a way that does not result in harm to humans or the surrounding environment (Donley, 2019).

The EU prohibits the approval and continued use of pesticides that the governing body has recognized as mutagens, carcinogens, reproductive toxicants or endocrine disruptors unless exposure to humans is considered negligible (Donley, 2019).

USEPA has regulated 53 organic chemical contaminants. The list of these contaminants and its MCL can be found at USEPA's website https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations#Organic

For more information refer to Table 7-3 in SFPUC Monitoring Review which summarizes the various unregulated chemical contaminants with their respective USEPA DWEL, CA NL and CA PHG, and a few regulated contaminants. A human health-based water guidance table is available from the Health Department of Minnesota; the information can be found out at https://www.health.state.mn.us/communities/environment/risk/guidance/gw/table.html.

In the USA, pesticide regulation is largely overseen by the USEPA, which regulates and enforces pesticide actions under the Federal Food, Drug, and Cosmetic Act (FFDCA) and the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Unlike the safety threshold afforded by the EU, the pesticide industry only has to demonstrate that its products "will not generally cause unreasonable adverse effects on the environment," which is partially defined as "any unreasonable risk to man or the environment, considering the economic, social, and environmental costs and benefits of the use of any pesticide…" (Donley, 2019).

Health Canada Maximum Acceptable Concentration

Health Canada has listed MAC for various organic contaminants and can be found in Table 2 at their website https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/pdf/pubs/water-eau/sum_guide-res_recom/sum_guide-res_recom-eng.pdf

Some examples are: Bromoxynil – 0.005 mg/L, Carbaryl – 0.09 mg/L, (Health Canada, 2019).

TREATMENT of VOCs

Nanomaterials

Various nanomaterials have been developed for VOCs mitigation, but their elimination mechanisms depend on the nanomaterial's physicochemical characteristics such as porosity, size, electrostatic interaction, surface functionality or chemical composition. Various studies reported the efficient application of nanomaterials for VOCs mitigation, in an effort to decrease environmental pollution. Such materials include, but are not limited to, carbon nanomaterials, metallic and metal oxide nano materials or polymer nanocomposites. Several investigations reported the use of nano- and micro-scale materials for the adsorption of VOCs from atmosphere and water (David et.al., 2021).

Aeration

Aeration processes are designed to achieve removal of gases and volatile compounds by air stripping. Transfer can usually be achieved using a simple cascade or diffusion of air into water. Air stripping can be used for removal of volatile organics (e.g. solvents) (WHO, 2017).

Chemical Coagulation

Coagulation is suitable for low solubility organochlorine pesticides. For organic chemicals, coagulation is generally ineffective, except where the chemical is bound to humic material or adsorbed onto particulates (WHO, 2017).

Activated Carbon Adsorption

Activated carbon is used for the removal of pesticides and other organic chemicals, taste and odor compounds, cyanobacterial toxins and total organic carbon (WHO, 2017).

SFPUC Soak Test Procedures

SFPUC periodically replaces or repairs internal linings in its drinking water system pipelines or water storage facilities. The linings are NSF 61 approved materials for drinking water application. As part of quality control and to test the workmanship of liner application, SFPUC conducts a non-regulatory “soak test” that consists of partial fill of tested facility with potable water, holding the water for 5 days and collecting samples for VOCs, SOCs, and other contaminants that may potentially leach out of the lining. If a contaminant is measured above a regulatory MCL (primary or secondary) or CA Notification Level, the engineer can take corrective actions, i.e., assess construction practices and re-test pipeline/tank. If a detected contaminant does not have an MCL or Notification Level, constituent falls into the CEC category. Engineer should follow the SFPUC soak test standard operating procedure (SOP) when assessing CEC detections (SFPUC, 2011).

Soak tests are conducted to verify the workmanship when facilities are lined with new or repaired materials. The tests benefit the customers and SFPUC to ensure that only approved materials are used and proper curing techniques are applied. In case any contaminants are detected as a result of the soak test, the engineer can take action according to the soak test SOP (SFPUC, 2011), including keeping the facility out of service and removal or reapplication of the liner. It is unlikely that transitory trace detects from indirect additives (such as tank linings) present a significant risk to health. As a result of these management practices, most contaminants analyzed are not detected. The California Division of Drinking Water (DDW) already addresses the issuethrough the Indirect Additive requirements in Title 22 (i.e., requirement to use NSF 61 materials).

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8. PPCP, EDC, and Hormones

Pharmaceuticals and Personal Care Products and Endocrine-Disrupting Chemicals (PPCP/EDC) include prescription and over-the-counter drugs, insect repellents, cosmetics, soaps, hormones, pesticides, organic compounds and dioxins that can disrupt endocrine systems. Due to advances in analytical methods, trace PPCP/EDC concentrations (ng/L) can be detected in wastewater and environment. Some hormones are both naturally occurring and used as pharmaceutical drugs. Hormones are essential for controlling large number of processes in the body, from early ones such as embryonic development and organ formation, to the control of tissue and organ functions in adulthood. (EC, 2018)

LOW PRIORITY FOR SFPUC

PPCP/EDC are a low priority because they are either not detected or infrequently detected at extremely low levels in SFPUC source and drinking waters. Reliable, low-level PPCP/EDC analysis is difficult and therefore detections are uncertain. International studies conducted have thus far indicated no appreciable risk to human health from low-level exposure to PPCP in drinking water. SFPUC has protected watersheds and source waters that are not impacted by wastewater discharges. Future recharge of reclaimed wastewater will need to be monitored to ensure that groundwater is not affected.

This section presents: (1) Screening Evaluation Table, (2) SFPUC Monitoring Review 2016-2021, and (3) Technical Review 2016-2021 of available scientific studies.

Table 8-1. Screening Evaluation Table for PPCP, EDC, and Hormones

GENERAL INFORMATION ON CEC	
Instructions	This Screening Evaluation may be applied to a CEC group or an individual CEC. The purpose of this section of the Evaluation is to develop background information on the CEC or CEC group.
CEC Name	**Pharmaceuticals and Personal Health Products (PPCP), Endocrine Disrupting Chemicals (EDC) & Natural Hormones**
CEC Description Is CEC a group? If individual CEC, which group is CEC part of?	PPCP/EDC include prescription and over-the-counter drugs, insect repellents, cosmetics, soaps, hormones, pesticides, organic compounds and dioxins that can disrupt endocrine systems. Some hormones are both naturally occurring and used as pharmaceutical drugs. Due to advances in analytical methods, trace PPCP/EDC concentrations (ng/L) can be detected in wastewater and environment. The endocrine system is a messenger system of the body. It uses hormones, signaling molecules which travel through the bloodstream, as a communication tool and to produce effects on distant cells, tissues and organs. Hormones are essential for controlling large number of processes in the body, from early ones such as embryonic development and organ formation, to the control of tissue and organ functions in adulthood. (EC, 2018)
CEC Grouping What is the basis for grouping? *(Grouping factors are: common health effects, treatment, and analytical method, and/or compound co-occurrence)*	PPCP/EDC can be grouped based on health effects, treatment, analytical methods, and co-occurrence. There is also variability of potential health impacts (e.g., a subset of PPCP are EDC, which are a potential risk even at low concentrations), degree of removal by treatment technologies, and optimal analytical methods. PPCP consist of thousands of chemicals; approximately 1,000 pharmaceuticals and about 6,000 cosmetics and additives. Analytical methods are limited to few hundred chemicals.

Examples and Indicators If group, what are notable examples? Are there possible indicator constituents? *(A suitable indicator occurs at quantifiable levels and may co-occur with other CEC, exhibit similar treatment removal and/or fate in the environment)*	Various indicators of wastewater have been proposed that could indicate the presence of PPCP/EDC because wastewater effluent is a major source of PPCP/EDC; e.g., boron, primidone, carbamazepine and caffeine. Caffeine is not a conservative tracer because of its biodegradation in water. Recent studies have demonstrated the use of sucralose and gadolinium to indicate the presence of domestic and hospital wastewater, respectively. (Hagemann et al., 2016). Naturally occurring hormones include steroids (produced by mammals and birds, e.g., cholesterol, estradiol, testosterone) and phytoestrogens (produced by plants, e.g., apigenin, genistein).
Health Advisories Does CEC have a USEPA Health Advisory (e.g., Drinking Water Equivalent Level [DWEL]) or California Notification Level?	There are no USEPA Health Advisories or California Notification Levels for PPCP/EDC in drinking water.
Regulatory Development Status Is CEC on USEPA Candidate Contaminant List (CCL), Unregulated Contaminant Monitoring Rule (UCMR) list, or California Public Health Goal (PHG) list?	Many of PPCP/EDC, except some pesticides/herbicides such as atrazine, are not currently regulated nor required to be routinely monitored. The USEPA Endocrine Disruptor Screening Program (EDSP) uses a two-tiered approach to screen pesticides, chemicals, and environmental contaminants for their potential effect on estrogen, androgen and thyroid hormone systems. https://www.epa.gov/endocrine-disruption/endocrine-disruptor-screening-program-edsp-overview. Draft CCL5 (2021) lists pesticides, chemicals used in commerce https://www.epa.gov/ccl/draft-ccl-5-chemicals. UCMR3 (2012) contained screening list of 7 hormones. UCMR5 (2021) list does not contain PPCP/EDC https://www.epa.gov/dwucmr/fifth-unregulated-contaminant-monitoring-rule.

CONTEXT OF CEC EVALUATION AT SFPUC	
Instructions	The purpose of this section is to report SFPUC experience with the CEC or CEC Group, including occurrence data for each source water if available.
Purpose Why is investigation undertaken? What is new about the issue that is considered 'emerging' (e.g., new chemical, new effect)?	PPCP/EDC have been detected at trace levels (ng/L) throughout the country, especially in source waters under the influence of wastewaters, and are an increasing area of research. The purpose is to improve understanding of the health significance, occurrence, treatment of these CEC and provide recommendations.
Customer Interaction Widespread public concerns? Media coverage?	Currently, SFPUC customers do not have major concerns about PPCP/EDC in drinking water. PPCP/EDC are unlikely to impact SFPUC water sources and customer satisfaction as long as SFPUC maintains source water protection.
Expected Outcomes What are the likely benefits of the investigation to SFPUC and its customers?	This evaluation and supporting data will help support planning efforts and communications with customers. Ongoing literature review and periodic monitoring, as knowledge about this group of CEC increases, will help assess their relevance to SFPUC drinking water supply.
Occurrence Data (US and SFPUC) What occurrence information is available? Have detections, if any, been confirmed by follow-up sampling and/or QA/QC review?	PPCP/EDC do not typically persist in surface water because of extensive biodegradation, UV radiation, higher temperature and a higher concentration of oxygen. Occurrence of PPCP/EDC in US surface waters has been presented in detail by (WRF, Park et al., 2017); see Table 8-6 in Monitoring Review. PPCP/EDC can be stable in groundwater for a long time because the degradation process is limited to hydrolysis. (Caban et al., 2016). USGS conducted the first large-scale, systematic assessment of PPCP/EDC occurrence in groundwater. Compounds most likely to be detected have relatively high solubility and low tendency to sorb. They are most common in shallower wells with a component of young groundwater, particularly in crystalline rocks, likely reflecting recent recharge. The observed detection frequencies and concentrations indicate similar or substantially lower occurrence compared with other organic compounds (pesticides, VOCs) in groundwater used for drinking. (Bexfield et al., 2019) Based on 2020/2021 SFPUC monitoring and additional sampling in 2012, it is evident that SFPUC surface source waters have much lower frequencies of detection/concentrations of PPCP/EDC and hormones than in the national surveys. This confirms conclusion from an earlier 2006 national survey that SFPUC protected

	surface waters are one of the best in the country in terms of either non-detected or extremely low detections of PPCP/EDC. The initial 2020/2021 monitoring of two Pleasanton wells, nine SFRWS wells and five San Francisco wells indicates no detections of the vast majority of 106 PPCP/EDC tested in all 16 wells. Sporadic extremely low detects of a few PPCP/EDC in five wells do not indicate groundwater contamination; possibly sample contamination. No hormones were detected in any of 16 wells. Monitoring of groundwater could be repeated in the future to confirm findings.
Supporting Information List key references.	Benotti MJ, Trenholm RA, Vanderford BJ, Holady JC, Stanford BD, Snyder SA. (2009). Pharmaceuticals and Endocrine Disrupting Compounds in U.S. Drinking Water. *Environ. Sci. Technol*., 43 (3), 597–603. Bexfield Laura M., Patricia L. Toccalino, Kenneth Belitz, William T. Foreman, and Edward T. Furlong (2019). Hormones and Pharmaceuticals in Groundwater Used as a Source of Drinking Water Across the United States. *Environ. Sci. Technol.* 2019, 53, 2950−2960 Water Research Foundation, Bruce, G.M. and Pleus, R.C. (2015). A Comprehensive Overview of EDCs and PPCPs in Water, WRF Project #4387b, May 2015. Water Research Foundation, Park Mi-Hyun, David Reckhow, Michael Lavine, Benjamin Stanford, Erik Rosenfeldt, David Lipsky, Alex Mofidi (2017). EDC/PPCP Benchmarking and Monitoring Strategies for Drinking Water Utilities. ISBN 978-1-60573-314-2. Project # 4386. WHO (2012). Pharmaceuticals in drinking-water. ISBN 978 92 4 150208 5, Geneva, Switzerland. WHO (2017). Guidelines for drinking-water quality: fourth edition incorporating the first addendum. ISBN 978-92-4-154995-0, Geneva, Switzerland.

DIAGNOSTIC QUESTIONS TO SUPPORT CEC PRIORITIZATION	
Instructions	The purpose of the Diagnostic Questions is to determine whether the CEC or CECs Group are significant to SFPUC drinking water and whether they merit further evaluation and/or action. All answers require explanation except those clearly not applicable. The Diagnostic Questions are divided into Health, Occurrence, and Treatment sections. The more questions are answered with a "Yes", the higher the probability that the CEC is a high priority or that a proactive approach should be taken.

HEALTH EFFECTS FROM SCIENTIFIC STUDIES

Question	Answer	Explanation and Comments
Is scientific knowledge on CEC health effects well developed?	**No**	Based on various risk assessments, a 2008 review stated that there is no convincing evidence to date that EDC (e.g., hormones) at the levels detected in drinking water cause adverse effects to humans. However, research has been limited to the potential long-term effects of low-level exposures to EDC (e.g., hormones) and PPCP (WRF, Snyder et al., 2008b). Research on potential human health impacts is ongoing, especially with respect to EDC and their impacts on vulnerable populations (Fono and McDonald, 2008).
Based on current scientific understanding, does the CEC pose potential health risk at the levels typically found in drinking water in the US?	**Unknown**	No clear link has been established between pharmaceuticals present in the environment and direct impacts on human health. Possible effects of long-term exposures may eventually be demonstrated, therefore PPCPs and EDCs are appropriately included on the EU Directive (EU) 2020/2184 watch list as well as the USEPA CCL. (EC, 2019, EU Directive 2020/2184, EPA CCL5)) Scientific concerns with hormones are mainly associated with ecological impacts, as hormones are considered EDC with documented impacts on fish. The exposure to PPCP/EDC from drinking water is small compared to other exposures (e.g., medications, food and beverages) (WRF, Snyder et al., 2008a).

Question	Answer	Explanation and Comments
Adverse health impacts observed in other drinking water systems? Are public health studies documenting human health impacts from drinking water (disease or outbreaks) available?	No **Not likely**	Potential human health impacts from PPCP/EDC are an area of study world-wide.To date, studies of the human health impacts from exposure to the levels likely to be found in drinking water indicate that human health effects from this exposure are not likely. Studies worldwide have identified the presence of PPCPs and EDCs in water resources, including in groundwater in France (Caban et al., 2016) and drinking water in China (Lv et al., 2019). While exposure to high levels of PPCP/EDC demonstrate the potential for adverse human health effects, exposure through the drinking water route does not attain a level of concern relevant to those studies. Studies of human health effects of PPCP/EDC exposure via drinking water are not likely to be pursued until a plausible mode of action of low levels such as those seen in drinking water has been identified. WHO reports that the weight of evidence from recent studies points to it being very unlikely that pharmaceuticals in drinking water pose a threat to human health at low concentrations. (EC, 2019)
Existing regulations or guidelines outside of US (e.g., WHO, EU)?	No	EU adopted provisions of the precautionary principle. EDC are substances of particular concern and scientific uncertainty remains regarding their assessment (for example as regards the safe limit of exposure), once it is proven that a substance is an EDC, the substance in principle cannot be authorized for use. (EU, 2018)
Existing US health advisories or CA notification levels?	No	There are no existing US health advisories or CA notification levels.
Likely US regulation in the next 10 years? Is CEC on a regulatory development list, such as CCL? Is there a pending regulation or California PHG?	No	CCL3 (2009) and CCL4 (2016) included 12 pharmaceuticals/hormones. Draft CCL5 (2021) includes some PPCP/EDC UCMR3 (2012) contained screening list of 7 hormones. UCMR5 (2021) list does not contain PPCP/EDC. Unlikely to be regulated in the US in the next 10 years.
SUMMARY – SIGNIFICANT TO PUBLIC HEALTH IN GENERAL? *(Based on above answers)*	**Possible**	The levels of PPCP/EDC in drinking water are very low and studies conducted have thus far indicated no appreciable risk to human health from exposure to PPCP/EDC in drinking water. Possible effects of long-term exposure on vulnerable populations warrant a precautionary approach.

OCCURRENCE		
Question	**Answer**	**Explanation and Comments**
Is scientific knowledge on CEC sources/formation well developed?	**Yes**	It is generally recognized that wastewater is the major source of PPCP/EDC to drinking waters. The levels of PPCP/EDC in drinking water depend primarily on the extent of wastewater discharge to the watershed from which the drinking water is sourced (WFR, Snyder, 2008b).
CEC presence reported in other water supplies? Are occurrence studies available?	**Yes**	Available studies have reported that concentrations of pharmaceuticals in surface waters, groundwater and partially treated water are typically less than 100 ng/L, and concentrations in drinking water are generally below 50 ng/L (WHO, 2012). Various surveys have been conducted for PPCP/EDC occurrence in drinking water in the US (WRF, Snyder et al., 2008a and 2008b; Benotti et al., 2009; and WRF, Bruce and Pleus, 2015).
CEC present in SFPUC watersheds and/or source waters? Are there complex issues involved in managing CEC; e.g., point vs. non-point sources?	**No**	PPCP/EDC are not expected in SFPUC's protected watersheds, because source waters are not impacted by wastewater discharges. Screening surveys conducted in 2006, 2012, 2013 and 2020/2021 indicated a limited number of PPCP/EDC detections at low levels near the detection limit (e.g., caffeine, DEET, triclosan) and also in some field blanks (though most PPCP/EDC were not detected). Reliable, low-level PPCP/EDC analysis is difficult and therefore in these cases the detections are uncertain. Hormones are naturally produced by mammals, birds, and plants (phytoestrogens). Occasional low-level detections in surface waters but not drinking water could be expected. SFPUC protected surface waters are one of the best in the country, also in terms of PPCP/EDC.

Question	Answer	Explanation and Comments
Is the CEC a potential groundwater contaminant?	No	There are no wastewater discharges in SFPUC watersheds that could impact Regional or San Francisco groundwater wells. Furthermore, groundwater wells are constructed at a depth and with proper seals such that they are not impacted by shallow contaminants. A limited number of PPCP/EDC were detected near the detection limit in groundwater and in some field blanks (though most PPCP/EDC were not detected) in monitoring of 16 wells in SFRWS and SFWS in 2020/2021. Hormones are not considered groundwater contaminants. The risk of exposure to PPCP/EDC through potable water could be higher when treated wastewater is used for artificial groundwater recharge. (Caban et al., 2016) No hormones were detected in groundwater monitoring of 16 wells in SFRWS and SFWS in 2020/2021. Please see further discussion of SFPUC results in Monitoring Review.
If the CEC is a potential groundwater contaminant, is it highly mobile in the subsurface? Is CEC low-sorbing and resistant to microbial degradation?	Yes	When PPCP/EDC enter the groundwater, they can be stable for a long time, because the degradation is limited to hydrolysis. The low dissolved oxygen concentration, low temperature and low concentrations of nutrients in ground water, favor long-term persistence of micro-pollutants in this environment. (Caban et al., 2016)
Precursor present in SFPUC source waters? *(Including surface waters and groundwaters)*	No	There are no chemical precursors to PPCP/EDC.
Formed or added during current SFPUC treatment? If so, describe whether the formation or addition of CEC can be controlled.	No	PPCP/EDC are not formed or added during drinking water treatment.

Question	**Answer**	**Explanation and Comments**
Formed or added within SFPUC storage or distribution? If so, describe whether the formation or addition of CEC can be controlled.	**No**	PPCP/EDC are not formed or added during storage or distribution of drinking water.
Detected in SFPUC drinking water?	**No**	PPCP/EDC have not been detected in SFPUC drinking water, except for rare detections close to the detection limit. The 2012 SFPUC monitoring detected triclosan (toothpaste, soap ingredient) in drinking Hetch Hetchy water at a low level very close to the detection limit. No hormones were detected in drinking water during UCMR3 monitoring in 2013 and in groundwater wells in 2020/2021.
SUMMARY – OCCURRENCE IN SOURCE OR DRINKING WATER? *(OR SIGNIFICANT POTENTIAL TO OCCUR)* *(Based on above answers)*	**No**	PPCP/EDC are not expected in SFPUC's protected watersheds, because source waters are not impacted by wastewater discharges. Monitoring conducted in 2006, 2012, 2013 and 2020/2021 indicated a limited number of PPCP/EDC detections at low levels near the detection limit. Same appears to be the case for groundwater based on 2020/2021 monitoring of 16 wells.

TREATMENT

Question	Answer	Explanation and Comments
Is scientific knowledge on CEC treatment/removal well developed?	**No**	Coagulation is largely ineffective in removing pharmaceuticals. Free chlorine removes up to 50% of the pharmaceuticals investigated, whereas chloramine has lower removal efficiency. Antibiotics showed high removal by free chlorine but low removal by chloramine. Advanced water treatment processes, such as ozonation, advanced oxidation, activated carbon and membranes (e.g. nanofiltration, reverse osmosis) are able to achieve higher removal rates (above 99%) for targeted pharmaceuticals. (WHO, 2012) There is no single treatment technology that acts as a 100% barrier to all PPCP/EDC. Oxidation products of PPCP/EDC may still present a toxicity risk (WRF, Snyder, 2008b; WRF, Reckhow, 2015).
Likely to pass through current treatment for Hetch Hetchy Supply? Describe any complex issues with the treatment/removal of CEC.	**Yes, but not present**	Ultraviolet (UV) treatment is not effective for hormones (Snyder, 2008c). Many natural hormones are destroyed by chlorine disinfection. Further, protected SFPUC watersheds are not subject to wastewater discharges and anthropogenic PPCP/EDC. Results of monitoring at Hetch Hetchy Reservoir (source) and drinking water provide evidence that PPCP/EDC are not expected to occur in Hetch Hetchy drinking water.
Likely to pass through current treatment at SVWTP? Describe any complex issues with the treatment/removal of CEC.	**Yes, but not present**	SVWTP utilizes chlorination as a primary disinfectant, which is not effective at oxidizing many pharmaceuticals (except hormones, which are easily oxidized by chlorine). Other treatment steps are not expected to remove PPCP/EDC. Ozonation is in pre-design phase for that WTP. Results of monitoring at Calaveras and San Antonio Reservoirs (source waters) and SVWTP drinking water provide evidence that PPCP/EDC are not expected to occur in SVWTP drinking water.
Likely to pass through current treatment at HTWTP? Describe any complex issues with the treatment/removal of CEC.	**No, but not present**	HTWTP uses ozone, which is in many cases effective at oxidizing trace concentrations of PPCP/EDC. Results of monitoring at San Andreas Reservoir (source water) and HTWTP drinking water provide evidence that PPCP/EDC are not expected to occur in HTWTP drinking water.

Question	Answer	Explanation and Comments
Likely to pass through current treatment for groundwater? Describe any complex issues with the treatment/removal of CEC.	**Yes, but not present**	SFPUC groundwater will be treated by chlorination, which is not effective at oxidizing many PPCP/EDC. Other treatment steps will involve chemical addition (and in some cases, iron/manganese treatment), which will not remove PPCP/EDC. Results of groundwater monitoring provide evidence that PPCP/EDC are not expected to occur in drinking water.
SUMMARY – LIKELY TO PASS (NOT REMOVED BY) CURRENT TREATMENT? *(Based on above answers)*	**Yes, but not present**	Conventional drinking water treatment and chlorination/chloramination are not expected to significantly remove most PPCP/EDC. PPCP/EDC are not expected to occur in SFPUC drinking water provided watershed protection is maintained and groundwater will not be affected by reclaimed water.
CEC PRIORITIZATION – CURRENT ASSESSMENT		
Instructions	This section prioritizes the CEC based upon the information developed in the above Diagnostic Questions as well as in the background information. For top priorities (high and medium priorities), monitoring and/or mitigation measures should be developed if feasible. For low priorities, WQD and SFDPH will monitor source water protection, track regulatory developments, health/technical studies and reevaluate priority when needed.	
Could CEC occur in SFPUC drinking water at levels of possible health significance? *(Based on above Diagnostic Questions)*	**NO** Monitoring of SFPUC source and drinking waters in 2006, 2012, 2013 and 2020/2021 has shown PPCP/EDC non-detects or very low-level (low confidence) detections. Studies and reviews conducted in the U.S. and internationally have thus far indicated no appreciable risk to human health from low-level exposure to PPCP/EDC in drinking water. PPCP/EDC are not expected to occur in SFPUC drinking water provided watershed protection is maintained and groundwater will not be affected by reclaimed water.	

CEC Prioritization for SFPUC High, Medium, or Low. Provide explanation. *(A high number of "Yes" answers to the Diagnostic Questions indicates a higher priority, and "No" or very few "Yes" answers indicates a lower priority.)*	**LOW PRIORITY FOR SFPUC** PPCP/EDC are a low priority because they are either not detected or infrequently detected at extremely low levels in SFPUC source and drinking waters. Reliable, low-level PPCP/EDC analysis is difficult and therefore detections are uncertain. International studies conducted have thus far indicated no appreciable risk to human health from low-level exposure to PPCP in drinking water. SFPUC has protected watersheds and source waters that are not impacted by significant wastewater discharges. Future recharge of reclaimed water will need to be monitored to ensure that groundwater is not affected.
Implemented Actions Indicate the progress and results of any action items, above, such as implemented in previous cycles of CEC review. Evaluate whether changes to the action plan are required.	• Maintained source water protection. • Participated in 2006 AWWARF national survey of 62 PPCP/EDC at 20 US drinking WTPs (WRF, Snyder et al., 2008a). 1 source water and 2 drinking water locations were monitored. • In June and July 2012, conducted monitoring of 7 UCMR3 hormones and 9 SWRCB recommended PPCP in Hetch Hetchy, San Antonio, Calaveras and San Andreas Reservoirs (source water), at Alameda East, SVWTP drinking water and HTWTP drinking water, and in CUP#10A and #11A (groundwater wells). • Conducted 2013 UCMR3 monitoring for 7 hormones, which were not detected in SFPUC drinking water at 4 distribution system locations. • Conducted 2020/2021 comprehensive monitoring of 98 PPCP/EDC and 8 hormones in surface water (5 locations), groundwater (16 wells) and drinking water (3 locations). • Design phase for ozonation at SVWTP.

Recommended Actions Does the situation merit investing additional resources or has the information gathered so far fulfilled due diligence? Actions could include monitoring and other measures (specified by source water, if necessary).	**Proposed (when feasible and appropriate for SFPUC or mandated by regulatory development):** 1. Implement ozonation at SVWTP. 2. Monitor water reclamation activities in SFRWS and SFWS. 3. During sampling and analysis, use field blanks (pour high-purity reagent water into sampling bottles during sample collection) and trip blanks (unopened bottles with high-purity reagent water) and special precautions for the sampling and laboratory staff. Reagent water for the field and trip blanks should be analyzed and data reviewed prior to sampling. 4. Repeat groundwater monitoring for PPCP/EDC in 2028 after groundwater wells are operated at design production rates. **Ongoing:** 1. Maintain source water protection, optimized multibarrier treatment and distribution operation. 2. Track federal and state regulatory developments. 3. Track peer-reviewed health/technical studies.

This evaluation was prepared based on available information (peer-reviewed literature and occurrence data) with the purpose of prioritizing work and informing the public on unregulated CEC. This evaluation will be updated every 6 years or when significant new research or occurrence data on CEC become available that may warrant changing priority and recommendations.

Water Quality Division, SFPUC Monitoring Review 2016 – 2021

Contaminants of Emerging Concern (CEC) in Drinking Water

Pharmaceuticals and Personal Care Products (PPCP), Endocrine Disrupting Chemicals (EDC) & Hormones

SFPUC's protected source waters are not impacted by wastewater discharges. SFPUC monitored its source and drinking waters for PPCP/EDC in 2006, 2012, 2013 and in 2020/2021, finding that most PPCP/EDC were below the detection limit, although some were detected at trace levels. Estrone, progesterone, caffeine, and DEET were detected at trace levels in raw water, and triclosan (near detection limit [DL]) was detected at Alameda East in drinking water (no studies have shown that there is any risk to human health from very low-level detects of PPCP/EDC in drinking water).

SFPUC Monitoring 2020-2021

Selection of Analytes for Monitoring. The 2016 CEC Report recommended monitoring PPCP/EDC every six years to confirm that PPCP/EDC are not present or present at very low levels; therefore, a round of PPCP/EDC monitoring was planned in the time period of 2019 to 2021. For PPCP/EDC and hormones, Eurofins Laboratory offered two different analytical suites: (1) PPCP/EDC by LC/MS/MS and (2) Hormones by EPA Method 539. These two suites of analytes were compared to seven monitoring and regulatory lists to ensure adequate contaminant coverage. These lists are noted in Table 8-2, when applicable. Table 8-3 includes CEC that were included in one or more of the seven reference lists but are not analyzed by Eurofins Laboratory's analytical suites of PPCP/EDC by LC/MS/MS and Hormones by EPA Method 539. Both Tables 8-2 and 8-3 provide information about use and source of contaminant to help interpret information.

Monitoring Locations. Surface water samples were taken from the following five locations: Hetch Hetchy Reservoir, San Antonio Reservoir, Calaveras Reservoir, Pond F3 and San Andreas Reservoir. Drinking water samples were collected at three locations: Alameda East, SVWTP, and HTWTP. Groundwater samples were taken at 16 different groundwater wells. Field blanks (reagent water poured in the field) were collected on each day of sampling.

Monitoring Results for Surface Raw and Drinking Waters. The results are listed in Tables 8-4 and 8-5. Out of 98 analytes tested in 2020/2021 by LC-MS-MS Method and 8 hormones by EPA 539, all at ng/L level (parts per trillion):

- 4 analytes of 106 tests were detected in Hetch Hechy Reservoir in May of 2021, all near method detection limit: Methylparaben (39 n/L, ingredient of cosmetics and personal care products), Propylparaben (5.9 ng/L, ingredient of cosmetics and food additive), caffeine (13 ng/L, ingredient in coffee, tea, chocolate and in some pharmaceutical products), and 4-androstene-3,17-dione (0.37 ng/L, steroid hormone supplement),
- 2 analytes of 106 tests were detected in Pond F3 in Alameda County: DEET (12 ng/L, insect repellent), 4-androstene-3,17-dione (0.49 ng/L, steroid hormone supplement),
- 1 analyte of 106 tests was detected in treated Hetch Hetchy drinking water at Alameda East in July of 2020: Propylparaben (14 ng/L, ingredient of cosmetics and food additive),
- 0 analytes (none of 106 tests) were detected in the following untreated source waters: San Antonio Reservoir (March 2020, mostly Hetch Hetchy water), in Calaveras Reservoir (March 2020, East Bay watershed), San Andreas Reservoir (March 2020, blend of Hetch Hetchy water and Peninsula watershed),
- 0 analytes (none of 106 tests) were detected in treated drinking waters: SVWTP (June 2020) and HTWTP (June 2020) effluents.
- Triclosan (12 n/L, ingredient of toothpastes, deodorants and soaps), caffeine (up to 50 ng/L), and DEET (12 ng/L, insect repellent) were detected in some samples in June and July 2012 monitoring listed for comparison also in Tables 8-4 and 8-5.
- All these contaminants are used for personal hygiene, as supplements or in beverages (caffeine) and could have resulted from minute sample contamination by the sampling staff despite thorough precautions taken. Field blanks were taken, which required pouring reagent water in the field into the sampling bottles. Trip blanks were not taken, which are unopened by the sampling staff. It is conceivable that sample contamination could have occurred at the analytical laboratory; possibly trip blanks could have been useful in detecting that. Often that is no explanation for low-level detects near the detection limit.

Table 8-6 compares the results of 2020/2021 monitoring by SFPUC (Table 8-5, source waters only) with the occurrences of EDC/PPCP in US surface waters (various surveys) reported by WRF (2017). Because of large numbers of possible analytes in US surveys and SFPUC monitoring, not all comparisons were possible. SFPUC monitoring detects, detection limits, and number of NDs are listed in the last column for comparison, where it was possible. SFPUC monitoring results from 2012 were included as shown in Table 8-4.

SFPUC has excellent surface water quality in terms of PPCP/EDC

Based on 2020/2021 SFPUC monitoring and additional sampling in 2012, out of 43 contaminants were comparisons were possible, it is evident that SFPUC surface waters have lower occurrences or concentrations (not detected for 38 contaminants) of PPCP/EDC and hormones than in the national surveys or California survey for the State Water Project. This confirms conclusion from an earlier 2006 national survey that SFPUC protected surface waters are one of the best in the country in terms of either non-detected or extremely low detections of PPCP/EDC. your reader's attention with a great quote from the document or use this space to emphasize a key point.

Monitoring Results for Groundwater. The results of monitoring at 16 wells are also listed in Tables 8-4 and 8-5. Out of 98 analytes tested in 2020/2021 by LC-MS-MS Method and 8 hormones by EPA 539, all at ng/L level (parts per trillion):

- 3 analytes of 106 tests were detected in GSR well SDW, all near method detection limit: Iohexal (28 n/L, consumer/industrial chemical), Propylparaben (7.6 ng/L, ingredient of cosmetics and food additive), sucralose (270 ng/L, artificial sweetener),
- 1 analyte of 106 tests was detected in San Francisco ZOO well #5 near method detection limit: DEET (10 ng/L, insect repellent),
- 1 analyte of 106 tests was detected in San Francisco well SSW near method detection limit: Sulfamethoxazole (6.4 ng/L, antibiotic medication),
- 1 analyte of 106 tests was detected in GSR well at Millbrae Yard: Thiabendazole (170 ng/L RELATIVELY HIGH CONCENTRATION, food preservative),
- 1 analyte of 106 tests was detected in GSR well MSW near method detection limit: 1-7 Dimethylxanthine (6 ng/L, stimulant),
- 0 analytes (none of 106 tests) were detected in the remaining 11 wells.

The initial 2020/2021 monitoring of two Pleasanton wells, nine SFRWS wells and five San Francisco wells indicates no detections of the vast majority of 106 PPCP/EDC tested in all 16 wells. Sporadic extremely low detects of a few PPCP/EDC in five wells do not indicate well contamination; possibly sample contamination. No hormones were detected in any of 16 wells. Monitoring could be repeated after wells are in service for some time with field and trip blanks and special precautions for the sampling staff and laboratory staff during the analysis. Reagent water for the field blanks should be analyzed and data reviewed prior to sampling.

Previous SFPUC Monitoring for PPCP/EDC

2006 AWWARF. SFPUC participated in the 2006 AwwaRF study of 62 EDCs and pharmaceuticals at 20 drinking water treatment plants in the USA (WRF, Snyder et al., 2008a, 2008b). One round of sampling was conducted for raw water at HTWTP (HTWTP_RAW), finished water (HTWTP_EFF_POST) and WDS at San Pedro Valve Lot (SA#2_SAN_PEDRO). These sites were selected as representative of all SFPUC water sources. All compounds were non-detect except estrone and progesterone (natural hormones) which were detected at HTWTP_RAW at 0.21 ng/L and 2.5 ng/L, respectively, and supported by duplicate analyses but not in drinking water.

The project's Principal Investigator, Dr. Shane Snyder, estimated that SFPUC water is one of the most pristine drinking waters in terms of CEC, and stated that "in terms of steroid hormones, this is not a drinking water issue as the concentrations are exceedingly minute and the reaction between phenolic hormones and chlorine is very fast". (EPA Webcast: A New Framework for Addressing Contaminants as a Group, 7/28/2010). Consistent with this statement, results were non-detect for finished waters.

2012 SFPUC Monitoring. SFPUC conducted a one-time sampling in June/July 2012 of raw surface water reservoirs (Hetch Hetchy, San Antonio, Calaveras, and San Andreas), treated water from each treatment facility (Alameda East Portal, SVWTP, and HTWTP), and raw groundwater from two wells (CUP 10A and 11A in Daly City). This effort was considered a preliminary screening to broadly compare SFPUC source waters and determine whether there is significant occurrence of PPCP/EDC. Analytes included the 7 hormones on UCMR3 and 9 PPCP on the SWRCB list for monitoring groundwater replenishment with recycled water (SWRCB, 2013) as well as other CECs. No hormones were detected. No PPCP were detected, with the following exceptions:

- <u>Caffeine</u> was detected in all raw surface waters (9 to 50 ng/L) but was also detected in two of four field blanks (6 and 40 ng/L). Caffeine was not detected in the treated waters (detection limit of 5 ng/L).
- <u>DEET</u> was detected in one raw surface water (12 ng/L), just above the detection limit of 10 ng/L. It was not detected in the treated waters.
- <u>Triclosan</u> was detected in one treated water (12 ng/L), just above the detection limit of 10 ng/L.
- Though PPCPs were not detected in the raw groundwater, 4 PPCPs were detected in the field blank prepared alongside the groundwater (41 to 230 ng/L).

Difficulty in Low-Level PPCP/EDC Analyses and Possibility of Low-Level Sample Contamination

PPCP/EDC detections near the detection limit and in field blanks underscore the difficulty of accurate, reliable, low-level PPCP/EDC analysis and suggest that the detections are uncertain. Though reliable analytical methods are available for many PPCP/EDC, low-level contamination is common (e.g., from personnel, sampling bottles and equipment, etc.).

UCMR3 Sampling in 2013. 7 hormones were monitored quarterly in the SPFUC system as part of the UMCR3 in 2013. Samples were collected at two distribution system entry points and two points of maximum residency. All samples were non-detect (method reporting limits were ≤ 0.9 ng/L).

Table 8-2. Recommended PPCP, EDC, and Hormones to Be Tested for in Surface Water and Groundwater Sources at SFPUC (WQD Project Initiation Form, Gregg Olson and Cameron Ripley, 10/29/2019)

Contaminant	**Use/Source**	**Reference Lists*** **[1-WRF, 2-NWRI, 3-SFPUC, 4-SWRCB (2013), 5-SWRCB (2019), 6-UCMR, 7-CCL 4]**
PPCPs and EDCs by LC-MS-MS (Eurofins)		
2,4-D	Systemic herbicide	N/A
4-nonylphenol	The main use of nonylphenol is in the manufacture of nonylphenol ethoxylates, which have been used in a wide range of industrial applications and consumer products including laundry detergents, cleaners, degreasers, paints and coatings and other uses	1, 7
4-tert-octylphenol	Detergents and rubber	N/A
Acesulfame	Artificial sweetener	N/A
Bendroflumethiazide	Diuretic medication used to treat high blood pressure (hypertension)	N/A
Bisphenol A	Used in plastics	1, 3
Butalbital	Medication used to treat pain and headaches	N/A
Butylparben	Preservative in cosmetics and skin care products	N/A
Chloramphenicol	Antibiotic medication used to treat bacterial infections	N/A
Clofibric Acid	Naturally occurring pharmaceutical compound	N/A
Diclofenac	Anti-inflammatory drug	1
Estradiol	Medication used to treat symptoms caused by menopause or removal of the ovaries	N/A
Estriol (also listed in Hormones by EPA 539)	Estrogenic hormone used in veterinary pharmaceuticals (placed in 2 locations, as constituent is both natural and anthropogenic, i.e., a pharmaceutical)	1, 3, 6, 7
Estrone (also listed in Hormones by EPA 539)	Estrogenic hormone used in veterinary and human pharmaceuticals (placed in 2 locations, as constituent is both natural and anthropogenic)	1, 3, 6, 7
Ethinyl Estradiol - 17-alpha (also listed in Hormones by EPA 539)	Estrogenic hormone used in veterinary and human pharmaceuticals	1, 3, 6

Contaminant	**Use/Source**	**Reference Lists*** **[1-WRF, 2-NWRI, 3-SFPUC, 4-SWRCB (2013), 5-SWRCB (2019), 6-UCMR, 7-CCL 4]**
Ethylparaben	Antifungal preservative	N/A
Gemfibrozil	Cholesterol drug	1, 2, 3, 4, 5
Ibuprofen	Pain reliever	N/A
Iohexal	Consumer/industrial chemical	5
Iopromide	X-ray and CT scan contrast agent	3, 4
Isobutylparaben	Preservative found in many skin care products	N/A
Methylparaben	Anti-fungal agent used in a variety of cosmetics and personal-care products	N/A
Naproxen	Nonsteroidal anti-inflammatory drug	1
Propylparaben	Preservative found in many water-based cosmetics and is used as a food additive	N/A
Salicylic Acid	Skin medicine	N/A
Sucralose	Food additive used as an artificial sweetener	3, 4, 5
Triclocarban	Antibacterial chemical that used to be used in soaps and lotions	N/A
Triclosan	Antibacterial and antifungal agent used in a variety of consumer products, including toothpastes, deodorants, and soaps	1, 3, 4
Warfarin	Blood thinner	N/A
1,7-Dimethylxanthine	Stimulant for the central nervous system	N/A
Acetaminophen	Pain reliever for minor aches and pains (e.g., Tylenol)	N/A
Albuterol	Medication to treat or prevent bronchospasm	N/A
Amoxicillin	Medication to treat infections and stomach ulcers	N/A
Andorostenedione (also listed in Hormones by EPA 539)	Steroid hormone	N/A
Atenolol	Beta blocker to treat high blood pressure and chest pain	1
Atrazine	Herbicide used to prevent weeds and is the most used herbicide in the U.S.	1, 2
Bezafibrate	Medication used to treat hyperlipidaemia	N/A

Contaminant	**Use/Source**	**Reference Lists*** **[1-WRF, 2-NWRI, 3-SFPUC, 4-SWRCB (2013), 5-SWRCB (2019), 6-UCMR, 7-CCL 4]**
Bromacil	Herbicide	N/A
Caffeine	Stimulant naturally present in virtually everyone's diet, including coffee, tea, chocolate, as well as in some pharmaceutical products	2, 3, 4
Carbadox	Veterinary drug that prevents swine infections (e.g. swine dysentery)	N/A
Carbamazepine	Anticonvulsant drug that treats seizures, nerve pain, and bipolar disorder	1, 2, 3
Carisoprodol	Medication to treat pain and stiffness from muscle spasms	N/A
Chloridazon	Herbicide	N/A
Chlorotoluron	Herbicide	N/A
Cimetidine	Medication to reduce stomach acid to treat ulcers and acid reflux	N/A
Cotinine	Substance found in tobacco	N/A
Cyanazine	Herbicide	N/A
DACT	Herbicide	N/A
DEA	Used in cosmetics, moisturizers, and sunscreens	N/A
N,N-Diethyl-meta-toluamide (DEET)	Insect repellent	1, 2, 3, 4
Dehydronifedipine	Metabolite in human plasma	N/A
DIA	Used in creams, lotions, sun products, and mineral oil to reduce greasiness	N/A
Diazepam	Medication for anxiety, muscle spasms, and seizures	1
Phenytoin (Dilantin)	Anticonvulsant medication to treat and prevent seizures	1, 2
Diltiazem	Medication to treat high blood pressure and chest pain	N/A
Diuron	Herbicide used to control weeds	2, 6, 7
Erythromycin	Medication to treat infections and acne	7
Flumeqine	Antibiotic to treat bacterial infections	N/A
Fluoxetine	Antidepressant medication	1
Isoproturon	Herbicide	N/A
Ketoprofen	Nonsteroidal anti-inflammatory drug	N/A

Contaminant	**Use/Source**	**Reference Lists*** **[1-WRF, 2-NWRI, 3-SFPUC, 4-SWRCB (2013), 5-SWRCB (2019), 6-UCMR, 7-CCL 4]**
Ketorolac	Nonsteroidal anti-inflammatory drug	N/A
Lidocaine	Anesthetic and antiarrhythmic medication to treat irregular heartbeats	N/A
Lincomycin	Antibiotic medication used to treat serious infections	N/A
Linuron	Herbicide	1, 6
Lopressor	Medication to treat high blood pressure, chest pain, and heart failure	N/A
Meclofenamic Acid	Medication used for joint, muscular pain, arthritis, and dysmenorrhea	N/A
Meprobamate	Medication to treat tension, anxiety, and nervousness	1
Metazachlor	Herbicide	N/A
Metformin	Anti-diabetic medication	N/A
Metolachlor	Herbicide for weed control on agricultural crops	1, 6, 7
Nifedipine	Medication to treat high blood pressure and chest pain	N/A
Norethindrone (19-Norethisterone)	Synthetic progesteronic hormone used in pharmaceuticals	7
OUST (Sulfameturon, methyl)	Herbicide	N/A
Oxolinic Acid	Veterinary drug used in aquaculture	N/A
Pentoxifylline	Vasodilator and anti-inflammatory medication to treat poor blood circulation by improving blood flow through the vessels	N/A
Phenazone	Nonsteroidal anti-inflammatory drug	N/A
Primidone	Anticonvulsant medication to treat seizures	2
Progesterone	Steroid hormone	1
Propazine	Herbicide	N/A
Quinoline **COVERED IN A DIFFERENT MONITORING PLAN**	It is used in the production of other substances, and as a pharmaceutical (anti-malarial) and as a flavoring agent (placed in 2 locations, industrial chemicals and pharmaceuticals)	7
Simazine	Herbicide	2

Contaminant	**Use/Source**	**Reference Lists*** **[1-WRF, 2-NWRI, 3-SFPUC, 4-SWRCB (2013), 5-SWRCB (2019), 6-UCMR, 7-CCL 4]**
Sulfachloropyridazine	Medication used for urinary tract infections and veterinary medicine	N/A
Sulfadiazine	Antibiotic used to treat urinary tract infections, malaria, ear infections, and toxoplasmosis	N/A
Sulfadimethoxine	Medication used to treat respiratory, urinary tract, enteric, and soft tissue infections	N/A
Sulfamerazine	Antibacterial medication	N/A
Sulfamethazine	Antibacterial medication	N/A
Sulfamethizole	Antibiotic medication	N/A
Sulfamethoxazole	Antibiotic medication	1, 2, 5
Sulfathiazole	Antibiotic medication	N/A
Tris (2-carboxyethyl) phosphine (TCEP)	Reducing agent used in fire retardants	1, 2, 3
TCPP (Fyrol PCF)	Fire retardant	1
TDCPP	Used in fire retardants, pesticides, plasticizers, and nerve gases	N/A
Testosterone (also listed in Hormones by EPA 539)	Steroid hormone	1, 3, 6
Theobromine	Lowers blood pressure and naturally found in chocolate, tea plant leaves, and kola nuts	N/A
Theophylline	Medication for respiratory diseases (e.g., chronic obstructive pulmonary disease and asthma)	N/A
Thiabendazole	Food preservative to control mold, blight, and other fungal diseases in fruits and vegetables	N/A
Trimethoprim	Antibiotic that treats urinary tract and ear infections	1

Hormones by EPA 539 Method (Eurofins)		
17-alpha-ethynylestradiol (Ethinyl Estradiol)	Estrogenic hormone used in veterinary and human pharmaceuticals	1, 3, 6
17-beta-Estradiol	Estrogenic hormone used in pharmaceuticals (placed in 2 locations, as constituent is both natural and anthropogenic, i.e., a pharmaceutical)	3, 4, 6, 7
4-androstene-3,17-dione	Steroid hormone supplement	3, 6
Andorostenedione	Steroid hormone	N/A
Equilin	Estrogenic hormone and is used in pharmaceuticals	3, 6, 7
Estriol	Estrogenic hormone and is used in veterinary pharmaceuticals (placed in 2 locations, as constituent is both natural and anthropogenic, i.e., a pharmaceutical)	1, 3, 6, 7
Estrone	Estrogenic hormone and is used in veterinary and human pharmaceuticals (placed in 2 locations, as constituent is both natural and anthropogenic)	1, 3, 6, 7
Testosterone	Steroid hormone	1, 3, 6

***Reference Lists:**

1. Water Research Foundation (formerly AwwaRF) study on PPCPs and EDCs, June 2006. Contaminants with >10% detection frequency.

2. National Water Research Institute study on PPCPs and EDCs in drinking water sources in California, April 2008 to April 2009. Contaminants with >10% detection frequency in State Project Water.

3. San Francisco Public Utilities Commission's CEC monitoring for surface water sources at SFPUC, Summer 2012.

4. State Water Resources Control Board's Recycled Water Policy, Table 1 - CECs to be Monitored, January 2013.

5. State Water Resources Control Board's Recycled Water Policy, Attachment A, Table 1: Health-based and performance indicator CECs, April 2019.

USEPA’s Unregulated Contaminant Monitoring Rules 1, 2, 3, or 4. UCMR 1 (2001-2005), UCMR 2 (2007-2011), UCMR 3 (2012-2016), or UCMR 4 (2017-2021).

7. USEPA’s Contaminant Candidate List 4's PPCPs and hormones (2016).

N/A = not applicable (not on any of the seven reference lists, above).

Table 8-3. CECs on a Reference List*, But Not Covered Under Two Eurofins Laboratory Suites (PPCPs/EDCs and EPA 539 Method) (WQD Project Initiation Form, Gregg Olson and Cameron Ripley, 10/29/2019)

Contaminant	Use/Source	Reference Lists* [1-WRF, 2-NWRI, 3-SFPUC, 4-SWRCB (2013), 5-SWRCB (2019), 6-UCMR, 7-CCL 4]
1,4-Dioxane	Used as a solvent for cellulose formulations, resins, oils, waxes and other organic substances. It is also used in wood pulping, textile processing, degreasing, in lacquers, paints, varnishes, and stains; and in paint and varnish removers	3, 5, 6, 7
17-alpha-estradiol	Estrogenic hormone and is used in pharmaceuticals (placed in 2 locations, as constituent is both natural and anthropogenic)	7
2,4,6-Trichlorophenol	Glue preservative	6
2-Methoxyethanol	Used in consumer products, such as synthetic cosmetics, perfumes, fragrances, hair preparations, and skin lotions	7
2-Propen-1-ol	Used in the production of other substances, and in the manufacture of flavorings and perfumes	7
Apigenin	Found in parsley and artichokes	1
Atorvastatin	Cholesterol drug	1
Benzyl chloride	Used in the production of other substances, such as plastics, dyes, lubricants, gasoline and pharmaceuticals	7
Equilenin	Estrogenic hormone and is used in pharmaceuticals	7
Formononetin	Found in many plants and herbs, such as clover	1
Galaxolide	Used in fragrances	1
Genistein	Found in soy beans	1
Glycitein	Found in soy beans	1
Mestranol	Estrogenic hormone and is used in veterinary and human pharmaceuticals	7
Methoxychlor	Insecticide	2
N-Nitrosodimethylamine (NDMA) **MONITORED SEMI-ANNUALLY**	Formerly used in the production of rocket fuels, anti-oxidants and softeners for copolymers. It is formed in cured foods and during high temperature cooking. It may be a leachate from rubber gaskets and fittings and may form as a disinfection byproduct	3, 4, 5, 6, 7

Contaminant	**Use/Source**	**Reference Lists*** **[1-WRF, 2-NWRI, 3-SFPUC, 4-SWRCB (2013), 5-SWRCB (2019), 6-UCMR, 7-CCL 4]**
Nitroglycerin	Used in pharmaceuticals, in the production of explosives, and in rocket propellants (placed in 2 locations, pharmaceuticals and industrial chemicals)	7
N-Methyl-2-pyrrolidone	Solvent in the chemical industry and is used in the formulation of pharmaceuticals for oral and dermal delivery (placed in 2 locations, pharmaceuticals and industrial chemicals)	7
N-Nitrosomorpholine (NMOR)	Industrial chemical	5
o,p-DDD	DDT breakdown product	2
o-Hydroxy atorvastatin	Cholesterol drug	1
o-Toluidine	Used in the production of dyes, rubber, pharmaceuticals and pesticides	7
p-Hydroxy atorvastatin	Cholesterol drug	1
Perfluorooctane sulfonate (PFOS) **COVERED IN A DIFFERENT MONITORING PLAN**	PFOS has been used to make carpets, leathers, textiles, fabrics for furniture, paper packaging, and other materials that are resistant to water, grease, or stains. It is also used in firefighting foams at airfields. Many of these uses have been phased out by its primary U.S. manufacturer; however, there are still some ongoing uses	3, 5, 6, 7
Perfluorooctanoic acid (PFOA) **COVERED IN A DIFFERENT MONITORING PLAN**	PFOA has been used to make carpets, leathers, textiles, fabrics for furniture, paper packaging, and other materials that are resistant to water, grease, or stains. It is also used in firefighting foams at airfields. Many of these uses are being phased out by U.S. manufacturers; however, there are still some ongoing uses	3, 5, 6, 7

***Reference Lists:**

1. Water Research Foundation (formerly AwwaRF) study on PPCPs and EDCs, June 2006. Contaminants with >10% detection frequency.

2. National Water Research Institute study on PPCPs and EDCs in drinking water sources in California, April 2008 to April 2009. Contaminants with >10% detection frequency in State Project Water.

3. San Francisco Public Utilities Commission's CEC monitoring for surface water sources at SFPUC, Summer 2012.

4. State Water Resources Control Board's Recycled Water Policy, Table 1 - CECs to be Monitored, January 2013.

5. State Water Resources Control Board's Recycled Water Policy, Attachment A, Table 1: Health-based and performance indicator CECs, April 2019.

6. USEPA’s Unregulated Contaminant Monitoring Rules 1, 2, 3, or 4. UCMR 1 (2001-2005), UCMR 2 (2007-2011), UCMR 3 (2012-2016), or UCMR 4 (2017-2021).

7. USEPA’s Contaminant Candidate List 4's PPCPs and hormones (2016).

N/A = not applicable (not on any of the seven reference lists, above).

Table 8-4. Comparison of PPCPs, EDCs, and Hormones Sampled in Surface Water and Groundwater Sources at SFPUC in 2012, 2020, and 2021, Raw Water and Treated Water

Contaminant	Units	Raw Water									Treated Water					
		Hetch Hetchy Reservoir		San Antonio Reservoir		Calaveras Reservoir		San Andreas Reservoir		Pond F3	Alameda East		SVWTP TWR Effluent		HTWTP Effluent Post	
		6/5/2012	5/26/2021	6/6/2012	3/16/2020	6/6/2012	3/16/2020	6/5/2012	3/9/2020		6/13/2012	7/9/2020	6/13/2012	6/25/2020	7/24/2012	6/4/2020
PPCPs and EDCs by LC-MS-MS (n=98)																
2,4-D	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
4-nonylphenol	ng/L		<400		<400		<400		<400	<400		<400		<400		<400
4-tert-octylphenol	ng/L		<50		<50		<50		<50	<50		<50		<50		<50
Acesulfame	ng/L		<20		<20		<20		<20	<20		<20		<20		<20
Bendroflumethiazide	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Bisphenol A	ng/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Butalbital	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Butylparben	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Chloramphenicol	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Clofibric Acid	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Diclofenac	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Estradiol	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Ethylparaben	ng/L		<20		<20		<20		<20	<20		<20		<20		<20
Gemfibrozil	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Ibuprofen	ng/L		<10		<10		<10		<10	<10		<10		<10		<10
Iohexal	ng/L		<10		<10		<10		<10	<10		<10		<10		<10
Iopromide	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Isobutylparaben	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Methylparaben	ng/L		39		<20		<20		<20	<20		<20		<20		<20
Naproxen	ng/L		<10		<10		<10		<10	<10		<10		<10		<10
Propylparaben	ng/L		5.9		<5		<5		<5	<5		14		<5		<5
Salicylic Acid	ng/L		<100		<100		<100		<100	<100		<100		<100		<100
Sucralose	ng/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
Triclocarban	ng/L		<20		<20		<20		<20	<20		<20		<20		<20
Triclosan	ng/L	<10	<20	<10	<20	<10	<20	<10	<20	<20	12 B1	<20	<10	<20	<10	<20
Warfarin	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
1,7-Dimethylxanthine	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Acetaminophen	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Albuterol	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Amoxicillin	ng/L		<20		<20		<20		<20	<20		<20		<20		<20
Atenolol	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Atrazine	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Bezafibrate	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Bromacil	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Caffeine	ng/L	9.1 B1	13	50 B2	<10	30 B2	<10	9.8 B1	<10	<10	<5	<10	<5	<10	<5	<10

		Raw Water									**Treated Water**					
		Hetch Hetchy Reservoir		**San Antonio Reservoir**		**Calaveras Reservoir**		**San Andreas Reservoir**		**Pond F3**	**Alameda East**		**SVWTP TWR Effluent**		**HTWTP Effluent Post**	
Contaminant	**Units**	**6/5/2012**	**5/26/2021**	**6/6/2012**	**3/16/2020**	**6/6/2012**	**3/16/2020**	**6/5/2012**	**3/9/2020**		**6/13/2012**	**7/9/2020**	**6/13/2012**	**6/25/2020**	**7/24/2012**	**6/4/2020**
Carbadox	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Carbamazepine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Carisoprodol	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Chloridazon	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Chlorotoluron	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Cimetidine	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Cotinine	ng/L		<10		<10		<10		<10	<10		<10		<10		<10
Cyanazine	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
DACT	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
DEA	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
N,N-Diethyl-meta-toluamide (DEET)	ng/L	<10	<10	12 B1	<10	<10	<10	<10	<10	12 B2	<10	<10	<10	<10	<10	<10
Dehydronifedipine	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
DIA	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Diazepam	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Phenytoin (Dilantin)	ng/L		<20		<20		<20		<20	<20		<20		<20		<20
Diltiazem	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Diuron	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Erythromycin	ng/L		<10		<10		<10		<10	<10		<10		<10		<10
Flumeqine	ng/L		<10		<10		<10		<10	<10		<10		<10		<10
Fluoxetine	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Isoproturon	ng/L		<100		<100		<100		<100	<100		<100		<100		<100
Ketoprofen	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Ketorolac	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Lidocaine	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Lincomycin	ng/L		<10		<10		<10		<10	<10		<10		<10		<10
Linuron	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Lopressor	ng/L		<20		<20		<20		<20	<20		<20		<20		<20
Meclofenamic Acid	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Meprobamate	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Metazachlor	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Metformin	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Metolachlor	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Nifedipine	ng/L		<20		<20		<20		<20	<20		<20		<20		<20
Norethindrone (19-Norethisterone)	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
OUST (Sulfameturon, methyl)	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Oxolinic Acid	ng/L		<5		<5		<5		<5	<5		<5		<5		<5

		Raw Water									Treated Water					
		Hetch Hetchy Reservoir		San Antonio Reservoir		Calaveras Reservoir		San Andreas Reservoir		Pond F3	Alameda East		SVWTP TWR Effluent		HTWTP Effluent Post	
Contaminant	**Units**	**6/5/2012**	**5/26/2021**	**6/6/2012**	**3/16/2020**	**6/6/2012**	**3/16/2020**	**6/5/2012**	**3/9/2020**		**6/13/2012**	**7/9/2020**	**6/13/2012**	**6/25/2020**	**7/24/2012**	**6/4/2020**
Pentoxifylline	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Phenazone	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Primidone	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Progesterone	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Propazine	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Quinoline COVERED IN A DIFFERENT MONITORING PLAN	ng/L		<20		<20		<20		<20	<20		<20		<20		<20
Simazine	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Sulfachloropyridazine	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Sulfadiazine	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Sulfadimethoxine	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Sulfamerazine	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Sulfamethazine	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Sulfamethizole	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Sulfamethoxazole	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Sulfathiazole	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Tris (2-carboxyethyl) phosphine (TCEP)	ng/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	No data	<10
TCPP (Fyrol PCF)	ng/L		<100		<100		<100		<100	<100		<100		<100		<100
TDCPP	ng/L		<50		<50		<50		<50	<50		<50		<50		<50
Theobromine	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Theophylline	ng/L		<10		<10		<10		<10	<10		<10		<10		<10
Thiabendazole	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Trimethoprim	ng/L		<5		<5		<5		<5	<5		<5		<5		<5
Hormones by EPA 539 Method (n=8)									**6/8/2020**	**7/1/2020**						
17-alpha-ethynylestradiol (Ethinyl Estradiol)	µg/L	<0.0004	<0.00045	<0.0004	<0.00045	<0.0004	<0.00045	<0.0004	<0.00045	<0.00045	<0.0004	<0.00045	<0.0004	<0.00045	<0.0004	<0.00045
17-beta-Estradiol	µg/L	<0.0009	<0.0002	<0.0009	<0.0002	<0.0009	<0.0002	<0.0009	<0.0002	<0.0002	<0.0009	<0.0002	<0.0009	<0.0002	<0.0009	<0.0002
4-androstene-3,17-dione	µg/L	<0.0003	0.00049	<0.0003	<0.00015	<0.0003	<0.00015	<0.0003	<0.00015	0.00037	<0.0003	<0.00015	<0.0003	<0.00015	<0.0003	<0.00015
Andorostenedione	µg/L		<0.00015		<0.00015		<0.00015		<0.00015	<0.00015		<0.00015		<0.00015		<0.00015
Equilin	µg/L	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002	<0.002	<0.004	<0.002	<0.004	<0.002	<0.004	<0.002
Estriol	µg/L	<0.0008	<0.0004	<0.0008	<0.0004	<0.0008	<0.0004	<0.0008	<0.0004	<0.0004	<0.0008	<0.0004	<0.0008	<0.0004	<0.0008	<0.0004
Estrone	µg/L	<0.002	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	<0.001	<0.001	<0.002	<0.001	<0.002	<0.001	<0.002	<0.001
Testosterone	µg/L	<0.0001	<0.00005	<0.0001	<0.00005	<0.0001	<0.00005	<0.0001	<0.00005	<0.00005	<0.0001	<0.00005	<0.0001	<0.00005	<0.0001	<0.00005

Notes

B1 = Low-level result as Field Blank is non-detect but one-half of the detection limit is ≥ 10% of the sample result. 10% Result =< 1.5 DL < Result.

B2 = Field Blank result ≥ 10% of the sample result. 10% Result =< FB < Result.

B3 = Sample result is unreliable and should be rejected due to gross contamination in the Field Blank (Field Blank result > sample result). Result < FB.

Table 8-5. Comparison of PPCPs, EDCs, and Hormones Sampled in Surface Water and Groundwater Sources at SFPUC in 2012, 2020, and 2021, Groundwater Wells

		San Francisco Groundwater Wells					Pleasanton Well Field		GSR Wells									
		Lake Merced Well (LMW)	Golden Gate Park Well (GCW)	South Sunset Well (SSW)	West Sunset Well (WSW)	Zoo Well #5	North	South	Colma Blvd. Well (CBW)	F St. Well (FSW)	Southwood Dr. Well (SDW)	Hickey Blvd. Well (HBW)	Poncetta Dr. Well (PDW)	Millbrae Yard Well (MYW)	B St. Well (BSW)	Serramonte Blvd. Well (SBW)	Mission Well (MSW)
Contaminant	**Units**	**6/9/2020**	**6/10/2020**	**6/9/2020**	**6/10/2020**	**7/7/2020**	**3/11/2020**	**3/11/2020**	**3/4/2020**	**3/4/2020**	**7/29/2020**	**3/10/2020**	**6/24/2020**	**6/4/2020**	**4/7/2020**	**9/2/2021**	**11/17/2021**
PPCPs and EDCs by LC-MS-MS (n=98)																	
2,4-D	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
4-nonylphenol	ng/L	<400	<400	<400	<400	<400	<400	<400	<400	<400	<400	<400	<400	<400	<400	<400	<400
4-tert-octylphenol	ng/L	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Acesulfame	ng/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Bendroflumethiazide	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Bisphenol A	ng/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Butalbital	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Butylparben	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Chloramphenicol	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Clofibric Acid	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Diclofenac	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Estradiol	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Ethylparaben	ng/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Gemfibrozil	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Ibuprofen	ng/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Iohexal	ng/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	28	<10	<10	<10	<10	<10	<10
Iopromide	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Isobutylparaben	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Methylparaben	ng/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Naproxen	ng/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Propylparaben	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	7.6	<5	<5	<5	<5	<5	<5
Salicylic Acid	ng/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
Sucralose	ng/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	270	<100	<100	<100	<100	<100	<100
Triclocarban	ng/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Triclosan	ng/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Warfarin	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5

		San Francisco Groundwater Wells					**Pleasanton Well Field**		**GSR Wells**								
		Lake Merced Well (LMW)	**Golden Gate Park Well (GCW)**	**South Sunset Well (SSW)**	**West Sunset Well (WSW)**	**Zoo Well #5**	**North**	**South**	**Colma Blvd. Well (CBW)**	**F St. Well (FSW)**	**Southwood Dr. Well (SDW)**	**Hickey Blvd. Well (HBW)**	**Poncetta Dr. Well (PDW)**	**Millbrae Yard Well (MYW)**	**B St. Well (BSW)**	**Serramonte Blvd. Well (SBW)**	**Mission Well (MSW)**
Contaminant	**Units**	**6/9/2020**	**6/10/2020**	**6/9/2020**	**6/10/2020**	**7/7/2020**	**3/11/2020**	**3/11/2020**	**3/4/2020**	**3/4/2020**	**7/29/2020**	**3/10/2020**	**6/24/2020**	**6/4/2020**	**4/7/2020**	**9/2/2021**	**11/17/2021**
1,7-Dimethylxanthine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	6
Acetaminophen	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Albuterol	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Amoxicillin	ng/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Atenolol	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Atrazine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Bezafibrate	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Bromacil	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Caffeine	ng/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Carbadox	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Carbamazepine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Carisoprodol	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Chloridazon	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Chlorotoluron	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Cimetidine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Cotinine	ng/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Cyanazine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
DACT	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
DEA	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
N,N-Diethyl-meta-toluamide (DEET)	ng/L	<10	<10	<10	<10	10 B2	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Dehydronifedipine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
DIA	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Diazepam	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Phenytoin (Dilantin)	ng/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Diltiazem	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Diuron	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Erythromycin	ng/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10

		San Francisco Groundwater Wells					Pleasanton Well Field		GSR Wells									
		Lake Merced Well (LMW)	Golden Gate Park Well (GCW)	South Sunset Well (SSW)	West Sunset Well (WSW)	Zoo Well #5	North	South	Colma Blvd. Well (CBW)	F St. Well (FSW)	Southwood Dr. Well (SDW)	Hickey Blvd. Well (HBW)	Poncetta Dr. Well (PDW)	Millbrae Yard Well (MYW)	B St. Well (BSW)	Serramonte Blvd. Well (SBW)	Mission Well (MSW)
Contaminant	**Units**	**6/9/2020**	**6/10/2020**	**6/9/2020**	**6/10/2020**	**7/7/2020**	**3/11/2020**	**3/11/2020**	**3/4/2020**	**3/4/2020**	**7/29/2020**	**3/10/2020**	**6/24/2020**	**6/4/2020**	**4/7/2020**	**9/2/2021**	**11/17/2021**
Flumeqine	ng/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Fluoxetine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Isoproturon	ng/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
Ketoprofen	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Ketorolac	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Lidocaine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Lincomycin	ng/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Linuron	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Lopressor	ng/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Meclofenamic Acid	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Meprobamate	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Metazachlor	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Metformin	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Metolachlor	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Nifedipine	ng/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Norethindrone (19-Norethisterone)	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
OUST (Sulfameturon, methyl)	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Oxolinic Acid	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Pentoxifylline	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Phenazone	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Primidone	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Progesterone	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Propazine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Quinoline COVERED IN A DIFFERENT MONITORING PLAN	ng/L	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Simazine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5

		San Francisco Groundwater Wells					Pleasanton Well Field		GSR Wells								
		Lake Merced Well (LMW)	Golden Gate Park Well (GCW)	South Sunset Well (SSW)	West Sunset Well (WSW)	Zoo Well #5	North	South	Colma Blvd. Well (CBW)	F St. Well (FSW)	Southwood Dr. Well (SDW)	Hickey Blvd. Well (HBW)	Poncetta Dr. Well (PDW)	Millbrae Yard Well (MYW)	B St. Well (BSW)	Serramonte Blvd. Well (SBW)	Mission Well (MSW)
Contaminant	**Units**	**6/9/2020**	**6/10/2020**	**6/9/2020**	**6/10/2020**	**7/7/2020**	**3/11/2020**	**3/11/2020**	**3/4/2020**	**3/4/2020**	**7/29/2020**	**3/10/2020**	**6/24/2020**	**6/4/2020**	**4/7/2020**	**9/2/2021**	**11/17/2021**
Sulfachloropyridazine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sulfadiazine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sulfadimethoxine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sulfamerazine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sulfamethazine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sulfamethizole	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sulfamethoxazole	ng/L	<5	<5	6.4	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sulfathiazole	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Tris (2-carboxyethyl) phosphine (TCEP)	ng/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
TCPP (Fyrol PCF)	ng/L	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	280	<100
TDCPP	ng/L	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Theobromine	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Theophylline	ng/L	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Thiabendazole	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	170	<5	<5	<5
Trimethoprim	ng/L	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Hormones by EPA 539 Method (n=8)																	
17-alpha-thynylestradiol (Ethinyl Estradiol)	µg/L	<0.00045	<0.00045	<0.00045	<0.00045	<0.00045	<0.00045	<0.00045	<0.00045	<0.00045	<0.00045	<0.00045	<0.00045	<0.00045	<0.00045	<0.00045	<0.00045
17-beta-Estradiol	µg/L	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
4-androstene-3,17-dione	µg/L	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015
Andorostenedione	µg/L	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015	<0.00015
Equilin	µg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Estriol	µg/L	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004
Estrone	µg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Testosterone	µg/L	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005

Notes

B1 = Low-level result as Field Blank is non-detect but one-half of the detection limit is ≥ 10% of the sample result. 10% Result =< 1.5 DL < Result.

B2 = Field Blank result ≥ 10% of the sample result. 10% Result =< FB < Result.

B3 = Sample result is unreliable and should be rejected due to gross contamination in the Field Blank (Field Blank result > sample result). Result < FB.

Table 8-6. Occurrences of EDCs/PPCPs in US Surface Waters (ng/L) (WRF, Park et al, 2017) Compared with SFPUC

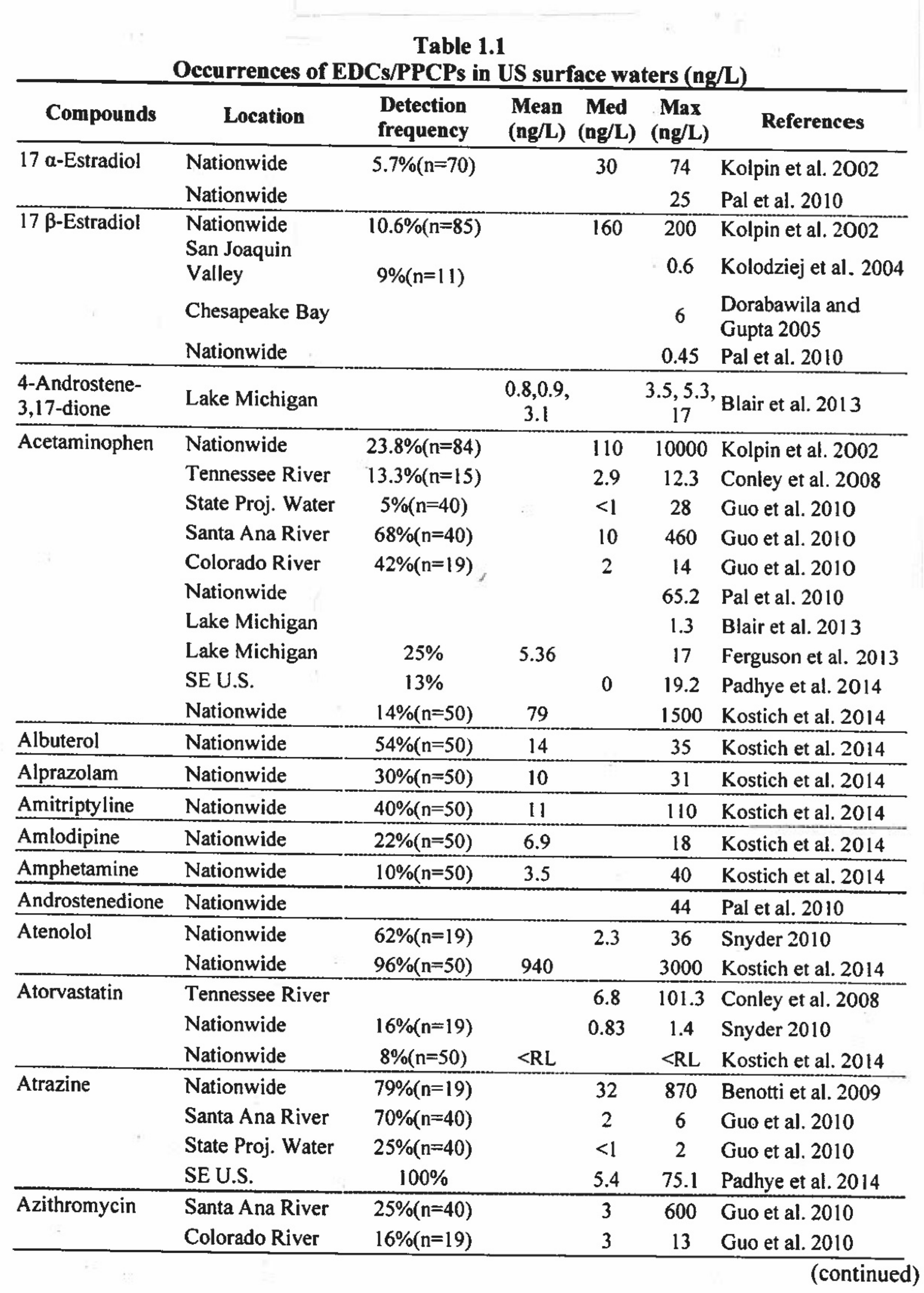

Table 1.1
Occurrences of EDCs/PPCPs in US surface waters (ng/L)

Compounds	Location	Detection frequency	Mean (ng/L)	Med (ng/L)	Max (ng/L)	References	SFPUC Data 2020/21, 201 Detects (ng/L MDL, ND n=#
17 α-Estradiol	Nationwide	5.7%(n=70)		30	74	Kolpin et al. 2002	<0.5, n=9
	Nationwide				25	Pal et al. 2010	
17 β-Estradiol	Nationwide	10.6%(n=85)		160	200	Kolpin et al. 2002	<0.9, n=4 <0.2, n=5
	San Joaquin Valley	9%(n=11)			0.6	Kolodziej et al. 2004	
	Chesapeake Bay				6	Dorabawila and Gupta 2005	
	Nationwide				0.45	Pal et al. 2010	
4-Androstene-3,17-dione	Lake Michigan		0.8,0.9, 3.1		3.5, 5.3, 17	Blair et al. 2013	0.49, 0.37 <0.3, n=4 <0.15, n=3
Acetaminophen	Nationwide	23.8%(n=84)		110	10000	Kolpin et al. 2002	<5, n=5
	Tennessee River	13.3%(n=15)		2.9	12.3	Conley et al. 2008	
	State Proj. Water	5%(n=40)		<1	28	Guo et al. 2010	
	Santa Ana River	68%(n=40)		10	460	Guo et al. 2010	
	Colorado River	42%(n=19)		2	14	Guo et al. 2010	
	Nationwide				65.2	Pal et al. 2010	
	Lake Michigan				1.3	Blair et al. 2013	
	Lake Michigan	25%	5.36		17	Ferguson et al. 2013	
	SE U.S.	13%		0	19.2	Padhye et al. 2014	
	Nationwide	14%(n=50)	79		1500	Kostich et al. 2014	
Albuterol	Nationwide	54%(n=50)	14		35	Kostich et al. 2014	<5, n=5
Alprazolam	Nationwide	30%(n=50)	10		31	Kostich et al. 2014	
Amitriptyline	Nationwide	40%(n=50)	11		110	Kostich et al. 2014	
Amlodipine	Nationwide	22%(n=50)	6.9		18	Kostich et al. 2014	
Amphetamine	Nationwide	10%(n=50)	3.5		40	Kostich et al. 2014	
Androstenedione	Nationwide				44	Pal et al. 2010	
Atenolol	Nationwide	62%(n=19)		2.3	36	Snyder 2010	<5, n=5
	Nationwide	96%(n=50)	940		3000	Kostich et al. 2014	
Atorvastatin	Tennessee River			6.8	101.3	Conley et al. 2008	
	Nationwide	16%(n=19)		0.83	1.4	Snyder 2010	
	Nationwide	8%(n=50)	<RL		<RL	Kostich et al. 2014	
Atrazine	Nationwide	79%(n=19)		32	870	Benotti et al. 2009	<5, n=5
	Santa Ana River	70%(n=40)		2	6	Guo et al. 2010	
	State Proj. Water	25%(n=40)		<1	2	Guo et al. 2010	
	SE U.S.	100%		5.4	75.1	Padhye et al. 2014	
Azithromycin	Santa Ana River	25%(n=40)		3	600	Guo et al. 2010	
	Colorado River	16%(n=19)		3	13	Guo et al. 2010	

(continued)

Table 1.1 Continued

Compounds	Location	Detection frequency	Mean (ng/L)	Med (ng/L)	Max (ng/L)	References	SFPUC Data 2020/21, 2012 Detects (ng/L) MDL, ND n=#
Benzo[a]pyrene	Santa Ana River	8%(n=40)		<25	422	Guo et al. 2010	
Bisphenol A	Nationwide	41.2%(n=85)		14	1200	Kolpin et al. 2002	<10, n=9
	Bayou St. John	100%(n=5)		2.4	44	Boyd et al. 2004	
	Lake Pontchartrain	100%(n=7)		19	57	Boyd et al. 2004	
	London Canal	100%(n=7)		56	158	Boyd et al. 2004	
	Mississippi River	100%(n=8)		33	113	Boyd et al. 2004	
	Orleans Canal	100%(n=7)		15.6	132	Boyd et al. 2004	
	State Proj. Water	3%(n=40)		<30	140	Guo et al. 2010	
	SE U.S.	75%		12.7	21.9	Padhye et al. 2014	
Caffeine	Nationwide	61.9%(n=85)		81	6,000	Kolpin et al. 2002	50, 30, 13 9.8, 9.1 <10, n=4
	Tennessee River	92.2 %(n=15)		28.8	175.7	Conley et al. 2008	
	Santa Ana River	100%(n=40)		47	2160	Guo et al. 2010	
	State Proj. Water	83%(n=40)		8	67	Guo et al. 2010	
	Colorado River	47%(n=19)		<5	1370	Guo et al. 2010	
	Santa Ana River	100%(n=40)		47	2160	Guo et al. 2010	
	Lake Michigan		18,37, 21,24		42.86, 35,39	Blair et al. 2013	
	Lake Michigan	44%	31		100	Ferguson et al. 2013	
	SE U.S.	50%		2.7	15.9	Padhye et al. 2014	
Carbamazepine	Tennessee River	79.7%(n=15)		5	23.1	Conley et al. 2008	<5, n=9
	Nationwide	79%(n=19)		4.1	5.1	Benotti et al. 2009	
	State Proj. Water	88%(n=40)		3	26	Guo et al. 2010	
	Santa Ana River	93%(n=40)		128	267	Guo et al. 2010	
	Colorado River	89%(n=19)		3	4	Guo et al. 2010	
	Nationwide				113.7	Pal et al. 2010	
	Nationwide	79%(n=19)		4.1	51	Snyder 2010	
	Lake Michigan					Blair et al. 2013	
	Lake Michigan	30%	2.23		10	Ferguson et al. 2013	
	Nationwide	96%(n=50)	97		240	Kostich et al. 2014	
	SE U.S.	100%		0.9	4.1	Padhye et al. 2014	
Cholesterol	Nationwide	84%(n=70-85)		830	60,000	Kolpin et al. 2002	
Cimetidine	Nationwide	9.5%(n=84)		74	580	Kolpin et al. 2002	<5, n=5
Ciprofloxacin	Nationwide	2.6%(n=115)		20	30	Kolpin et al. 2002	
	Tennessee River	10.2%(n=15)		6.9	54.2	Conley et al. 2008	
	Santa Ana River	28%(n=40)		25	69	Guo et al. 2010	
	Nationwide	61%(n=50)	67		260	Kostich et al. 2014	
Clarithromycin	SE U.S.	100%		0.6	1.7	Padhye et al. 2014	

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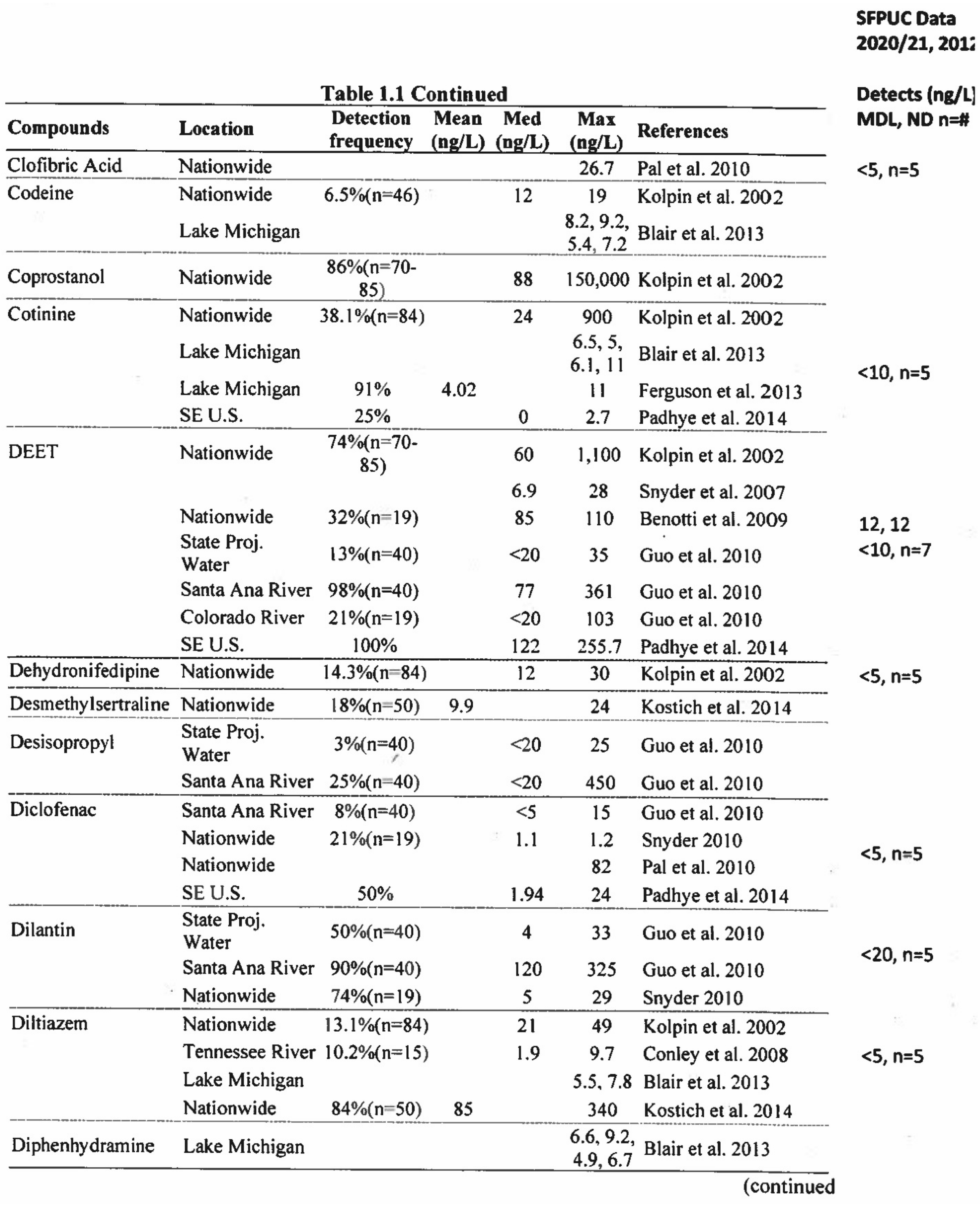

Table 1.1 Continued

Compounds	Location	Detection frequency	Mean (ng/L)	Med (ng/L)	Max (ng/L)	References	SFPUC Data 2020/21, 201 Detects (ng/L MDL, ND n=#
Clofibric Acid	Nationwide				26.7	Pal et al. 2010	<5, n=5
Codeine	Nationwide	6.5%(n=46)		12	19	Kolpin et al. 2002	
	Lake Michigan				8.2, 9.2, 5.4, 7.2	Blair et al. 2013	
Coprostanol	Nationwide	86%(n=70-85)		88	150,000	Kolpin et al. 2002	
Cotinine	Nationwide	38.1%(n=84)		24	900	Kolpin et al. 2002	<10, n=5
	Lake Michigan				6.5, 5, 6.1, 11	Blair et al. 2013	
	Lake Michigan	91%	4.02		11	Ferguson et al. 2013	
	SE U.S.	25%		0	2.7	Padhye et al. 2014	
DEET	Nationwide	74%(n=70-85)		60	1,100	Kolpin et al. 2002	12, 12 <10, n=7
				6.9	28	Snyder et al. 2007	
	Nationwide	32%(n=19)		85	110	Benotti et al. 2009	
	State Proj. Water	13%(n=40)		<20	35	Guo et al. 2010	
	Santa Ana River	98%(n=40)		77	361	Guo et al. 2010	
	Colorado River	21%(n=19)		<20	103	Guo et al. 2010	
	SE U.S.	100%		122	255.7	Padhye et al. 2014	
Dehydronifedipine	Nationwide	14.3%(n=84)		12	30	Kolpin et al. 2002	<5, n=5
Desmethylsertraline	Nationwide	18%(n=50)	9.9		24	Kostich et al. 2014	
Desisopropyl	State Proj. Water	3%(n=40)		<20	25	Guo et al. 2010	
	Santa Ana River	25%(n=40)		<20	450	Guo et al. 2010	
Diclofenac	Santa Ana River	8%(n=40)		<5	15	Guo et al. 2010	<5, n=5
	Nationwide	21%(n=19)		1.1	1.2	Snyder 2010	
	Nationwide				82	Pal et al. 2010	
	SE U.S.	50%		1.94	24	Padhye et al. 2014	
Dilantin	State Proj. Water	50%(n=40)		4	33	Guo et al. 2010	<20, n=5
	Santa Ana River	90%(n=40)		120	325	Guo et al. 2010	
	Nationwide	74%(n=19)		5	29	Snyder 2010	
Diltiazem	Nationwide	13.1%(n=84)		21	49	Kolpin et al. 2002	<5, n=5
	Tennessee River	10.2%(n=15)		1.9	9.7	Conley et al. 2008	
	Lake Michigan				5.5, 7.8	Blair et al. 2013	
	Nationwide	84%(n=50)	85		340	Kostich et al. 2014	
Diphenhydramine	Lake Michigan				6.6, 9.2, 4.9, 6.7	Blair et al. 2013	

(continued

Table 1.1 Continued

Compounds	Location	Detection frequency	Mean (ng/L)	Med (ng/L)	Max (ng/L)	References	SFPUC Data 2020/21, 201 Detects (ng/L) MDL, ND n=#
Diuron	State Proj. Water	88%(n=40)		81	873	Guo et al. 2010	<5, n=5
	Santa Ana River	98%(n=40)		83	9440	Guo et al. 2010	
Erythromycin-H2O	SE U.S.	100%		2.2	2.7	Padhye et al. 2014	<10, n=5
Estriol	Nationwide	21.4%(n=70)		19	51	Kolpin et al. 2002	
	Nationwide				12	Pal et al. 2010	<0.8, n=5
	Lake Michigan				3.9, 5.0	Blair et al. 2013	<0.4, n=4
Estrone	Nationwide	21%(n=70)		27	112	Kolpin et al. 2002	<2, n=4 <1, n=5
					2.12	Williams et al. 2003	
					17	Kolodziej et al. 2004	
	Nationwide	79%(n=19)		0.3	0.9	Benotti et al. 2009	
	Nationwide				38	Pal et al. 2010	
Ethynylestradiol	Nationwide	5%(n=10)		1.4	1.4	Snyder 2010	
Fluoxetine	Nationwide	1.2%(n=84)		12	12	Kolpin et al. 2002	
	Tennessee River	1.6%(n=15)		7	10.1	Conley et al. 2008	<5, n=5
	Nationwide	16%(n=19)		0.8	3	Snyder 2010	
	Nationwide	37.5%(n=50)	8.7		31	Kostich et al. 2014	
	SE U.S.	38%		0	0.9	Padhye et al. 2014	
Furosemide	Nationwide	90%(n=50)	280		810	Kostich et al. 2014	
Gemfibrozil	Nationwide	3.6%(n=84)		48	790	Kolpin et al. 2002	<5, n=9
	State Proj. Water	53%(n=40)		5	162	Guo et al. 2010	
	Santa Ana River	75%(n=40)		28	590	Guo et al. 2010	
	Nationwide				16	Pal et al. 2010	
	Nationwide	58%(n=19)		2.2	24	Snyder 2010	
	Lake Michigan		1.6, 3.1		4.5, 19	Blair et al. 2013	
	Lake Michigan	98%	7.03		49	Ferguson et al. 2013	
	Nationwide	76%(n=50)	420		2300	Kostich et al. 2014	
Hydrochlorothiazide	Nationwide	100%(n=50)	1100		2800	Kostich et al. 2014	
Hydrocodone	Nationwide	44%(n=50)	22		92	Kostich et al. 2014	
Ibuprofen	Orleans Canal	29%(n=7)		<2.6	85	Boyd et al. 2004	<10, n=5
	London Canal	33%(n=7)		38	674	Boyd et al. 2004	
	Bayou St. John	0%z(n=5)		<2.6	<2.6	Boyd et al. 2004	
	Lake Pontchartrain	29%(n=7)		<2.6	38	Boyd et al. 2004	
	Mississippi River	0%(n=8)		<2.6	<2.6	Boyd et al. 2004	
	Santa Ana River	65%(n=40)		17	530	Guo et al. 2010	
	Colorado River	5%(n=19)		<10	36	Guo et al. 2010	
	State Proj. Water	3%(n=40)		<10	47	Guo et al. 2010	
	Nationwide				34	Pal et al. 2010	
	Lake Michigan	31%	7.88		84	Ferguson et al. 2013	

(continued

Table 1.1 Continued

Compounds	Location	Detection frequency	Mean (ng/L)	Med (ng/L)	Max (ng/L)	References	SFPUC Data 2020/21, 2012 Detects (ng/L) MDL, ND n=#
	Nationwide	46%(n=50)	460		4200	Kostich et al. 2014	
	SE U.S.	38%		0	132.9	Padhye et al. 2014	
Levofloxacin	Tennessee River	6.3%(n=15)		11.9	59.3	Conley et al. 2008	
	SE U.S.	38%		0	1.3	Padhye et al. 2014	
Lincomycin	Nationwide	19.2%(n=104)		60	730	Kolpin et al. 2002	<10, n=5
	Lake Michigan	81%	4.28		7.6	Ferguson et al. 2013	
Linuron	State Proj. Water	5%(n=40)		<5	5	Guo et al. 2010	<5, n=5
	Santa Ana River	18%(n=40)		<5	8	Guo et al. 2010	
Lisinopril	Nationwide	47%(n=49)	180		3300	Kostich et al. 2014	
Lovastatin	Tennessee River	2.3%(n=15)		18.3	102.9	Conley et al. 2008	
Methoxychlor	State Proj. Water	18%(n=40)		<20	66	Guo et al. 2010	
	Santa Ana River	8%(n=40)		<20	31	Guo et al. 2010	
Methylparaben	State Proj. Water	10%(n=40)		<20	744	Guo et al. 2010	39
	Colorado River	5%(n=19)		<20	35	Guo et al. 2010	<20, n=4
Metoprolol	Nationwide	98%(n=50)	410		660	Kostich et al. 2014	
Meprobamate	Nationwide	84%(n=19)		8.2	73	Snyder 2010	
Metoprolol	SE U.S.	100%		0.1	0.3	Padhye et al. 2014	
Metformin	Lake Michigan		240, 270, 120,110		820, 840, 160, 160	Blair et al. 2013	<5, n=5
Naproxen	Orleans Canal	85%(n=7)		5.1	93	Boyd et al. 2004	
	London canal	86%(n=7)		7.8	145	Boyd et al. 2004	
	Bayou St. John	100%(n=5)		3.1	4.8	Boyd et al. 2004	
	Lake Pontchartrain	100%(n=7)		6.1	36	Boyd et al. 2004	
	Mississippi	89%(n=8)		3.7	12.4	Boyd et al. 2004	<5, n=5
	Nationwide	58%		0.9	32	Benotti et al. 2009	
	Nationwide	58%(n=19)		0.93	32	Snyder 2010	
	Nationwide				135.2	Pal et al. 2010	
	Lake Michigan		2.5		15	Blair et al. 2013	
	Lake Michigan	100%	6.32		30	Ferguson et al. 2013	
	SE U.S.	13%		0	9.2	Padhye et al. 2014	
Nonylphenol	Nationwide	51%(n=70-85)		800	40,000	Kolpin et al. 2002	
					15000	Petrovic et al. 2004	<400, n=5
					920	Petrovic et al. 2004	
					640	Petrovic et al. 2004	
					1200	Petrovic et al. 2004	
					420	Petrovic et al. 2004	

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Table 1.1 Continued

Compounds	Location	Detection frequency	Mean (ng/L)	Med (ng/L)	Max (ng/L)	References	SFPUC Data 2020/21, 2012 Detects (ng/L) MDL, ND n=#
	Nationwide	42%(n=19)		100	130	Benotti et al. 2009	
	Colorado River	5%(n=19)		<50	143	Guo et al. 2010	
	SE U.S.	100%		83.2	185.6	Padhye et al. 2014	
Nonylphenol ethoxylates					1050	Ferguson et al. 2013	
					31000	Petrovic et al. 2004	
					10000	Petrovic et al. 2004	
					600	Petrovic et al. 2004	
					520	Petrovic et al. 2004	
					11000	Petrovic et al. 2004	
Norfluoxetine	Nationwide	17%(n=50)	7.7		15	Kostich et al. 2014	
Norverapamil	Nationwide	52%(n=46)	5.8		20	Kostich et al. 2014	
Octylphenol	State Proj. Water	3%(n=40)		<20	68	Guo et al. 2010	
Octylphenol and ethoxylates					40	Ferguson et al. 2013	
					190	Petrovic et al. 2004	
					84	Petrovic et al. 2004	
					90	Petrovic et al. 2004	
					13000	Petrovic et al. 2004	
Ofloxacin	Nationwide	90%(n=48)	160		660	Kostich et al. 2014	
Oxycodone	Nationwide	60%(n=49)	53		310	Kostich et al. 2014	
o-Hydroxy Atorvastatin	Nationwide	16%(n=19)		0.66	1.2	Snyder 2010	
o,p-DDD	State Proj. Water	20%(n=40)		<20	82	Guo et al. 2010	
	Santa Ana River	15%(n=40)		<20	51	Guo et al. 2010	
	Colorado River	21%(n=19)		<20	46	Guo et al. 2010	
p-Hydroxy Atorvastatin	Nationwide	16%(n=19)		1	2	Snyder 2010	
Paraxanthine	Lake Michigan		11		9.7, 39, 8.746	Blair et al. 2013	
	Lake Michigan	98%	46.2		76	Ferguson et al. 2013	
Phenytoin	Nationwide	74%(n=19)		5.1	29	Benotti et al. 2009	
Primidone	Santa Ana River	93%(n=40)		89	158	Guo et al. 2010	<5, n=5
	State Proj. Water	70%(n=40)		4	21	Guo et al. 2010	
	Colorado River	79%(n=19)		3	4	Guo et al. 2010	

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Table 1.1 Continued

Compounds	Location	Detection frequency	Mean (ng/L)	Med (ng/L)	Max (ng/L)	References	SFPUC Data 2020/21, 2012 Detects (ng/L) MDL, ND n=#
Progesterone	Nationwide	4.3%(n=70)		110	199	Kolpin et al. 2002	
	Nationwide				27	Pal et al. 2010	
	Lake Michigan		1.0,1.5, 15, 2.6		4.9, 8.7, 88, 13	Blair et al. 2013	<5, n=5
Propoxyphene	Nationwide	25%(n=50)	17		34 (46)	Kostich et al. 2014	
Propranolol	Nationwide	88%(n=48)	33		260	Kostich et al. 2014	
Propylparaben	State Proj. Water	3%(n=40)		<20	83	Guo et al. 2010	5.9 <5, n=4
Ranitidine	Nationwide	1.2%(N=84)		10	10	Kolpin et al. 2002	
	Lake Michigan				3.7	Blair et al. 2013	
	Nationwide	38%(n=50)	120		1400	Kostich et al. 2014	
Salicylic Acid	Nationwide				121	Pal et al. 2010	<100, n=5
Sertraline	Tennessee River	3.1%(n=15)		3.5	12.4	Conley et al. 2008	
Simazine	State Proj. Water	38%(n=40)		<20	408	Guo et al. 2010	
	Santa Ana River	50%(n=40)		<20	115	Guo et al. 2010	<5, n=5
Sulfadimethoxine	Lake Michigan	97%	0.94		2.5	Ferguson et al. 2013	<5, n=5
Sulfamerazine	Nationwide	4.8%(n=104)		20	120	Kolpin et al. 2002	
	Lake Michigan	97%	0.92		1.5	Ferguson et al. 2013	<5, n=5
Sulfamethoxazole	Nationwide	12.5%(n=104)		150	1900	Kolpin et al. 2002	
	Tennessee River	85.9%(n=15)		7.9	33	Conley et al. 2008	
	State Proj. Water	88%(n=40)		11	71	Guo et al. 2010	
	Santa Ana River	93%(n=40)		89	721	Guo et al. 2010	
	Colorado River	84%(n=19)		10	17	Guo et al. 2010	
	Nationwide				211	Pal et al. 2010	<5, n=5
	Nationwide	89%(n=19)		12	110	Snyder 2010	
	Lake Michigan		5.1, 4.5		6.2. 7.0, 7.3, 10	Blair et al. 2013	
	Lake Michigan	100%	26		220	Ferguson et al. 2013	
	Nationwide	80%(n=50)	910		2900	Kostich et al. 2014	
	SE U.S.	88%		2.4	7.4	Padhye et al. 2014	
Sulfathiazole	Lake Michigan	97%	0.92		1.5	Ferguson et al. 2013	<5, n=5

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Table 1.1 Continued

Compounds	Location	Detection frequency	Mean (ng/L)	Med (ng/L)	Max (ng/L)	References	SFPUC Data 2020/21, 2012 Detects (ng/L) MDL, ND n=#
TCEP	Nationwide	58%(n=70-85)		100	540	Kolpin et al. 2002	<10, n=9
	Nationwide	53%(n=19)		120	530	Benotti et al. 2009	
	State Proj. Water	70%(n=40)		7	34	Guo et al. 2010	
	Santa Ana River	100%(n=40)		208	1320	Guo et al. 2010	
	Colorado River	26%(n=19)		<5	9	Guo et al. 2010	
	SE U.S.	88%		2.4	7.4	Padhye et al. 2014	
Testosterone	Nationwide	2.8%(n=70)		116	214	Kolpin et al. 2002	<0.1, n=4 <0.05, n=5
	Nationwide				16	Pal et al. 2010	
	Lake Michigan		1.5, 6.4, 1.4		4.5, 9.1, 38, 7.0	Blair et al. 2013	
Triclocarban	Lake Michigan	98%	5.72		14	Ferguson et al. 2013	<20, n=5
Triclosan	Nationwide	57.6%(n=85)		140	2,300	Kolpin et al. 2002	<20, n=5 <10, n=4
	Bayou St. John	0%(n=5)		<0.2	<0.2	Boyd et al. 2004	
	Lake Pontchartrain	100%(n=7)		4.6	14.9	Boyd et al. 2004	
	London Canal	100%(n=7)		15	29	Boyd et al. 2004	
	Mississippi River	38%(n=8)		<0.2	3.1	Boyd et al. 2004	
	Orleans Canal	57%(n=7)		15.2	20	Boyd et al. 2004	
	Nationwide	32%(n=19)		85	110	Benotti et al. 2009	
	Santa Ana River	25%(n=40)		<5	13	Guo et al. 2010	
	Lake Michigan		0.8,3.0, 2.7, 1.4		2.1, 16, 7.4, 6.5	Blair et al. 2013	
	SE U.S.	63%		3.3	105.8	Padhye et al. 2014	
Trimethoprim	Nationwide	12.5%(n=104)		150	710	Kolpin et al. 2002	<5, n=5
	Tennessee River	32%(n=15)		5.6	63.3	Conley et al. 2008	
	Nationwide	58%		0.8	11	Benotti et al. 2009	
	Lake Michigan	80%	5.15		18	Ferguson et al. 2013	
	Nationwide				212	Pal et al. 2010	
	Nationwide	58%(n=19)		0.75	11	Snyder 2010	
	Nationwide	86%(n=50)	170		370	Kostich et al. 2014	
	SE U.S.	100%		5.8	10.9	Padhye et al. 2014	

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Water Quality Division, Technical Review 2016 – 2021

Contaminants of Emerging Concern (CEC) in Drinking Water

Pharmaceuticals and Personal Care Products (PPCP), Endocrine Disrupting Chemicals (EDC) & Hormones

EDCs/PPCPs include various compounds such as hormones, pharmaceuticals, personal care products as well as pesticides, organic compounds and dioxins that can disrupt endocrine systems of many species in ecosystem. (WRF, Park et al., 2017)

Endocrine disruptors are chemical substances that alter the functioning of the endocrine system and negatively affect the health of humans and animals. They may either be of synthetic or natural origin. Exposure to endocrine disruptors can occur from different sources, such as residues of pesticides or consumer products used or present in our daily life. (EC, 2018)

What is the endocrine system?

The endocrine system is a messenger system of the body. It uses hormones, signaling molecules which travel through the bloodstream, as a communication tool and to produce effects on distant cells, tissues and organs. Hormones are essential for controlling large number of processes in the body, from early ones such as embryonic development and organ formation, to the control of tissue and organ functions in adulthood. (EC, 2018)

REGULATIONS

USEPA Endocrine Disruptor Screening Program. Many of EDCs/PPCPs, except some pesticides/herbicides such as atrazine, are not currently regulated nor required to be routinely monitored. The SDWA amendments in 1996 require that EPA screen pesticide chemicals for their endocrine disrupting effects. (WRF, Park et al., 2017) The USEPA Endocrine Disruptor Screening Program (EDSP) uses a two-tiered approach to screen pesticides, chemicals, and environmental contaminants for their potential effect on estrogen, androgen and thyroid hormone systems. More information about the program can be accessed at https://www.epa.gov/endocrine-disruption/endocrine-disruptor-screening-program-edsp-overview.

Overview of the First List of Chemicals for Tier 1 Screening under the EDSP can be accessed at https://www.epa.gov/endocrine-disruption/overview-first-list-chemicals-tier-1-screening-under-endocrine-disruptor. The Final Second List of Chemicals for Tier 1 Screening was published in 2014 and can be accessed at https://www.epa.gov/sites/default/files/2015-08/documents/1.pdf.

USEPA CCL Lists and California SWRCB. CCL5 that can be subject to future regulation under SDWA, including pesticides, pharmaceuticals, chemicals used in commerce (see the draft CCL5 list at https://www.epa.gov/ccl/draft-ccl-5-chemicals.

California SWRCB has a website about emerging contaminants, which contains links to resources at https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/EmergingContaminants.html. There are no PPCP or hormones on the California Public Health Goal (PHG) list.

WHO Guidelines. The concentrations of pharmaceuticals found in drinking-water are typically orders of magnitude less than the lowest therapeutic doses. Therefore, exposure to individual compounds in drinking-water is unlikely to have appreciable adverse impacts on human health. Formal guideline values are therefore not proposed in WHO Guidelines. (WHO, 2017)

The Strategic Approach of EU for Pharmaceuticals. The adopted approach is complementary to the recently adopted Strategy on Endocrine Disruptors (EC, 2018, 2019). Measures should not only include end-of-pipe controls (e.g. improved wastewater treatment) but also address the original sources of emissions (e.g. production and use) and consider the terrestrial as well as the aquatic environment. This Communication set out six areas for action:

- Increase awareness and promote prudent use of pharmaceuticals,
- Support the development of pharmaceuticals intrinsically less harmful for the environment and promote greener manufacturing,
- Improve environmental risk assessment and its review,
- Reduce wastage and improve the management of waste,
- Expand environmental monitoring,
- Fill other knowledge gaps. (EC, 2019)

EU regulatory consequences for endocrine disruptors. Different regulatory approaches exist in different pieces of legislation for substances identified as endocrine disruptors. For pesticides and biocides, the co-legislators adopted specific provisions “underpinned by the precautionary principle” and based on number of considerations. Taking for example into account the specific nature of the products in question, that endocrine disruptors are substances of particular concern, and that scientific uncertainty remains regarding their assessment (for example as regards the existence of a safe limit of exposure), they decided that once it is proven that a substance is an endocrine disruptor, the substance in principle cannot be authorized for use. There are very limited derogation possibilities. (EU, 2018)

Under REACH, endocrine disruptors are specifically mentioned as substances that can be identified as Substances of Very High Concern and, if prioritized, are subject to authorization requirements. Other legislative instruments, such as for example the Regulation on cosmetics, although they do not mention endocrine disruptors specifically, consider them like other substances that can negatively affect human health. (EU, 2018)

Previous US Regulatory Developments. USEPA CCL3 and CCL4 included 12 pharmaceuticals/hormones: 17-alpha-estradiol, equilenin, equilin, erythromycin, estradiol (17-beta estradiol), estriol, estrone, ethinyl estradiol (17-alpha ethynyl estradiol), mestranol, nitroglycerin, norethindrone (19-Norethisterone), quinoline. USEPA UCMR3 (monitored in 2013) included 7 hormones: 17-alpha-Ethynylestradiol, 17-beta-estradiol, equilin, estriol, estrone, testosterone, and 4-androstene-3,17-dione.

UCMR4 did not include PPCPs or hormones.

PPCP in Recycled Water. In 2013 the California State Water Resources Control Board (SWRCB) amended its Recycled Water Policy to require CEC monitoring programs when a system recharges a drinking water aquifer with recycled water (SWRCB, 2013) SWRCB monitoring requirements for PPCPs include: 17-beta estradiol, caffeine, triclosan, gemfibrozil, iopromide, DEET and sucralose.

California Draft Regulations for Groundwater Replenishment with Recycled Water (June 18, 2014) require annual monitoring for indicators of PPCPs specified by CDPH and the Regional Water Quality Control Board (RWQCB) (CDPH, 2014).

HEALTH

Analysis of the results indicated that appreciable adverse health impacts to humans are very unlikely from exposure to the trace concentrations of pharmaceuticals that could potentially be found in drinking-water. Concentrations of pharmaceuticals in drinking-water are generally more than 1000-fold below the MTD, which is the lowest clinically active dosage. The findings from these three case-studies are in line with the evidence published over the past decade, which suggests that appreciable risks to health arising from exposure to trace levels of pharmaceuticals in drinking-water are extremely unlikely.

No clear link between pharmaceuticals in the environment and human health

No clear link has been established between pharmaceuticals present in the environment and direct impacts on human health. The WHO reports that the weight of evidence from several recent studies points to it being very unlikely that pharmaceuticals in drinking water pose a threat to human health at the low concentrations found. However, it notes that the issue of pharmaceutical residues cannot be ignored and mentions the possible effects of long-term exposure on vulnerable populations, hence the need for a precautionary approach. (EC, 2019)

Several antimicrobial (antibiotic and antifungal) pharmaceuticals from the treatment of humans and animals have been found in water and soil: their presence may play a role in accelerating the development, maintenance and spread of resistant bacteria and fungi. There is also limited monitoring of "hotspot" locations, such as those affected by hospital effluents. Even less is known about concentrations in soils, and about the presence of antimicrobial resistant micro-organisms and antimicrobial resistance genes. In addition, possible "cocktail" effects from the combined presence of many pharmaceuticals and other chemicals in the environment are not well understood. (EC, 2019)

Evidence linking exposure to EDC with human diseases or negative impact on wildlife is stronger

The scientific evidence linking exposure to endocrine disruptors with human diseases or negative impact on wildlife has become stronger. There is now broad consensus on the definition, whereby an endocrine disruptor is defined as "an exogenous substance or mixture that alters function(s) of the endocrine system and consequently causes adverse health effects in an intact organism, or its progeny, or (sub)populations". (EC, 2018)

Consensus also exists that the most sensitive window of exposure to endocrine disruptors is during important periods of development, such as fetal development and puberty. Exposure to endocrine disruptors during these periods may cause permanent effects and result in increased susceptibility to diseases later in life. It is also generally recognized that endocrine disruptors can interfere with the endocrine system in different ways. So far, science has focused mainly on a limited number of endocrine modalities. However, in recent years, it has been shown that other aspects of the endocrine system can be sensitive to endocrine disruptors as well. There is also increasing evidence showing that endocrine disruptors can work together to produce additive effects ("mixture effect", or "cocktail effect") so that exposure to a combination of endocrine disruptors may produce an adverse effect at concentrations at which individually no effect has been observed (even if this effect is not specific to endocrine disruptors). (EC, 2018)

Several studies have examined the public health risks of EDCs/PPCPs and provided guidance values for the presence of selected compounds in drinking water and in fact show that the vast majority of EDCs/PPCPs in wastewater effluents are already below human health threshold safety values. The guidance values represent a threshold below which the risk to public health is expected to be minimal. Table 1.4 in that reference presents some examples of these guidelines. (WRF, Park et al., 2017)

The basis for many regulatory standards as well as the simplest assessment of human risk factors is Acceptable Daily Intakes (ADI) or Tolerable Daily Intakes (TDIs). Unfortunately, for most new pollutants, these values are not available. Thus, there is a need for more advanced assessments. The simplest estimation of risk to human health is to compare concentrations of pharmaceuticals with the Predicted

No Effect Concentration (PNEC). In the USA, a model of human health risk assessment based on ADIs, PNECs and measured environmental concentrations, indicated that there is no appreciable human risk associated with the presence of active pharmaceuticals ingredients (APIs) in surface and drinking water. The authors then discussed different approaches taken in UK, Portugal and the Netherlands and the issue of unknown effects of mixtures. (Caban et al., 2016)

> Despite a very low risk, the problem of the presence of pharmaceutical residues in drinking water cannot be ignored because there is a lack of information about long-term low-level human exposure to pharmaceuticals, its metabolites and degradation products. (Caban et al., 2016)

The majority of human health risk assessments have proven that there is no direct negative effect of pharmaceutical residues in drinking water. However, it was suggested that the presence of steroidal hormones (especially ethinylestradiol) in groundwater in France could have an influence on human health, taking into account studies on the exposure of pregnant women to some pharmaceuticals. All researchers point out the need for further investigations in this area, due to the lack of information about the presence or the adverse effects of mixtures of pharmaceuticals, transformation products and /or their disinfection byproducts. (Caban et al., 2016)

The risk that humans may be exposed to pharmaceuticals through potable water is minor but could be much higher when surface or treated wastewaters are used for artificial groundwater recharge. (Caban et al., 2016)

Lv et a. (2019) investigated the presence of antibiotics in drinking water and their contribution to antibiotic exposure of school children in Shanghai. The results indicated that drinking water contaminated by antibiotics in Shanghai played a limited role in the total antibiotic exposure in children. However, as a low-dose antibiotic exposure risk factor, antibiotic contamination of drinking water led to the long-term exposure of children to low dose antibiotics. Current studies on the potential health hazards of antibiotics are based on antibiotic use or relevant high-dose exposure. (Lv et al., 2019)

Most studies have focused on the short-term effects of high-dose antibiotic exposures. Because a significant difference exists between the two kinds of exposure modes (i.e., short-term exposure to high-dose antibiotics and long-term exposure to low-dose antibiotics), more studies are needed to clarify the effects of the latter's exposure mode on human health. (Lv et al., 2019)

OCCURRENCE: VARIOUS LITERATURE STUDIES

Available studies have reported that concentrations of pharmaceuticals in surface waters, groundwater and partially treated water are typically less than 100 ng/L, and concentrations in treated water are generally below 50 ng/L (WHO, 2012).

Sampling. Assessing EDCs/PPCPs is expensive, time-consuming, and complex, requiring the analyses of large numbers of compounds, possibly at multiple locations, with some degree of a priori knowledge of what compounds may be of concern for a community and why they should be monitored. Therefore, the selection of analytes should be carefully designed in order to effectively and efficiently assess EDCs/PPCPs in surface waters. It may be possible to reduce the amount of redundant information in a suite of analytes by forgoing the measurement of compounds which presence is indicated by either other co-occurring compounds or related conventional water quality constituents. (Hagemann et al., 2016)

Sampling campaigns should be conducted at a consistent set of stations at a regular time interval. In order to investigate the patterns of compounds in different weather conditions or different hydrological years. (Hagemann et al., 2016)

Indicators. Previous studies have proposed various tracers of wastewater that could indicate the presence of EDCs/PPCPs because wastewater effluent is a major source of EDCs/PPCPs. For example, boron has been used as an indicator of wastewater in surface waters in which ambient levels are suitably low. Caffeine and 35 other commonly detected chemicals including PPCPs have been identified as indicator candidates for wastewater. Caffeine is a good indicator of anthropogenic effects but is not a conservative tracer because of its biodegradation in water. Primidone and carbamazepine have also been suggested as indicators of wastewater. Recent studies have demonstrated the use of sucralose and gadolinium to indicate the presence of domestic and hospital wastewater, respectively. (Hagemann et al., 2016)

Because chemical analyses of EDCs/PPCPs are expensive, a well-designed preliminary monitoring program should include a suite of more easily measurable parameters as potential indicators. Previously, suggested wastewater tracers had limited utility as surrogates for EDCs/PPCPs, and this utility varied by different water systems. TDS and conductivity occasionally clustered with certain compounds (in Lake Mead), but nowhere was this relationship strong enough to be considered predictive. It is unlikely that TDS or conductivity would be a suitable surrogate where ambient levels are high, for example, in brackish water or when road runoff containing deicing agents is introduced in winter. Other indicators of wastewater such as nitrate were available only in limited numbers for LVW and were not available in the other water systems in this study. Among more easily measured water quality parameters, only gadolinium was found to be useful as a surrogate of EDCs/PPCPs in Assabet River. However, the applicability of such surrogates will vary by each water system. (Hagemann et al., 2016) recent compilation of PPCP occurrence data collected from 61 published reports or scientific articles gathered data on 162 different PPCPs in drinking water influent (WRF, Bruce, 2015). The most commonly detected PPCP surveyed as a percent of total samples analyzed were as follows:

- Carbamazepine, anticonvulsant (86%)
- Meprobamate, anti-anxiety drug (74%)
- Phenytoin, anti-epileptic (67%)
- Erythromicin, antibiotic (63%)
- Flumequine, antibiotic (58%)
- Acetaminophen, analgesic (56%)
- Naproxen, analgesic (55%)
- Sulfamethoxazole, antibiotic (52%)

- Atenolol, antihypertensive (52%)

In the 2008-2009 NWRI survey (Guo et al., 2010), the most commonly detected pharmaceuticals in the raw water of State Project Water (as percent of detection frequency) were as follows:

- Carbamazepine, anticonvulsant (88%)
- Sulfamethoxazole, antibiotic (88%)
- Primidone, anticonvulsant (70%)
- Gemfibrozil, cholesterol drug (53%)
- Phenytoin, anti-epileptic (50%)
- Acetaminophen, pain reliever (5%)
- Ibuprofen, pain reliever (3%)

A literature review of PPCP studies (Daughton, 2010) indicated that the six most frequently reported PPCP in drinking water were (in descending order) carbamazepine, ibuprofen, sulfamethoxazole, clofibric acid, gemfibrozil, and iopromide, and the six PPCP with the highest concentrations were ibuprofen, triclosan, carbamazepine, phenazone, clofibric acid, and acetaminophen.

A 2006 - 2007 study of 19 U.S. water utilities (Benotti et al., 2009) identified atenolol, atrazine, DEET, estrone, meprobamate, and trimethoprim as indicator compounds representing potential contamination from PPCP/EDC and for use in gauging the efficacy of treatment processes.

A 2006 Water Research Foundation (formerly AwwaRF) study (WRF, Snyder et al., 2008a) evaluated 19 water systems in the USA, and detected the following steroids and phytoestrogens in raw waters (% indicates frequency of detection in raw waters, below). The study recommended that estrone and progesterone may be good indicators of hormone presence in drinking water supplies because they have the highest occurrence in several studies.

Steroids (produced by mammals and birds):

- Estrone (74%)
- Progesterone (16%)
- Testosterone (11%)

Phytoestrogens:

- Apigenin (found in parsley, artichokes) (18%)
- Formononetin (found in clovers) (18%)
- Genistein (found in soybeans) (18%)

Sources of EDCs/PPCPs. EDCs/PPCPs are introduced from point sources to waters directly through wastewater discharge or accidental spills and through stormwater runoff. The principal source of EDCs/PPCPs is WWTP effluent from domestic households, hospitals, and/or industrial plants. Combined sewer overflows are discharged from WWTPs during heavy rainfall events. Domestic EDCs/PPCPs can be directed to septic tanks or landfills and discharged via groundwater. Other sources include pollution from agricultural activities. Hormones are introduced from both point sources and nonpoint sources. Veterinary pharmaceuticals and hormones are directly released from aquaculture and indirectly discharged through stormwater runoff from animal feedlots. Pesticides/herbicides/ insecticides are transported from croplands and urban/suburban yards. The types and amount of pesticides/herbicides/insecticides applied to these areas vary depending on the type of crops and plants. Some pesticides can be transported to waters distant from their sources via various routes. (Hagemann et al., 2016; WRF Park et al., 2017)

Occurrence in US Surface Waters

The persistence of pharmaceuticals in surface water is normally shorter, because of extensive biodegradation, UV radiation, higher temperature and a higher concentration of oxygen. During colder periods of the year, solar irradiance and temperatures are lower, as is the biological activity of bacteria in natural water as well as in WWTPs. This causes higher concentrations of some pharmaceuticals in the drinking water supply. (Caban et al., 2016) Occurrence of EDC/PPCPs in US surface waters has been presented in detail by WRF (WRF Park et al., 2017); see Table 8-6 in the Monitoring section of this Report.

Occurrence in China. PPCPs were detected in all watersheds, treatment facilities, and municipal tap water samples investigated in this study. Some concentrations were particularly high across the three water sample types and various locations in China, such as for ampicillin, penicillin V, roxithromycin, sulfamethoxazole, sulfanilamide, caffeine, cotinine, and carbamazepine. Moreover, some pharmaceuticals were detected in concentrations higher than those typically found in other countries. While removal rates for pharmaceuticals, via different water treatment methods, were promising, the issue of long-term low-dose exposure to pharmaceuticals remains. This study represents the most extensive investigation of pharmaceuticals in tap water and finished water in Chinese river basins. Of the 59 selected PPCPs, 47, 43, and 42 of these compounds were detected in raw, finished, and tap water samples, respectively. The concentrations of pharmaceuticals were in the nanogram per liter range. Among the detected antibiotics, ampicillin, penicillin V, roxithromycin, sulfamethoxazole, sulfanilamide, and oxolinic acid were predominant in finished water and tap water samples. Among the other pharmaceuticals, caffeine, codeine, dimethylxanthine, and cotinine were predominant in finished water and tap water samples, at relatively high concentrations. The concentrations of most pharmaceuticals detected in finished water and tap water were lower than those in raw water, indicating positive removal efficiency during water treatment. However, incomplete removal of pharmaceuticals during water treatment led to contamination of drinking water. This contamination is concerning, even at low concentrations, since the consequential health effects are not fully understood. (Lv et al., 2019)

Las Vegas Wash (NV). At LVW, 13 compounds (65% of total analytes) were detected with >85% frequency, with pharmaceuticals making up the most frequently detected analytes. The detection frequencies of many of these compounds were greater than those previously found in US waters as LVW is dominated by wastewater discharge, which is the primary source of PPCPs. Conversely, hormones (i.e., estradiol, ethynylestradiol, progesterone, testosterone) were detected at low frequency (<10%) possibly because of their high removal efficiencies through wastewater treatment processes.

Alfred Merritt Smith treatment plant inflow (NV). In AMS raw water from Lake Mead, five compounds (25% of total analytes) were detected above 80% frequency, with the remaining compounds detected less than 25% of the time. Most of the five frequently detected compounds were pharmaceuticals that were also frequently detected at LVW except atrazine, which was infrequently detected at LVW. Several compounds detected with>85% frequency at LVW (i.e., *N*,*N*-Diethyl-*meta*-toluamide[DEET], trimethoprim, triclosan, naproxen, gemfibrozil) were less frequently detected in AMS. Even compounds detected with >60% frequency at LVW (i.e., TCEP, fluoxetine, diclofenac, musk ketone, diazepam) were detected in only a single sample or not at all in AMS inflow.

Assabet River (MA). In the Assabet River, eight compounds (25% of total analytes) were detected with >50% frequency—most of these pharmaceuticals. The most frequently detected compounds were DEET and sulfamethoxazole (>70%), which were previously reported to be frequently present in US waters. Hormones (i.e., estrone, estradiol) were detected at low frequency (<10%).

Santa Ana River (CA). In the Santa Ana River, eight compounds were detected with >85% frequency (50% of total analytes), with only three detected in fewer than half of the samples (Figure 2, part D). The most frequently detected compounds above MDLs were caffeine, TCEP, diuron, DEET, sulfamethoxazole, primidone, carbamazepine, and Dilantin (≥75%). TCEP and caffeine, the most frequently detected compounds in SAR, were previously identified as frequently detected compounds in US waters (>30%) Diuron, an herbicide frequently detected in US surface waters and one of the most-used herbicides in California. (Hagemann et al., 2016)

Swimming Pools. Pool water and fill water samples were collected from 31 swimming pools in eastern Minnesota and western Wisconsin, from March to July in 2015 and analyzed for 24 PPCPs. A variety of pool types were sampled (outdoor, indoor, hotel, school, apartment/condominium/homeowners association, waterpark, therapy and fitness facilities) to identify contamination sources in a larger range of pool types than previous studies. A questionnaire was issued at each site to collect information about the venue type and shower and toilet accessibility. The 24 PPCPs included analgesics (acetaminophen, diclofenac and ibuprofen), antimicrobials (clarithromycin, erythromycin anhydrate, roxithromycin, sulfamethoxazole, triclosan and trimethoprim), antidepressants (fluoxetine and paroxetine), one antiepileptic (carbamazepine), β-blockers (atenolol and metoprolol), lipid regulators (atorvastatin and gemfibrozil), stimulants (caffeine and cotinine), one fragrance (tonalide), one UV filter (benzophenone-3), one insect repellant (N,Ndiethyl-meta-toluamide [DEET]), one flame retardant (tris(2-carboxyethyl)phosphine [TCEP]), one detergent degradate (nonylphenol) and one herbicide (atrazine). These PPCPs were selected based on the likelihood of use by swimmers and frequent occurrence in finished drinking water. (Suppes et al., 2017)

DEET, ibuprofen, caffeine and TCEP were detected most frequently. Of the 24 PPCPs in this study, 20 were present in pool water at least once. The four PPCPs not present in any pool water samples were atenolol, clarithromycin, roxithromycin and triclosan. PPCPs were also present in fill water. Like pool water, atenolol, clarithromycin and roxithromycin were not present in fill water. With the exception of triclosan, which was detected at 4% frequency in fill water, every PPCP present in fill water was also present in pool water. (Suppes et al., 2017)

Groundwater. USGS conducted the first large-scale, systematic assessment of hormone and pharmaceutical occurrence in groundwater used for drinking across the United States. Samples from 1091 sites in Principal Aquifers representing 60% of the volume pumped for drinking-water supply had final data for21 hormones and 103 pharmaceuticals. (Bexfield et al., 2019)

Occurrence of Pharmaceuticals in Groundwater

When pharmaceuticals enter the groundwater, they can be stable for a long time, because the degradation process in this component is limited to hydrolysis. The low dissolved oxygen concentration, low temperature and low concentrations of nutrients in ground water, favor long-term persistence of micro-pollutants in this environment. (Caban et al., 2016)

At least one compound was detected at 5.9% of 844 sites representing the resource used for public supply across the entirety of 15 Principal Aquifers, and at 11.3% of 247 sites representing the resource used for domestic supply over subareas of nine Principal Aquifers. Of 34 compounds detected, one plastics component (bisphenol A), three pharmaceuticals (carbamazepine, sulfamethoxazole, and meprobamate), and the caffeine degradate 1,7-dimethylxanthine were detected in more than 0.5% of samples. Hydrocortisone had a concentration greater than a human-health benchmark at 1 site. Compounds with high solubility and low Koc were most likely to be detected. Detections were most common in shallow wells with a component of recent recharge, particularly in crystalline-rock and mixed land-use settings. Results indicate vulnerability of groundwater used for drinking water in the U.S. to contamination by these compounds is generally limited, and exposure to these compounds at detected concentrations is unlikely to have adverse effects on human health. (Bexfield et al., 2019)

USGS Groundwater Survey of PPCP/EDC

This first large-scale, systematic assessment of a substantial portion of the groundwater resource used for drinking water across the U.S. indicates vulnerability to contamination by hormones and pharmaceuticals is not widespread, and where these compounds are detected, they generally are at concentrations that are not expected to have adverse human-health effects. Compounds most likely to be detected have relatively high solubility and low tendency to sorb onto soil, sediment, or rock, but are not necessarily among the most used. They are most common in shallower wells with a component of young groundwater, particularly in crystalline rock settings (where the detection frequency is 16%), likely reflecting the presence of recent recharge that has been affected by human activities. (Bexfield et al., 2019)

Detection frequency is highest in areas of mixed land use, where further investigation would be needed to identify major sources and controlling factors. The observed detection frequencies and concentrations indicate similar or substantially lower occurrence compared with other classes of organic compounds (pesticides, VOCs) in groundwater used for drinking, with similarly rare HHB exceedances. However, some high-use pharmaceutical compounds were not included in this study, and some detected compounds do not have HHBs, which could result in underrepresentation of groundwater vulnerability and human-health implications. Nevertheless, information from this study can be used to prioritize hormone and pharmaceutical compounds and environmental settings for future monitoring and research into environmental fate and potential human-health risks. (Bexfield et al., 2019)

Bottled Water. Reports show that, in 2018, 64% of produced bottles were made of polyethylene terephthalate (PET), 34% of high-density polyethylene (HDPE), 1.8% of polypropylene and 1% other (polycarbonate (PC) included here). According to the American Chemistry Council (ACC), in 2018, 0.31 million pounds of postconsumer PC bottles were collected for recycling. PET and HDPE continued to dominate as selected resins to produce plastic bottles (97.1% by weight of produced bottles has made of PET or HDPE). Although BPA is not used in the manufacture of PET, it should consider the use of recycled PET (R-PET) as a possible source of BPA coming from cross-contamination, not only during the recycling process but also during the manufacture of virgin PET. The highest concentrations of bisphenol A (BPA), benzyl butyl phthalate (BBP), di-nbutyl phthalate (DBP) and di (2-ethylhexyl) phthalate (DEHP) in all the bottled waters studied were found to be 5.7, 12.11, 82.8 and 64.0 µg/L, respectively. DBP was the most compound detected and the main contributor by bottled water consumption with 23.7% of the Tolerable Daily Intake (TDI). Based on the risk assessment, BPA, BBP, DBP and DEHP in commercial water bottles do not pose a serious concern for humans. The average estrogen equivalent level revealed that BPA, BBP, DBP and DEHP in bottled waters may induce adverse estrogenic effects on human health. (Silva Costa et al., 2021)

The estrogenic activity and BPA concentrations in PET bottled water from South Africa are similar to bottled water from other countries. Although the risk determined in the current assessment is low, other chemicals, not tested for in this study, may be present in bottled water and contribute to the total health risk. As an example, antimony is classified as a possible carcinogen and has been shown to migrate from PET. Furthermore, this study only measured the contribution of bottled water to EDC exposure and other sources may increase contamination levels. The observed increased estrogenic activity and higher concentrations of BPA at 40^{o}C lead to the recommendation that bottled water should be stored at room temperature or below so that the potential exposure to EDCs is minimized. (Aneck-Hahn et al., 2018)

Survey of Antibiotics in Bottled and Tap Water in China. The study by Ben et al. (2020) is the first attempt to simultaneously identify and quantify 92 antibiotic residues in filtered tap water (multistage filtration at the tap) (n = 36) collected from 10 areas of a large city in southern China, 10 Chinese brands of bottled/barreled water (n = 30) and six foreign brands of bottled water (n = 18) obtained from the Chinese market.

Complex Antibiotic Pollution in Chinese Drinking Water

The average and median concentrations of all detected antibiotic compounds was 182 and 92 ng/L in filtered tap water, 180 and 105 ng/L in Chinese brands of bottled/barreled water, and 666 and 146 ng/L in foreign brands of bottled water, respectively. A total of 58 antibiotics were detected in the filtered tap water, and 45 and 36 antibiotics were detected in the Chinese and foreign brands of bottled water, respectively. More types of antibiotics were detected in Chinese brands of bottled water than in the other bottled waters. In addition, Chinese waters had high roxithromycin concentrations, while the foreign brands of bottled water had high concentrations of dicloxacillin. The results suggested a complex antibiotic pollution in Chinese drinking water, with a prevalence of macrolides.

Based on the levels of antibiotic residues analyzed in different types of drinking water, the individual and overall values of daily intake of all the detected antibiotics were estimated for three scenarios: only filtered tap water was consumed, only Chinese brands of bottled water were consumed, and only foreign brands of bottled water were consumed. Risk of human exposure to trace antibiotics via drinking water was assessed individually, indicating that the individual antibiotic residues in drinking water may pose low risk to human health. However, the data and knowledge required to comprehensively characterize the overall risks of antibiotic residues exposure is severely limited. Further research is needed for a more in-depth understanding of the potential adverse effects of exposure to environmental antibiotic residues on the human microbiome. (Ben et al., 2020)

TREATMENT

The chemical and/or metabolic stability of some pharmaceuticals means that up to 90% of the active ingredient is excreted (or washed off) in its original form. Wastewater treatment varies in its ability to eliminate pharmaceutical residues, depending upon the substance and the level of treatment; in some cases, substantial amounts are removed, in others, only a small percentage; but even the best, most expensive, current treatments are not 100% effective. The release of veterinary medicines to the environment tends to come from untreated diffuse sources such as the spreading of manure. (EC, 2019)

The fate of EDCs/PPCPs varies because of their diverse physical and chemical properties. Some EDCs/PPCPs are degraded through photolysis, biodegradation, and/or sorption, while other compounds are persistent in waters. The rates of degradation are dependent on characteristics of the analyte and environment, leading to the different behaviors across sites and compounds. (Hagemann et al., 2016)

Effectiveness of Wastewater Treatment

Conventional wastewater treatment facilities generally have activated sludge processes or other forms of biological treatment such as biofiltration. These processes have demonstrated varying removal rates for pharmaceuticals, ranging from less than 20% to greater than 90%. The efficiency of these processes for the removal of pharmaceuticals varies within and between studies and is dependent on operational configuration of the wastewater treatment facility. Factors influencing removal include sludge age, activated sludge tank temperature and hydraulic retention time. Comparatively, advanced wastewater treatment processes, such as reverse osmosis, ozonation and advanced oxidation technologies, can achieve higher removal rates for pharmaceuticals. (WHO, 2012)

Effectiveness of Water Treatment

Studies on conventional drinking-water treatment processes have shown that coagulation is largely ineffective in removing pharmaceuticals. Free chlorine is able to remove up to approximately 50% of the pharmaceuticals investigated, whereas chloramines have lower removal efficiency. Compounds that showed high removal by free chlorine but low removal by chloramines include antibiotics, such as sulfamethoxazole, trimethroprim and erythromycin. Advanced water treatment processes, such as ozonation, advanced oxidation, activated carbon and membranes (e.g. nanofiltration, reverse osmosis), are able to achieve higher removal rates (above 99%) for targeted pharmaceutical compounds in various studies in the published literature. (WHO, 2012)

Fate and Transport of EDCs/PPCPs. EDCs/PPCPs in water are variously transported, adsorbed, or degraded, which is determined by various factors, including the physical properties of individual compounds and water chemistry. Some EDCs/PPCPs such as anti-convulsants (e.g., carbamazepine and primidone) are recalcitrant to degradation and transported without any changes in structures and properties. Other EDCs/PPCPs can be adsorbed to sediment without degradation. Sorption is controlled by properties such as the acid dissociation constant, Ka, organic partition coefficient, Koc, the octanol-water partition coefficient, Kow, the solid-water distribution coefficient, Kd and other factors. For example, benzafibrate, fluoxetine, fluvoxamine and ibuprofen are reported to be highly sorbed. Table 1.2 in that reference presents the physical properties of selected compounds. EDCs/PPCPs can be degraded via photolysis, hydrolysis, and biodegradation. Photolysis is a chemical process by which compounds are degraded by light exposure. Some EDCs/PPCPs can be directly photodegraded by absorbing light while others indirectly photodegraded when light initiates a reaction in other compounds in surface waters that react with EDCs/PPCPs. For example, triclosan, diclofenac, iopromide, and sulfonamide antibiotics are degraded primarily by direct photolysis while ibuprofen, ketoprofen, and cimetidine are degraded by indirect photolysis. Photolysis rates are different for individual compounds depending on their structure. Reported photolysis half-lives range from one day to around hundred days. Biodegradation and hydrolysis are not significant processes for PPCPs in waters, particularly where light penetrates. Caffeine and cotinine partition into sediments and are subsequently biodegraded. Sulfonamide antibiotics (e.g., sulfamethoxazole) are biodegradable and sorbed to sediments. Gemfibrozil and ibuprofen are degraded by photolysis and biodegradation. (WRF, Park et al., 2017)

Treatment of EDCs/PPCPs. Conventional WWTPs are not specifically designed to remove EDCs/PPCPs and therefore may not effectively remove EDCs/PPCPs. The removal rates of EDCs/PPCPs vary depending on their chemical properties and process design and those compounds not removed after treatment processes will be discharged to receiving waters. EDCs/PPCPs can be removed by adsorption onto suspended solids, biodegradation, and/or chemical degradation. Table 1.3 in that reference summarizes treatment and removal efficiencies of selected EDCs/PPCPs from the literature. The sorption to sludge can be determined by the octanol-water partition coefficient, Kow; the solid-water distribution coefficient, Kd; the organic partition coefficient, Koc. Some compounds (e.g., ibuprofen, diclofenac, ketoprofen, ofloxacin, azithromycin, loratidine, propanolol, galaxolide, tonalide, and 17β-estradiol) are partially removed by adsorption to sludge in primary sedimentation. (WRF, Park et al., 2017) Dutta and Mala (2020) presented a review of adsorption materials for the removal of antibiotics.

In conventional WWTPs, the majority of EDCs/PPCPs are removed by biological degradation in secondary treatment. The removal efficiencies depend on the biochemical oxygen demand, suspended solids load, hydraulic residence time, solids retention time, food-microorganism ratio, mixed liquor-suspended solids, pH, and temperature. For example, ibuprofen, bezafibrate, 17β-estradiol, estrone, estriole, and 17α-ethinylestradiol have been reported as completely removed with a solid retention time (SRT) of 10 days. Disinfection in both drinking and wastewater treatment can remove EDCs/PPCPs. For example, steroid hormones and nonsteroidal anti-inflammatory drugs (NSAIDs) are partially removed by chlorination. Ozone is a highly selective oxidant and compounds containing activated aromatic rings react very quickly. Ozone has been found to successfully remove certain EDCs/PPCPs (e.g., atenolol, carbamazepine, dilantin, meprobamate, primidone, trimethoprim) especially with hydrogen peroxide or ultraviolet light. Ultraviolet light degrades EDCs/PPCPs via photolysis. However, certain EDCs/PPCPs (e.g., carbamazepine) are resistant to removal. (WRF, Park et al., 2017)

Overall, the combination of computational and experimental chemistry and toxicity methods used in this project suggests that disinfection of potent EDCs and PPCPs will produce a large number of TPs, which are unlikely to produce compounds of increased specific toxicity (e.g., endocrine activity) but may result in increased reactive and non-specific toxicity. Future research into "activation" of micropollutants from disinfection reactions should perhaps focus on weak and moderate endocrine active compounds (rather than potent compounds), as these have the highest likelihood of producing more potent chemical structures. (WRF, WRA, Leusch et al., 2018)

Constructed Wetlands. CWs are effective in significantly reducing the environmental risk caused by many PPCP. Based on risk assessment, 12 PPCP were classified under high risk category (oxytetracycline>ofloxacin> sulfamethoxazole>erythromycin> sulfadiazine>gemfibrozil >ibuprofen>acetaminophen> salicylic acid> sulfamethazine> naproxen>clarithromycin), which could be considered for regular monitoring, water quality standard formulation and control purposes. Biodegradation (aerobic and anaerobic) is responsible for the removal of the majority of PPCP, often in conjunction with other mechanisms (e.g., adsorption/sorption, plant uptake, and photodegradation). The physicochemical properties of molecules play a pivotal role in the elimination processes and could serve as important predictors of removal. The correlation and multiple linear regression analysis suggest that organic carbon sorption coefficient (Log Koc), octanol-water distribution coefficient (Log Dow), and molecular weight form a good predictive linear regression model for the removal efficiency of PPCP.

A very high range of variability in the influent and effluent concentrations, and removal efficiencies exist among the studied PPCP across the case study regions around the world. While CWs could effectively remove most of the PPCP and their metabolites, some cases of negative removal also occur. However, despite large variability, CWs have demonstrated their capability to effectively and efficiently remove a large number of PPCP from wastewater (e.g., 96 out of 113 compounds or 85% of the sample show a positive removal efficiency). An in-depth analysis of the 34 most widely studied PPCP indicated a moderate to high potential of CWs for the removal of monensin, ofloxacin, oxytetracycline, sulfapyridine, caffeine, salicylic acid, atenolol, furosemide, doxycycline, codeine, diltiazem, acetaminophen, naproxen, ibuprofen, metoprolol, and sulfadiazine. There is an encouraging trend in studies related to ecological risk assessment posed by PPCP, which should be continued to enhance the available knowledge. The available evidence revealed that CWs could considerably reduce the environmental risk posed by PPCP. However, the risk is not fully eliminated by CWs, although significantly reduced in most cases. Based on this analysis, and on data from several countries, a number of PPCP could be classified under the high-risk category: oxytetracycline, ofloxacin, sulfamethoxazole, erythromycin, sulfadiazine, gemfibrozil, ibuprofen, acetaminophen, salicylic acid, sulfamethazine, naproxen, and clarithromycin. These high-risk PPCP could be considered for regulatory monitoring, water quality standard formulation, and control purposes. For instance, the EU watch list of four PPCP (azithromycin, clarithromycin, erythromycin, and diclofenac) could be enhanced by considering these PPCP. Since this analysis is based on several countries across the world, these assessments could also inform the WHO's global guidelines on PPCP. However, it is recognized that in-depth studies are essential for a specific water and environmental context to establish risk and consequent monitoring and management actions. The most widely reported mechanism for PPCP' removal in CWs is biodegradation (aerobic and anaerobic). The other notable mechanisms are adsorption/sorption, plant uptake (planted CWs), and photodegradation (FWSCW). Most readily biodegradable PPCP and the ones removed via several mechanisms are likely to demonstrate the highest removal efficiencies. In contrast, most of the PPCP reveal moderate to low removal efficiency when one of their most dominant removal mechanisms is adsorption, photodegradation, or plant uptake. The role of physicochemical properties of PPCP is pivotal in the removal processes. Among the studied properties, Log Koc, Log Dow, and molecular weight could (together) explain about 65% of the variance in the removal efficiency. Thus, these three factors could be seen as important predictors of removal efficiency of PPCP, and therefore, could contribute to a screening process for potential removal of PPCP by CWs. Finally, an optimal design of CWs and other wastewater treatment technologies must be underpinned by the evidence-based scientific knowledge on the compound specific variability in removal efficiency, complexity of governing physicochemical properties and removal mechanisms of the targeted PPCP in a specific environmental context. (Ilyas et al., 2020)

RECOMMENDATIONS

WHO Recommendations

Development of Formal WHO Guideline Values for Pharmaceuticals is Unwarranted

Concerns over pharmaceuticals should not divert the attention and valuable resources of water suppliers and regulators from the various bacterial, viral and protozoan waterborne pathogens and other chemical priorities, such as lead and arsenic. The current levels of exposure to pharmaceuticals in drinking-water also suggest that the development of formal guideline values for pharmaceuticals in the WHO Guidelines for Drinking-water Quality is unwarranted. (WHO, 2012)

As outlined in the WHO Guidelines for Drinking-water Quality, the water safety plan approach is “the most effective means of consistently ensuring the safety of a drinking-water supply through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in the water supply from catchment to consumer”. Water safety plans highlight the importance of considering risk assessment and risk management comprehensively from source to tap and adopting preventive measures to address the source of risks. (WHO, 2012)

Prevent Pharmaceuticals from Entering the Water Supply Cycle

Adapting the water safety plan approach to the context of pharmaceuticals in drinking-water means that preventing pharmaceuticals from entering the water supply cycle during their production, consumption (i.e. excretion) and disposal is a pragmatic and effective means of risk management. Preventive measures need to be applied as close as possible to the source of the risk and hazard. Inappropriate disposal practices, such as flushing unwanted or excess drugs down toilets and sinks and discarding them into household waste, are common and may be the main contributors to pharmaceuticals in wastewater and other environmental media, such as surface waters and landfill leachate. (WHO, 2012)

Preventive measures, such as policies promoting or regulations governing disposal practices at concentrated point sources (e.g. healthcare and veterinary facilities), can reduce the amount of pharmaceutical waste entering water bodies. In addition, take-back programs, guidance and enhanced consumer education will support efforts for the proper disposal of medicines and reduce the impact of pharmaceuticals entering our water sources. (WHO, 2012)

Targeted Monitoring Where Necessary

Routine monitoring of pharmaceuticals in water sources and drinking water at the national level and the installation of specialized drinking water treatment infrastructure to reduce the very low concentrations of pharmaceuticals in drinking-water are not currently deemed necessary given the limited additional health benefits. However, where specific circumstances, such as a catchment survey, indicate a potential for elevated concentrations of pharmaceuticals in the water cycle (surface water, groundwater, wastewater effluent and drinking-water), relevant stakeholders could undertake targeted, well-designed and quality-controlled investigative studies to obtain more information to assess potential health risks arising from exposure through drinking-water. If necessary, screening values could be developed and an assessment of the need for treatment enhancement could also be considered within the context of other risks and priorities using the water safety plan. (WHO, 2012)

Risk Communication

Enhanced risk communication to the public and public education efforts on water quality issues from the human health standpoint will help the public to better understand this issue relative to other hazards, such as pathogenic microbial risks. This means conveying the risks of exposure to very low concentrations of pharmaceuticals in drinking-water to the public using plain language. (WHO, 2012)

Knowledge gaps and future research. Although current published risk assessments indicate that trace concentrations of pharmaceuticals in drinking-water are very unlikely to pose risks to human health, knowledge gaps exist in terms of assessing risks associated with long term exposure to low concentrations of pharmaceuticals and the combined effects of mixtures of pharmaceuticals. (WHO, 2012)

Sampling objectives are essential to help inform the spatial and temporal components of the design. While some utilities have only sampled EDCs/PPCPs at their raw water intakes (RWIs), others have engaged in broader watershed sampling campaigns. In designing a systematic testing program to evaluate the presence, or potential presence, of EDCs/PPCPs in a drinking water supply, one must incorporate a thorough understanding of the variables in the watershed: sources of contaminants, land use, watershed inputs, contaminant frequency distributions, temporal/seasonal variations, impact of varying hydrological conditions, analytical methodologies, sample handling techniques, and interpreting data within a human health-based context. (WRF, Park et al., 2017)

EU Strategic Approach to Pharmaceuticals in the Environment provided following recommendations:

- Promote the development of guidelines for healthcare professionals on the prudent use of pharmaceuticals posing a risk to or via the environment;
- Explore, in cooperation with relevant stakeholders, how environmental aspects could become part of medical training and professional development programs;
- Facilitate the exchange of best practices among healthcare professionals on the environmentally safe disposal of medicinal products and clinical waste, and the collection of pharmaceutical residues as appropriate (EC, 2019)

Common chemometric approaches to finding patterns among conventional water quality parameters include cluster analysis (CA) and principal component analysis (PCA). CA divides a set of observations into groups that are based on their similarity. PCA is commonly used to identify underlying patterns in the data and to find combinations of variables explaining the largest amount of a data set’s total variance (Hagemann et al., 2016)

Providing showers at swimming pools is necessary for meeting pre-swim shower recommendations and is required in the CDC Model Aquatic Health Code (MAHC). The MAHC is the US model swimming pool code available for state and local health departments to adopt. Toilets are also required at swimming pools in the MAHC. Bathers release on average 30 mL of urine during swimming. (Suppes et al., 2017)

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9. Microplastics and Nanoplastics

Microplastics in drinking water are defined as solid polymeric materials to which chemical additives or other substances may have been added, which are particles that have at least three dimensions greater than 1 nm and less than 5,000 micrometers (µm). (SWRCB, 2021) Plastic particles can also be classified as nanoplastics <1 µm in diameter across their widest dimension, distinct from the larger microplastics (1− 5000 µm) and macroplastics (>5000 µm). (Brewer et al., 2021)

Traditional regulatory frameworks typically focus on short-term risks from chemicals with known hazards. Highly complex, persistent contaminants with unknown hazards are being recognized as potential irreversible global scale threats and are being precautionarily evaluated by regulators and scientists. (Coffin et al., 2021)

LOW PRIORITY FOR SFPUC

Because SFPUC source waters come from protected watersheds, occurrence of nano and microplastics (NMP) is unlikely. Little is known about NMP occurrence in US drinking waters and health significance. These CECs are subject of evolving research. In general, concentrations of NMP in drinking water are likely to be extremely low, if even detectable.

WHO suggested that if plastic emissions into the environment continue at current rates, NMP could become more widespread in aquatic ecosystems (WHO, 2019), and SFPUC's protected watersheds may be at increased risk of becoming contaminated with NMP.

SFPUC is considering participation in SWRCB pilot program to monitor NMP in our system.

This section presents: (1) Screening Evaluation Table and (2) Technical Review 2016-2021 of available scientific studies. No SFPUC Monitoring is available at this time.

Table 9-1. Screening Evaluation Table for Microplastics and Nanoplastics

GENERAL INFORMATION ON CEC	
Instructions	This Screening Evaluation may be applied to a CEC group or an individual CEC. The purpose of this section of the Evaluation is to develop background information on the CEC or CEC group.
CEC Name	**Nanoplastics + Microplastics (NMP)**
CEC Description Is CEC a group? If individual CEC, which group is CEC part of?	‘Microplastics in Drinking Water’ are defined as solid polymeric materials to which chemical additives or other substances may have been added, which are particles that have at least three dimensions greater than 1 nm and less than 5,000 micrometers (µm). (SWRCB, 2021) Plastic particles can also be classified as nanoplastics <1 µm in diameter across their widest dimension, distinct from the larger microplastics (1−5000 µm) and macroplastics (>5000 µm). (Brewer et al., 2021) For the purpose of this review nanoplastics and microplastics (NMP) term is going to be used to encompass all materials greater than 1 nm.
CEC Grouping What is the basis for grouping? *(Grouping factors are: common health effects, treatment, and analytical method, and/or compound co-occurrence)*	NMP are emerging contaminants and as a group they can contain two types of chemicals: (i) additives and polymeric raw materials (e.g., monomers or oligomers) originating from the plastics, and (ii) chemicals absorbed from the surrounding ambience. (Campanale et al., 2020) NMP contamination of the environment is directly linked to waste management. In terms of polymeric composition, PET and PP were the most prevalent polymers identified in bottled water. In tap water, polymeric composition varied with PET and PP present along with polyester, PTT and rayon. (Danopoulos et al., 2020) NMP are rarely deliberately incorporated into a product to serve a specific function, but generally occur as so-called secondary plastics, resulting from the unintentional release and fragmentation of larger pieces of plastics. (Hüffer et al., 2017)

Examples and Indicators If group, what are notable examples? Are there possible indicator constituents? *(A suitable indicator occurs at quantifiable levels and may co-occur with other CEC, exhibit similar treatment and fate in environment)*	No surrogate methods for NMP have been rigorously evaluated. Several candidate surrogate methods (i.e. total organic carbon, turbidity, total suspended solids) are commonly used, and water systems receiving monitoring orders will be required to submit data using these techniques alongside NMP monitoring data. (SWRCB, 2021) The order of the five most abundant polymers can be roughly explained by two factors; global plastic demand and polymer density. Global plastic demand would cause an order of Polyethylene (PE) > Polypropylene (PP) > Polyvinyl chloride (PVC) > Polyethylene Terephthalate (PET) > Polystyrene (PS). (Koelmans et al., 2019) NMP are also not broadly comparable to the many other types of nanosized pollutants that have been identified. While they may overlap in terms of their size range, they can be radically different when considering other important characteristics that dictate behavior, such as density, morphology, and surface chemistry. (Brewer et al., 2021)
Health Advisories Does CEC have a USEPA Health Advisory (e.g., Drinking Water Equivalent Level [DWEL]) or California Notification Level?	There is insufficient evidence at the time of writing this [California SWRCB] Policy to issue a Notification Level or other numerical guidance for NMP. (SWRCB, 2021)
Regulatory Development Status Is CEC on USEPA Candidate Contaminant List (CCL), Unregulated Contaminant Monitoring Rule (UCMR) list, or California Public Health Goal (PHG) list?	NMP are not listed on any Federal or State contaminant lists. California S.B. 1422 of 2018 requires the SWRCB to adopt a standard method for analysis of microplastics and requires four years of testing and reporting to the State and public regarding the occurrence of microplastics in drinking water. Traditional regulatory frameworks typically focus on short-term risks from chemicals with known hazards. Highly complex, persistent contaminants with unknown hazards are being recognized as potential irreversible global scale threats and are being precautionarily evaluated by regulators and scientists. (Coffin et al., 2021)

CONTEXT OF CEC EVALUATION AT SFPUC	
Instructions	The purpose of this section is to report SFPUC experience with the CEC or CEC Group, including occurrence data for each source water if available.
Purpose Why is evaluation undertaken? What is new about the issue that is considered 'emerging' (e.g., new chemical, new effect)?	The growing threat of plastic pollution has been recognized for decades, with global plastic production currently exceeding 320 million tons per year and expected to double in the next 20 years. (Brewer et al., 2021)
Customer Interaction Widespread public concerns? Media coverage?	The San Francisco Bay Regional Monitoring Program, which ranks CEC monitored in water, sediment, and biota into tiered, risk-based categories classified NMP as a constituent class of "Moderate Concern" (Coffin et al., 2021)
Expected Outcomes What are the likely benefits of the evaluation to SFPUC and its customers?	SFPUC is considering participation in a pilot monitoring for NMP conducted by SWRCB, provided laboratory resources are available. Data obtained through the efforts detailed in this Policy will provide valuable insights for determining exposure to consumers through drinking water. (SWRCB, 2021)
Occurrence Data (US and SFPUC) What occurrence information is available? Have detections, if any, been confirmed by follow-up sampling and/or QA/QC review?	The Policy includes a two-step iterative four-year plan for monitoring and reporting NMP in a systematic and harmonized manner. To date, no government in the world has required monitoring for NMP in drinking water. In Phase I, monitoring will focus on characterizing occurrence in source waters for NMP larger than 20 µm in length. Phase II will focus on the occurrence in drinking water for NMP both smaller than, and larger than 20 µm in length (SWRCB, 2021) NMP smaller than 10 µm in length have an increased likelihood of causing adverse health effects in mammals and should be prioritized for monitoring when possible. (SWRCB, 2021) No standard methods exist for sampling and quantifying, which are more likely to be elevated near urban centers and in depositional sediments near municipal wastewater treatment plant (WWTP) outfalls. The predominant source of fibers is likely from washing clothes and antifouling boat paints. (WE&RF, Burton, 2017) At the moment, methodological consensus concerning sample size does not exist.

Supporting Information List key references.	Campanale C. et al. (2020). Review. A Detailed Review Study on Potential Effects of Microplastics and Additives of Concern on Human Health. Int. J. Environ. Res. Public Health 2020, 17, 1212; doi:10.3390/ijerph17041212. Coffin S, Wyer H, Leapman JC (2021). Addressing the environmental and health impacts of microplastics requires open collaboration between diverse sectors. PLoS Biol 19(3):e3000932. Danopoulos E, et al. (2020). Microplastic contamination of drinking water: A systematic review. PLoS ONE 15(7): e0236838. Koelmans A, et al. (2019). Microplastics in freshwaters and drinking water: Critical review and assessment of data quality. Water Research 155 (2019) 410-422. SWRCB (2021). DRAFT MICROPLASTICS IN DRINKING WATER POLICY HANDBOOK. November 10, 2021. THE DIVISION OF DRINKING WATER, STATE WATER RESOURCES CONTROL BOARD, STATE OF CALIFORNIA. Water Environment & Reuse Foundation, G. Allen Burton, Jr. (2017). White Paper – Microplastics in Aquatic Systems, An Assessment of Risk. University of Michigan, Submitted to the WE&RF Lola Olabode, M.P.H., Project Number: CEC7R17. WHO (2019). Microplastics in drinking-water. Geneva: World Health Organization; 2019. License: CC BY-NC-SA 3.0 IGO.

DIAGNOSTIC QUESTIONS TO SUPPORT CEC PRIORITIZATION	
Instructions	The purpose of the Diagnostic Questions is to determine whether the CEC or CECs Group are significant to SFPUC drinking water and whether they merit further evaluation and/or action. All answers require explanation except those clearly not applicable. The Diagnostic Questions are divided into Health, Occurrence, and Treatment sections. The more questions are answered with a “Yes”, the higher the probability that the CEC is a high priority or that a proactive approach should be taken.

HEALTH EFFECTS FROM SCIENTIFIC STUDIES		
Question	**Answer**	**Explanation and Comments**
Is scientific knowledge on CEC health effects well developed?	**No**	Studies conducted in recent years have shown strong evidence that humans are exposed to NMP dispersed ubiquitously in the environment. Currently, there are insufficient hazard and exposure data, as well as insufficient conceptual approaches, to perform a meaningful human health risk assessment of NMP. (Noventa et al., 2021)
Based on current scientific understanding, does the CEC pose potential health risk at the levels typically found in drinking water in the US?	**No**	Based on the limited evidence available, chemicals and microbial pathogens associated with NMP in drinking-water pose a low concern for human health. Although there is insufficient information to draw firm conclusions on the toxicity of NMP, no reliable information suggests it is a concern. (WHO, 2019) Not enough information is available to fully understand the implications of NMP for human health; however, effects may potentially be due to their physical properties (size, shape, and length), chemical properties (presence of additives and polymer type), concentration, or microbial biofilm growth. (Campanale et al., 2020)
Adverse health impacts observed in other drinking water systems? Are public health studies documenting human health impacts (disease or outbreaks) available?	**No**	Neither occurrence in US drinking waters nor potential health-related impacts from drinking water have been evaluated.

Question	Answer	Explanation and Comments
Existing regulations or guidelines outside of US (e.g., WHO, EU)?	**No**	European Union classified NMP as a non-threshold contaminant for risk assessment purposes; uncertainties regarding toxicities; an upward trend in both plastic production and environmental detection; and persistence. (Coffin et al., 2021)
Existing US health advisories or CA notification levels?	**No**	No US health advisories or CA notification levels are available for NMP in drinking water.
Likely US regulation in the next 10 years? Is CEC on a regulatory development list, such as CCL? Is there a pending regulation or California PHG?	**No**	Because NMP are an emerging topic of study in environmental monitoring and human health risk, there is not adequate information on which to base regulation. Hence US regulation is not likely within the next 10 years.
SUMMARY – SIGNIFICANT TO PUBLIC HEALTH IN GENERAL? *(Based on above answers)*	**Unknown**	Available evidence does not highlight specific issues or concerns with respect to the existence of a widespread risk to human health. However, quantitative information regarding NMP exposure and toxicity is too scarce to allow for definitive conclusions on NMP risks for human health, both at present and in the future, where NMP pollution is expected to rise. (Noventa et al., 2021)
OCCURRENCE		
Is scientific knowledge on CEC sources/formation well developed?	**Yes**	NMP are ubiquitous in the environment and have been detected in marine water, wastewater, fresh water, food, air and drinking-water, both bottled and tap water. NMP enter freshwater environments in several ways: primarily from surface run-off and wastewater effluent (both treated and untreated), but also from combined sewer overflows, industrial effluent, degraded plastic waste and atmospheric deposition. However, there are limited data to quantify the contribution of each the different inputs and their upstream sources. Further, the limited evidence indicates that some NMP found in drinking-water may come from treatment and distribution systems for tap water and/or bottling of bottled water. (WHO, 2019) MPs are generally higher in bottled water than tap water and increase with the number of openings/closings of the bottles.

Question	Answer	Explanation and Comments
CEC presence reported in other water supplies? Are occurrence studies available?	**Unknown**	Conclusions among studies and water types are difficult to draw due to the differences in targeted particle sizes. (Koelmans et al., 2019) The inverse relationship between the size of NMP and their abundance is supported by the findings. Generally low NMP numbers of 0.174 NMP/L (> 6.6 µm) found a Swedish distribution system suggest that the consumption of drinking water, processed by a high-performance drinking water treatment plant, does not particularly add to potential risks to human health. (Kirstein et al., 2021) 94 % of Danish tap water samples contained NMP below the Limit of detection of 0.58 NMP/L (> 100 µm). (Strand et al., 2018)
CEC present in SFPUC watersheds and/or surface waters? Are there complex issues involved in managing CEC ;e.g., point vs. non-point sources?	**Unknown**	NMP have not been monitored in SFPUC watersheds and source waters but are not expected to occur because watersheds and source waters are not impacted by wastewater discharges or urban runoff. If we compare NMP particle numbers to the adverse effect of TSS it becomes apparent that NMP particles are insignificant, meaning microbeads are even less so. Fish are adversely affected by TSS at levels ranging from 30-160 mg/liter. At the worst sites for NMP pollution, such as Lake Erie, their concentrations are from 10 to 1 million-fold lower than adverse TSS levels. (WE&RF, Burton, 2017) Surface waters typically have high detection frequencies of NMP. There is a high probability for the occurrence of NMP as large as 5,000 micrometers in length in surface waters. SWRCB (2021)
Is the CEC a potential groundwater contaminant?	**Unknown**	Groundwaters typically have low detection frequencies of NMP. SWRCB (2021)
If the CEC is a potential groundwater contaminant, is it highly mobile in the subsurface? *Is* the CEC low-sorbing and resistant to microbial degradation?	**No**	Not likely to be a groundwater contaminant. Migration of MPs is likely to be low in groundwater.

Question	Answer	Explanation and Comments
Precursor present in SFPUC source waters? *(Including surface waters and groundwaters)*	**No**	No. Watersheds and source waters are not impacted by wastewater discharges or urban runoff. Inputs from wastewater reuse are likely to be minimal since reverse osmosis (RO) would remove MPs to a greater extent than conventional drinking water facilities.
Formed or added during current SFPUC treatment? If so, describe whether the formation or addition of CEC can be controlled.	**No**	Water-soluble polymers like polyacrylamides (PAM) are used as a flocculant in water treatment. Only insoluble polymers are considered for monitoring at this point. The most likely input would be shedding from plastic fixtures or rubber seals within the treatment plant.
Formed or added within SFPUC storage or distribution? If so, describe whether the formation or addition of CEC can be controlled.	**Unknown**	NMP are not formed or added within SFPUC storage or distribution.
Detected in SFPUC drinking water?	**Unknown**	NMP have not been monitored in SFPUC drinking water. Likely they occur, but at lower concentrations than in bottled water and drinking waters from other cities where the water supply is less pristine.
SUMMARY – OCCURRENCE IN SOURCE AND DRINKING WATER? *(OR SIGNIFICANT POTENTIAL TO OCCUR)* *(Based on above answers)*	**Unknown**	Concentrations in bottled water are higher than in tap water, which may reflect the higher influx of airborne particles in the factories, wear from caps or bottle walls after production, or the fact that these studies also included smaller sized particles. (Koelmans et al., 2019) Current evidence suggests that there are higher rates of NMP contamination in bottled water compared with tap water, both in terms of frequency and quantity. (Danopoulos et al., 2020)

TREATMENT		
Question	**Answer**	**Explanation and Comments**
Is scientific knowledge on CEC treatment/removal well developed?	**Yes**	Conventional treatment, when optimized to produce treated water of low turbidity, can remove particles larger than a 1 µm through coagulation, flocculation, sedimentation/flotation and filtration. Advanced treatment can remove smaller particles. NF can remove particles >0.001 µm while UF can remove particles >0.01µm. These facts combined with well-understood removal mechanisms point to the rational conclusion that water treatment processes can effectively remove NMP. (WHO, 2019)
Likely to pass through current treatment for Hetch Hetchy Supply? Describe any complex issues for treatment/removal of CEC.	**Unknown**	NMP would not be removed by the current treatment at Tesla but they are not expected to occur in Hetch Hetchy water because watersheds are not impacted by wastewater discharges or urban runoff.
Likely to pass through current treatment at SVWTP? Describe any complex issues involved with the treatment/removal of CEC.	**No** **(> 1 µm)** **Yes** **(< 1 µm)**	Several commonly used drinking water treatment technologies, including conventional treatment at SVWTP, incidentally remove NMP larger than 20 micrometers in length. SWRCB (2021) A plant that can remove Cryptosporidium oocysts which are 4 to 6 µm in size should remove most NMP. However, many NMP may be closer to the nano-size, which is a potential concern that has not been addressed. (WE&RF, Burton, 2017). An average microfiber removal efficiency is over 70%.
Likely to pass through current treatment at HTWTP? Describe any complex issues involved with the treatment/removal of CEC.	**No** **(> 1 µm)** **Yes** **(< 1 µm)**	Several commonly used drinking water treatment technologies, including direct filtration at HTWTP, incidentally remove NMP larger than 20 micrometers in length. SWRCB (2021) A plant that can remove Cryptosporidium oocysts which are 4 to 6 µm in size should remove most NMP. However, many NMP may be closer to the nano-size, which is a potential concern that has not been addressed. (WE&RF, Burton, 2017). An average microfiber removal efficiency is over 70%.

Likely to pass through current treatment for groundwater? Describe any complex issues for treatment/removal of CEC.	**No**	Groundwaters typically have low detection frequencies of NMP. SWRCB (2021)
SUMMARY – LIKELY TO PASS (NOT REMOVED BY) CURRENT TREATMENT? *(Based on above answers)*	**No**	NMP are not expected to occur because watersheds are not impacted by wastewater discharges or urban runoff. The technologies used for pre-treatment of potential future reuse streams (rain garden filtration beds and RO for reuse) remove MPs to a greater extent than conventional drinking water and also in bottled water.

CEC PRIORITIZATION – CURRENT ASSESSMENT	
Instructions	This section prioritizes the CEC based upon the information developed in the above Diagnostic Questions as well as in the background information. For high and medium priorities, develop monitoring and/or mitigation measures as appropriate. For low priorities, maintain current measures, track regulatory developments, health/technical studies and reevaluate priority when needed.
Could CEC occur in SFPUC drinking water at levels of possible health significance? *(Based on above Diagnostic Questions)*	**UNKNOWN.** Based on this body of evidence, the risk associated with ingestion of NMP through drinking-water remains uncertain; however, at this point, no data suggest overt health concerns associated with exposure to NMP particles through drinking-water. (WHO, 2019) In 2019, WHO suggested that if plastic emissions into the environment continue at current rates, NMP could become more widespread in aquatic ecosystems, and SFPUC's protected watersheds may become at increased risk of becoming contaminated with this group. (WHO, 2019)

CEC Prioritization for SFPUC High, Medium, or Low. Provide explanation. *(A high number of "Yes" answers to the Diagnostic Questions indicates a higher priority, and "No" or very few "Yes" answers indicates a lower priority.)*	**LOW PRIORITY FOR SFPUC** Because SFPUC source waters come from protected watersheds, occurrence of NMP is unlikely. Little is known about NMP occurrence in US drinking waters and health significance. These CECs are subjects of evolving research. In general, concentrations of NMP in drinking water are likely to be extremely low, if even detectable.
Implemented Actions Indicate the progress and results of any action items, above, such as implemented in previous cycles of CEC review. Evaluate whether changes to the action plan are required.	• Evaluation of participation by SFPUC WQD in a SWRCB pilot to monitor NMP in our system. • Evaluated health and technical studies on NMP.
Recommended Actions Does the situation merit investing additional resources or has the information gathered so far fulfilled due diligence? Actions could include monitoring and other measures (specified by source water, if necessary).	• Participate in SWRCB pilot program to monitor NMP in our system, if resources allow. It would be worthwhile to incorporate bottled water testing as a comparison set for the SWRCB testing. • Maintain source water protection and optimized multibarrier water treatment and distribution system operation. • For researchers, it would be appropriate to undertake targeted, well designed and quality-controlled investigative studies to better understand the sources and occurrence of NMP in fresh water and drinking-water, the efficacy of different treatment processes and combinations of processes, and the significance of the potential return of NMP to the environment from treatment waste streams including the application of sludge biosolids to agricultural land. (WHO, 2019) • Water suppliers should ensure that control measures are effective and should optimize water treatment processes for particle removal and microbial safety, which will incidentally improve the removal of NMP. (WHO, 2019)

	• Routine monitoring of NMP in drinking-water is not recommended at this time, as there is no evidence to indicate a human health concern. Concerns over NMP in drinking-water should not divert resources of water suppliers and regulators from removing microbial pathogens, which remains the most significant risk to human health from drinking-water along with other chemical priorities. (WHO, 2019) • Where simple, low-cost actions can be taken to make even a small difference to plastic inputs to the environment, it would be sensible to implement them. The benefits of plastic must also be considered before introducing policies and initiatives. (WHO, 2019) • It might be prudent to start considering whether to incorporate consideration of the potential to shed plastics from materials used in water treatment process units during future designs.

This evaluation was prepared based on available information (peer-reviewed literature and occurrence data) with the purpose of prioritizing work and informing the public on unregulated CEC. This evaluation will be updated every 6 years or when significant new research or occurrence data on CEC become available that may warrant changing priority and recommendations.

Water Quality Division, Technical Review 2016 – 2021

Contaminants of Emerging Concern (CEC) in Drinking Water

Microplastics and Nanoplastics

Journal “Nature” recently reported (Journal Nature article is attached at the end of this review): Richard Thompson, a marine ecologist at the University of Plymouth, UK, coined the term in 2004 to describe plastic particles smaller than 5 millimetres across, after his team found them on British beaches. Scientists have since seen microplastics everywhere they have looked: in deep oceans; in Arctic snow and Antarctic ice; in shellfish, table salt, drinking water and beer; and drifting in the air or falling with rain over mountains and cities. These tiny pieces could take decades or more to degrade fully. “It’s almost certain that there is a level of exposure in just about all species.” From limited surveys of microplastics in the air, water, salt and seafood, children and adults might ingest anywhere from dozens to more than 100,000 microplastic specks each day. Regulators are taking the first step towards quantifying the risk to people’s health — measuring exposure. The California State Water Resources Control Board will become the world’s first regulatory authority to announce standard methods for quantifying microplastic concentrations in drinking water, with the aim of monitoring water over the next four years and publicly reporting the results. (Lim, 2021)

Almost 400 million tonnes of plastics are produced each year, a mass projected to more than double by 2050. Even if all plastic production were magically stopped tomorrow, existing plastics in landfills and the environment — a mass estimated at around 5 billion tonnes — would continue degrading into tiny fragments that are impossible to collect or clean up, constantly raising microplastic levels […], a “plastic time bomb”. (Lim, 2021)

The state of California has taken legislative action on plastics and microplastics. In September 2018, California governor Jerry Brown signed S.B. 1422 into law. This bill requires the State Water Resources Control Board (SWRCB) to adopt a definition of microplastics on or before July 1, 2020. More importantly for water utilities, this legislation also requires the SWRCB to adopt a standard method for analysis of microplastics and requires four years of testing and reporting to the state and public regarding the occurrence of microplastics in drinking water. (Smith et al., 2019)

Definition of Microplastics by California SWRCB

'Microplastics in Drinking Water' are defined as solid polymeric materials to which chemical additives or other substances may have been added, which are particles which have at least three dimensions that are greater than 1 nm and less than 5,000 micrometers (µm). Polymers that are derived in nature that have not been chemically modified (other than by hydrolysis) are excluded. (SWRCB, 2021)

Microplastics (MPs) in the aquatic environment have become a focus of concern in recent years for. Reports of millions to trillions of these small particles (less than 500 microns) occurring in freshwaters and marine systems have alarmed many and led to widespread banning and phasing out of microbeads (one component of MPs). A number of conclusions can be drawn concerning MPs in the environment (WE&RF, Burton, 2017):

- Macro-plastics, not MPs, damage fish-eating birds, aquatic mammals and reptiles, and fish due to physical harm.
- MPs measured in recent field studies have not yet been shown to cause adverse effects to aquatic wildlife (fish, shellfish, and macroinvertebrates) at environmentally relevant concentrations (in the laboratory or field) but estimation techniques remain inadequate.
- MPs adsorb some toxic chemicals but are not an exposure route of significance in aquatic birds or aquatic organisms, as compared to prey consumption.
- MPs are more likely to be elevated near urban centers and in depositional sediments near municipal wastewater treatment plant (WWTP) outfalls.
- Benthic macroinvertebrates in sediments near WWTP outfalls are the most likely receptors to be exposed to potentially adverse levels of MPs.
- MP concentrations in waters containing the highest number of reported particles are below 10 particles per 1,000 liters, resulting in very low potential for exposure and uptake by biota.
- MPs in aquatic systems are typically dominated by fibers and/or fragments while microbeads are a minor component.
- While microbeads are being phased out of consumer products in the United States, MPs will not likely decrease due to fibers and breakdown fragments from macro-plastics.
- The predominant source of fibers is likely from washing clothes and antifouling boat paints.

- WWTPs remove the majority of MPs, with most being captured in sludge.
- Filtration is an optimal treatment for removing MPs from wastewater effluents and intake waters.
- Several governmental agencies have identified similar knowledge gaps and research needs to better manage and understand the environmental implications of MPs.
- It is questionable whether currently existing aquatic toxicity tests assess the potential physical impacts of MPs.
- Improved MP exposure models for effluent discharges into receiving waters are needed to predict whether they may be a stressor of concern.
- No standard methods exist for sampling and quantifying MPs, therefore making it impossible to compare studies or reliably predict exposure, effects, hazard, or risk. (WE&RF, Burton, 2017)

Uncertainty Related to Microplastics

One of the key challenges facing utilities as they engage in drinking-water risk management discussions related to microplastics is the large amount of uncertainty. The lack of research leaves utilities without guidance on the general distribution of microplastics, health effects, or toxicity, and with little knowledge about the treatment techniques for removing these substances. Large uncertainty also makes it difficult for a utility to develop a meaningful sampling plan, evaluate the effectiveness of current treatment processes in removing any size of microplastics, or to identify whether additional testing or treatment for the removal of smaller microplastics is necessary. The lack of regulatory standards for sampling or treatment of microplastics creates another level of microplastics management uncertainty. (Smith et al., 2019)

Recent research has shown that MP contamination of the environment is directly linked to waste management. In terms of polymeric composition, PET and PP were the most prevalent polymers identified in bottled water. In tap water, polymeric composition varied with PET and PP present along with polyester, PTT and rayon. Rayon is a man-made but not synthetic fibre and is not included in most MP research. It should be noted that the most produced and used polymers for the last 15 years have been PE and PP. Our findings support the omnipresent MPs contamination of drinking water. (Danopoulos et al., 2020)

Precautionary Principle on Food Safety Risk Management Applied to Microplastics

Current food and drinking water safety regulation and standards around the world adopt the precautionary principle on food safety risk management. The principle dictates that in the face of scientific uncertainty concerning possible harmful effects, after an initial assessment of available evidence has been completed and a comprehensive risk assessment is anticipated, risk management measures must be adopted in order to ensure the protection of health. The weight of the current evidence suggests that the time may have come to implement protective measures against the ingestion of MPs. (Danopoulos et al., 2020)

The San Francisco Bay Regional Monitoring Program. The San Francisco Bay Regional Monitoring Program, which ranks contaminants of emerging concern monitored in water, sediment, and biota into tiered, risk-based categories (based on occurrence and hazard ratios), initially classified microplastics as a constituent class of “Possible Concern” based on uncertainties regarding toxicity, but later elevated microplastics to “Moderate Concern,” despite a noted lack of certainty regarding hazard thresholds. The San Francisco Bay Regional Monitoring Program justified this departure from their established risk-based framework based on the EU’s decision to classify microplastics as a non-threshold contaminant for risk assessment purposes; uncertainties regarding toxicities; an upward trend in both plastic production and environmental detection; and persistence. (Coffin et al., 2021)

“Widespread ecological risk may arise within the next century.”

These decisions are in congruence with conclusions made by the Science Advice for Policy by European Academies, which state that while risk thresholds are exceeded at some locations (i.e., predicted or measured concentrations are greater than predicted no-effect levels), it is unlikely that exceedances of risk thresholds are geographically widespread; however with expected increases in exposure to microplastics, widespread ecological risk may arise within the next century. In other words, while traditional regulatory frameworks typically focus on short-term risks from chemicals with known hazards, highly complex, persistent contaminants with unknown hazards are being recognized as potential irreversible global scale threats and are being precautionarily evaluated by regulators and scientists. (Coffin et al., 2021)

Primary and Secondary Microplastics. MP are rarely deliberately incorporated into a product to serve a specific function, but generally occur as so-called secondary MP, resulting from the unintentional release and fragmentation of larger pieces of plastics. An exception here are primary MP, which are specifically produced as microscale particles and used predominantly in personal care products, for example, in the form of microbeads in cosmetic peelings. These primary MP, which make up only about 0.1−3% of the MP in the natural environment, may dominate locally, for example, in wastewater effluents of urban environments, but are globally of minor importance. The predominantly unintentional generation of secondary MPs makes it harder to quantify their sources for mass flow models as total production volumes of plastics may be less relevant in this context, compared to breakup/fragmentation/release processes during or after the use stage. For the release quantification of secondary MP two steps are required: (i) quantification of mismanaged plastic waste which is released in the aquatic environment, and (ii) determination of the rates of fragmentation of the released plastic waste in the aquatic environment. (Hüffer et al., 2017)

Microplastics and Nanoplastics. Microplastics are defined as "solid polymer-containing particles, to which additives or other substances may have been added (⋯) of all dimensions 100 nm ≤ x ≤ 5 mm". Nanoplastics, however, are defined as particles from 1 nm ≤ x ≤ 1 µm. The size ranges of micro and nanoplastics overlap slightly and definition of microplastic should be revisited and the lower limit set to 1 µm. However, scientists need to distinguish nanoscale particles independently because they have distinct physicochemical behaviors and biological interactions. Nanoplastics in environmental matrices are typically covered by molecules to form what is called an eco-corona. In natural waters, in addition to interacting with dissolved organic molecules (natural or pollutants) and ions (natural or not), nanoplastics can bind with colloids such as clay particles or colloidal organic matter. (Halle and Ghiglione, 2021) The chemical nature of the corona drives the stability of the particles and aggregation behavior. Typically, organic matter that coats colloids can impart a negative charge and prevent aggregation. However, more apolar organic matter, especially chain-like structures, can lead to aggregation through the formation of bridges. Likewise, some ions can induce the formation of clusters by the bridging effect. In parallel with nanotechnology, where engineered nanoparticles tend to aggregate into clusters up to several micrometers in size, it is expected that nanoplastics may also aggregate spontaneously together as well and exist as large colloids a few hundred nanometers in size. Additional smaller plastic particles would then likely bind to these larger colloids. (Halle and Ghiglione, 2021)

This dynamic processes of spontaneous nanoplastic heteroaggregation and disaggregation are key factors in determining the reactivity, toxicity, fate, transport, and risk to the environment and organisms. Nanoplastic particles are highly reactive and easily destabilized or aggregated, which can lead to substantial losses during sample preparation. These losses have not yet been quantified, preventing reliable quantification of nanoplastic presence. In contrast, microplastic methods of quantification have been more extensively evaluated and discussed. (Halle and Ghiglione, 2021)

Nanoplastics

Plastic nanoparticles (PNPs) are potentially high-risk emerging pollutants in both aquatic and soil environments. PNPs are here defined as plastic debris <1 µm in diameter across their widest dimension, distinct from the larger microplastics (1− 5000 µm) and macroplastics (>5000 µm). The growing threat of plastic pollution has been recognized for decades, with global plastic production currently exceeding 320 million tons per year and expected to double in the next 20 years. Plastic waste disposal has been problematic, and 4.8−12.7 million metric tons of plastic waste is estimated to be released into the oceans each year. Nanoplastic pollution has been conclusively identified in the oceans, alpine snow, and agricultural soil and is expected to be present in lakes, rivers, and seafloor sediments. PNPs are likely a nearly ubiquitous contaminant worldwide, and investigations into their behavior in the environment are critical. (Brewer et al., 2021)

Primary and Secondary Nanoplastics. Nanoplastics are categorized as either primary or secondary depending on their origin. Primary nanoplastics are particles synthesized intentionally as PNPs, for example, for use in personal care products and other consumer items. Secondary nanoplastics, on the other hand, are produced unintentionally through the degradation of larger plastic waste. In the environment, this degradation typically occurs through some combination of mechanical, photochemical, thermal, and even biological processes. Even small amounts of plastic, such as a single tea bag, are capable of degrading into billions of PNPs. These secondary PNPs tend to have a more irregular morphology and may exhibit altered chemical characteristics compared to primary PNPs. For instance, primary PNPs may be functionalized with specific surface groups targeted to a particular purpose, while the surface functionality of secondary PNPs will likely be determined by the polymer composition of the plastic material and the aging process. Both primary and secondary PNPs can therefore have highly variable surface charges and reactivities. In the environment, the breakdown of larger plastic debris into nanoparticles is inevitable, given sufficient time, so the millions of tons of existing plastic waste will continue to contribute to PNP generation for the foreseeable future. Regardless of type or origin, an understanding of PNP behavior in the environment is critical for any assessment of the risks associated with this emerging contaminant. (Brewer et al., 2021)

Nanoplastics are a Unique Category Different from Nanomaterials. Nanoplastics are also not broadly comparable to the many other types of nanosized pollutants that have been identified. While PNPs and these other particles may overlap in terms of their size range, they can be radically different when considering other important characteristics that dictate behavior, such as density, morphology, and surface chemistry. The extremely large volumes of plastic contaminants entering the environment compared to most engineered nanoparticles (e.g., Ag, CeO2, or carbon nanoparticles) further underscore the necessity of singling out nanoplastics as a unique potential hazard. To accurately assess this threat, it is not possible to simply equate nanoplastic behavior in the environment to that of other nanoparticles, especially because PNPs themselves exhibit significant heterogeneity. Few studies have directly compared the behavior of PNPs and other nanoparticles under controlled conditions. However, in one example, PNPs and fullerene (C60) were found to exhibit distinct transport characteristics through sand, particularly at elevated salinities. In another instance, environmental changes produced different trends in the stability of suspended PNPs compared to TiO2 nanoparticles and CeO2 nanoparticles. To fully understand the risks of PNP pollution, it is therefore critical to investigate nanoplastics as a unique category of highly heterogeneous particles that cannot be generalized as just another type of nanomaterial. (Brewer et al., 2021)

Nanoplastics are a Unique Category Different from Microplastics. It is important to recognize that nanoplastics are a categorically separate type of plastic pollutant that is behaviorally distinct from the larger microplastics and macroplastics. PNPs are small enough to easily penetrate various biological barriers (e.g., human bronchial epithelia) that block larger particles, giving them a unique potential for toxicity and for spreading other, adsorbed toxins within an organism. Their small size also affects their transport and mobility in natural environments. Compared to larger particles, PNPs are less immediately vulnerable to physical straining as they pass through a soil or sediment. However, they are also more reactive than the larger plastic particles due to their high surface area-to-volume ratio, so they may be more readily affected by interactions with coexisting aqueous and solid materials. For example, the ζ potential of smaller particles is more readily affected by interactions with ions in solution, which can lead to changes in particle size due to aggregation under some conditions. Finally, there is also a significant difference between the methodological requirements for nano and microplastics. PNPs are much more difficult to quantify, especially in natural samples, which is reflected in the lack of studies focused on nanoplastics in nature compared to the plethora of microplastics studies. Nanoplastics should not be generalized as simply another form of plastic pollutant given their many differences in properties and behavior compared to larger plastic detritus. (Brewer et al., 2021)

Transport Phenomena of Nanoplastics. PNPs are known to have spread rapidly throughout many natural systems and are considered a highly mobile pollutant in soils and groundwater. Once released into the environment, the mobility of PNPs may be controlled by a variety of processes. The PNPs may form homoaggregates with other, similar PNPs or heteroaggregates with different aqueous or particulate matter in the fluid phase.12,13 They may also become attached to immobile substrate material, like soil minerals and organic matter, or may interact with various microorganisms. The resulting PNP transport behavior in a specific system will be determined by both the PNP characteristics, such as particle size and surface functionality, and the environmental conditions, including the concentration of dissolved metals, the presence of particulate and dissolved organic matter, and the presence of any suspended inorganic colloids. Ultimately, PNP mobility in different natural environments is expected to be highly variable, and substantial study will be required to predict the extent of PNP transport in a specific system. (Brewer et al., 2021)

PNPs in suspension are expected to be highly mobile in the environment unless additional variables act to limit their stability. The effect of ionic strength on PNP mobility in aqueous systems varies based on the surface functionality and size of the nanoplastic contaminants, but a high ionic strength is typically expected to decrease PNP mobility. Given the strong potential for interactions between PNPs and organic matter, it is expected that PNPs in nature will typically exhibit similar, negative surface charges. Organic material will tend to be adsorbed by positively charged PNPs, coating them and imparting a net negative charge, while negatively charged PNPs will either remain dispersed in solution, largely retaining their original characteristics, or will form negatively charged heteroaggregates with organic matter and metal cations. The presence of inorganic colloids often destabilizes PNPs in solution because the PNPs tend to become attached to the colloid surfaces, forming relatively unstable heteroaggregates. Interactions between the PNPs and inorganic colloids are largely dependent on the respective ζ potential of those particles. Overall, suspended minerals may enhance or degrade PNP stability in the water column depending on the environmental conditions and colloid characteristics; however, the presence of inorganic colloids appears most often to decrease PNP mobility. The complex compositions of many natural waters provide conditions conducive to PNP heteroaggregation, and this increased particle size is expected to be correlated to the removal of PNPs from suspension due to sedimentation. These settled particles would require another process, such as turbulence or bioturbation, to resuspend them in the water column and restore their mobility. Sedimentation may indeed be one of the major mechanisms controlling PNP mobility, especially in oceans and other large bodies of water. (Brewer et al., 2021)

The transport of PNPs through natural porous media, for example, in a water-saturated soil or sediment, may be limited by the attachment of PNPs or PNP aggregates to the substrate surfaces and/or by the physical restriction of particle mobility. Both processes have been observed, often together, as a function of PNP characteristics and environmental conditions, and they may produce a variety of trends in PNP transport. Our current understanding of PNPs is primarily predictive, based on studies of how well-constrained plastics behave under controlled laboratory conditions, and has minimal basis in actual observations of the particles in nature. An improved understanding of secondary PNP generation, alteration, and composition will be critical in determining PNP behavior in natural systems. Aging, for example, can have a major effect on the stability and mobility of these particles and warrants further study. The use of relatively simple PNPs also largely neglects the toxicity and mobility effects of other pollutants, such as heavy metals and pesticides, that may accumulate on and/or within the PNPs, as well as the toxic additives (e.g., catalysts and flame retardants) that may be present in the plastic itself. These other pollutants and their co-transport with PNPs may be the most significant threat that PNPs pose to the environment and to human health. (Brewer et al., 2021)

Particle Shapes. Microplastics of different shapes were reported. Several factors limit a potential quantitative analysis of reported data on the relative abundance of shapes among water types. First, many studies typically only analysed shapes of a subset of all isolated particles and it is not clear how representative these subsets were when it comes to particle shape. Second, studies targeted different size ranges which also limits their comparability. For instance, fibres are typically small, so easily missed when trawling. Third, studies differed in the extent their water samples were representative of the studied water systems or water type, which in turn is affected by spatial and temporal variability. Fourth, although some particles' shapes were quite well-defined and thus interpreted similarly across studies, some others are more ambiguous, like nurdle, pellet, pre-production pellet, sphere, resin or granule. Nevertheless, we can provide a relatively robust view of the relative importance of particle shapes by showing the frequency of shapes observed across studies. The reviewed studies reported (in the order of decreasing reporting frequency): fragment, fibre, film, foam, pellet, sphere, line, bead, flake, sheet, granule, paint, foil and nurdle**.** We argue that this order also reflects a relative order of importance of shapes, that is, the most frequent shapes detected in a high number of locations globally, as the reviewed studies concerned many different locations on the globe (Koelmans et al., 2019)

Polymer Types. Often, relative abundances per study are not provided, or may not be considered accurate due to limited or biased subsets of particles used for the polymer identification. Most frequently observed polymer types across studies and records are PE > PP > PS > PVC > PET, with Acrylic or acrylic-related compounds, PA, PEST and PMMA reported in five or more records. The order of the five most abundant polymers can be roughly explained by two factors; global plastic demand and polymer density. Global plastic demand would cause an order of PE > PP > PVC > PET > PS. (Koelmans et al., 2019)

Microbeads and Product Bans. Waste management is generally managed locally, but microplastic debris have global implications. Microbeads brought microplastics to the attention of many people who were previously unaware of this issue. The rapid passage of the Microbead-Free Waters Act marked a landmark moment in efforts to mitigate this burgeoning global concern. Due to the magnitude of the contamination of microplastics, complete removal via clean-up is not possible. The most effective solutions are those that eliminate microplastics at the source. Bans on non-biodegradable plastic tableware (e.g., in France), single-use grocery bags (e.g., in California), and packaging (e.g., in Nantucket, Massachusetts) have been passed recently in various jurisdictions, microbeads are one type of microplastic. They are designed and manufactured as they are found (i.e., primary microplastics). In the context of the Act, plastic microbeads are defined as synthetic polymers, typically between 10 and 500 µm (for comparison, the diameter of a human hair is roughly 80 µm), which are used in rinse-off personal care products to exfoliate or cleanse. Microbeads are often made out of polyethylene, polylactic acid, polypropylene, or polystyrene. The microbead-containing products are applied to the body, then rinsed off and washed down the drain into a wastewater stream or directly into watersheds. During the treatment process, a small fraction of microbeads remains in the final effluent and is released to rivers, lakes, and oceans. The rest are entrained in biosolids (sewage sludge). Land-application of biosolids reintroduces microbeads to the terrestrial environment, with the potential to enter aquatic habitats via runoff following a storm or irrigation. Once in the environment, they are available to wildlife and have been found in the gut content of fish. (McDewitt et al., 2017)

California recently became the first state to ban single-use plastic bags (Proposition 67). Such bans do not typically come easily and can be controversial. Relative to other single-use items, microbeads were a legislative low hanging fruit. The societal benefit of plastic microbeads in rinse-off personal care products is not compelling, and the waste management strategy for microbeads assures they will end up in the environment. Moreover, drop-in replacements (e.g., ceramic microbeads or crushed walnut shells) are readily available in the market. the Federal "Microbead-Free Waters Act" does not eliminate all microbeads from aquatic habitats, let alone all microplastics. It is estimated to eliminate only a small fraction, between 0.1% and 4.1%, of the microplastics that enter aquatic habitats. Although many other sources of microplastics exist, including some that may be more prevalent (e.g., microfibers from textiles), the Act focuses on just one source: microbeads in rinse-off personal care products. Overall, the Act was well-intentioned and provides tangible benefits, but improved language would have yielded a bill that is both more effective public policy and viewed more favorably by people on all sides of the issue. For example, some environmentalists argue the Act is too limited in scope and does not do enough to solve the microplastics issue, some scientists argue it puts too much attention on a contaminant (i.e., plastic microbeads) whose hazards are less well-understood than others (e.g., pesticides), and some industry groups argue that the prohibition of all plastic microbeads stunts innovation. Unquestionably, the lack of standards and scientific consensus defining biodegradation of plastics contributed to the imperfect final language in the Act. (McDewitt et al., 2017)

Biodegradation into Natural Carbon Cycle. Biodegradation (i.e., degradation mediated by microorganisms) is a term that is widely used to suggest environmental acceptability. Ultimately, a standard for environmentally benign materials should require that the materials degrade into products that are readily incorporated into the natural carbon cycle, are nontoxic, and do not lead to the accumulation of persistent additives in food chains. we propose and define a new term: “Ecocyclable”. This standard covers the extent and rate of degradability, along with the end products of degradation (both their toxicity and ability for assimilation in the carbon cycle). We wanted to use a term that was: (i) not already widely used to describe commercial products (e.g., “ecosafe”), and (ii) suggestive that a material could be naturally and safely recycled into the carbon cycle without any human intervention. (McDewitt et al., 2017)

Formation of Microplastics from Biodegradation. Biodegradable polymers have been regarded as a promising solution to tackle the pollutions caused by the wide use of conventional polymers. However, during the biodegradation process, the material fragmentation leads to microplastics. In this work, the formation of microplastics from biodegradable poly (butylene adipate-co-terephthalate) (PBAT) in different aquatic environments was investigated and compared with the common non-biodegradable low-density polyethylene (LDPE). The results showed that a much larger quantity of plastic fragments/particles were formed in all aquatic environments from PBAT than from LDPE. In addition, UV-A pretreatment, simulating the exposure to sunlight, increased the rate of PBAT microplastic formation significantly. The size distribution and shapes of the formed microplastics were systematically studied, along with changes in the polymer physicochemical properties such as molecular weight, thermal stability, crystallinity, and mechanical properties, to reveal the formation of microplastics. This study shows that the microplastic risk from biodegradable polymers is high and needs to be further evaluated with regards to longer timeframes, the biological fate of intermediate products, and final products in freshwater, estuarine and seawater natural habitats. Especially, considering that these microplastics may have good biodegradability in warmer 20 –25 °C water but will most likely be highly persistent in the world’s cold deep seas. (Wei et al., 2021)

Overview of Plastic Additives and Effects on Human Health (Campanale et al., 2020)

Microplastics can contain two types of chemicals: (i) additives and polymeric raw materials (e.g., monomers or oligomers) originating from the plastics, and (ii) chemicals absorbed from the surrounding ambience. Additives are chemicals intentionally added during plastic production to give plastic qualities like color and transparency and to enhance the performance of plastic products to improve both the resistance to degradation by ozone, temperature, light radiation, mold, bacteria and humidity, and mechanical, thermal and electrical resistance. They include inert or reinforcing fillers, plasticizers, antioxidants, UV stabilizers, lubricants, dyes and flame-retardants. The additives, in almost all cases, are not chemically bound to the plastic polymer; only some flame retardants are polymerized with plastic molecules, becoming part of the polymeric chain. Though these additives improve the properties of polymeric products, many of them are toxic, and their potential for the contamination of soil, air and water is high. The study by Campanale et al. (2020) emphasizes the most toxic and dangerous chemical substances that are contained in all plastic products to describe the effects and implications of these hazardous chemicals on human health, providing a detailed overview of studies that have investigated their abundance on microplastics.

Water soluble polymers. European Chemical Agency's proposal to restrict intentionally added microplastics, defined as "synthetic water insoluble polymers of 5 mm or less in any dimension". This has the implication that persistent, water-soluble polymers like polyacrylamides (PAM) and polycarboxylates would ipso facto not be considered microplastic or even nanoplastic to many researchers. Persistent, water-soluble polymers like PAM and polycarboxylates have annual production volumes well into the millions of tonnes, with many uses associated with direct environmental emissions. (Arp and Knutsen, 2020) A potential consequence of this insoluble spotlight is that deeper insights into the fate and impacts of these persistent, water-soluble polymers will not gain as much attention as they should.

Soluble and Insoluble Polymers

Insoluble polymers overlap directly and indirectly with their soluble counterparts. Direct environmental emissions of PAM come from its use as a flocculant in water treatment, as an agricultural soil conditioner, and increasingly, as a viscosity enhancer in oil and gas drilling and fracking. PAMs, polycarboxylates, and other water-soluble polymers are also used in detergents and as water-absorbing polymers in many consumer products. Degradation of these polymers occurs more rapidly under industrial or water treatment processes than under environmental conditions. (Arp and Knutsen, 2020)

This results in environmental emissions of both commercial products and lower molecular-weight breakdown products of varying persistence. With increasing market demand for water-soluble polymers, environmental concentrations of them and their degradation products will inevitably increase. At sufficient environmental concentrations, and lack of responsible use, these would act like flocculants and detergents in recipient waters that they were not intended for, and as conditioners of soils and sediments other than in intended areas. In extreme cases this could cause long-lasting changes to natural ecological processes, independent of direct toxicity effects. (Arp and Knutsen, 2020)

Fate of Polyacrylamides (PAM)

Water-soluble polymers are in general considered immobile in soil and porous media due to intensive ionic and van der Wall interactions with organic matter and minerals. However, as just presented, some will degrade to smaller, more mobile polymers, in addition to oligomers, monomers, and other chemical byproducts. An example is PAM releasing its monomer acrylamide, a potent neurotoxin, under anaerobic conditions. Because of the unknowns related to PAM degradation products, including their potential to cross or foul cell membranes, it has been recently argued that "the toxicity, transport, fate, and removal efficiency of degraded PAM needs to be re-examined in light of existing information on both PAM and the acrylamide monomer." In the oil-and gas industry, concentrations of degraded PAM in wastewater have been reported at 10−1000 mg/L, which is at levels where acute ecotoxic effects have been reported. (Arp and Knutsen, 2020)

Water-soluble polymers appear to have great potential to mitigate emissions of insoluble microplastics and nanoplastic, as well as other contaminants, into receiving waters. Persistent, water-soluble polymers being outside the predominant definition of microplastic does not mean they should be ignored. Many analytical techniques are suitable for both insoluble and water-soluble polymers, including size exclusion chromatography, infrared spectroscopy, and mass spectroscopy. In many environmental samples, both types of synthetic polymers can co-occur. Understanding the environmental behavior of water-soluble polymers will help us better understand the behavior of insoluble polymers, and how to avoid harmful environmental impacts thereof. The spotlight should shine on all persistent polymers. (Arp and Knutsen, 2020)

REGULATORY DEVELOPMENTS

State Water Board staff in collaboration with the Southern California Coastal Water Research Project and subject matter experts conducted research regarding the human health impacts of microplastics.

Insufficient Evidence to Issue Notification Level or Numerical Guidance for Microplastics

A principal research finding relevant to monitoring is that microplastics smaller than 10 µm in length have an increased likelihood of causing adverse health effects in mammals and should be prioritized for monitoring when possible. There is insufficient evidence at the time of writing this Policy to issue a notification level or other numerical guidance for microplastics. (SWRCB, 2021)

A challenge in implementing California's legislative requirements to address microplastics in drinking water (SB 1422) was the apparent lack of a consensus definition for "microplastics." Despite calls for a unified, internationally agreed-upon definition for "microplastics", it seems that no such definition had emerged due (in part) to the lack of both standardized methods and regulations. Due to the regulatory impacts (i.e., monitoring and reporting and communicating health effects to consumers) associated with adopting a definition of microplastics in the context of drinking water, California's State Water Board recognized that the definition they adopted in June 2020 would likely be used for nondrinking water purposes and by other government agencies and scientific bodies. In drafting an initial regulatory definition for microplastics (which have extreme uncertainties in regards to exposure and hazards for humans), a principal consideration was to use terms that broadly encompass particle sizes (1 nm to 5 mm), types (e.g., theoretically soluble plastics), and polymers (e.g., including biodegradable polymers, for which limited toxicity information is available) to avoid inappropriately restricting risk assessments based on regulatory definitions, as well as research, monitoring, and collection of data—at least until the adoption of a more narrow definition can be justified. (Coffin et al., 2021)

California SWRCB Policy

This Microplastics in Drinking Water Policy Handbook's (Policy) purpose is to implement Health and Safety Code section 116376 by setting forth the requirements for conducting monitoring and reporting of microplastics in drinking water. The Policy includes a two-step iterative four-year plan for monitoring and reporting microplastics in a systematic and harmonized manner. To date, no government in the world has required monitoring for microplastics in drinking water, and the data obtained through the efforts detailed in this Policy will provide valuable insights for determining exposure to consumers through drinking water. (SWRCB, 2021).

Analytical Considerations. The Method Study assessed precision, repeatability, cost, and other factors, and had twenty-two laboratory participants. Methods for sampling extraction via filtering/sieving, optical microscopy, infrared spectroscopy, and Raman spectroscopy were evaluated. Each laboratory received three spiked samples of simulated clean water and a laboratory blank. Spiked samples contained known amounts of microplastics in four size fractions (1-20 µm, 20-212 µm, 212-500 µm, >500 µm), four polymer types (polyethylene, polystyrene, polyvinyl chloride, and polyethylene terephthalate), and six colors (clear, white, green, blue, red and orange). Spiked samples also included false positives (natural hair, fibers and shells) that may be mistaken for microplastics. Overall, participants demonstrated excellent average recovery and chemical identification for particles greater than 20 micrometers and 50 micrometers in size using Raman spectroscopy and infrared spectroscopy, respectively, with opportunity for increased accuracy and precision through training and further method refinement. (SWRCB, 2021)

The Method Study determined that costs and analysis time for microplastics analysis using the standardized methodologies are higher than many unregulated and regulated contaminants. Method Study participants evaluated the potential for inexpensive, rapid surrogate monitoring methods to indicate the presence of microplastics, which may be used to determine if additional monitoring using Raman or infrared spectroscopy is appropriate. Some examples of potentially viable surrogate methods include techniques that are commonly employed in water systems such as total organic carbon or turbidity analysis, while additional methods are more novel, such as spectral flow cytometry or automated imaging microscopy using Nile Red dye. (SWRCB, 2021)

Surrogate Monitoring Tools

At the time of writing this Policy, no surrogate methods for microplastics have been rigorously evaluated, however several candidate methods identified by Method Study participants. Several candidate surrogate methods (i.e. total organic carbon, turbidity, total suspended solids) are commonly used, and water systems receiving monitoring orders will be required to submit data using these techniques alongside microplastics monitoring data. State Water Board staff will assess the potential capabilities for surrogate monitoring tools to indicate the presence of microplastics using submitted data. (SWRCB, 2021)

Accreditation. At the time of writing this Policy, no government has required monitoring for microplastics, and as such there are few commercial or utility laboratories capable of monitoring microplastics, nor are there any suppliers of proficiency testing samples representative of microplastics in drinking water to independently assess the performance (e.g., recovery, precision, accuracy, etc.) of laboratories. Despite a lack of proficiency testing samples, laboratory performance for microplastics larger than 20 micrometers in length can be reliably assessed using quality assurance criteria developed through the Method Study in combination with commercially available laboratory fortified blank sample materials. (SWRCB, 2021)

Two-Phase Iterative Approach. State Water Board will employ a two-phase iterative approach for monitoring microplastics to obtain sufficient information to estimate risk through exposure via drinking water. Each step will last two (2) years, with a six (6) month interim period to allow for State Water Board staff to assess results from the first phase and plan the second phase of monitoring accordingly. For both phases, the State Water Board will issue orders to water systems and/or wholesaler providers to monitor microplastics in source waters and/or treated drinking water. In Phase I, monitoring will focus on characterizing occurrence in source waters used for drinking for microplastics larger than 20 micrometers in length. Phase II monitoring will be directed towards characterizing occurrence in treated drinking water for microplastics both smaller than, and larger than 20 micrometers in length. (SWRCB, 2021)

Selection of Systems for Monitoring

Public water systems will be selected for monitoring based on concepts utilized by the United States Environmental Protection Agency's UCMR program. Wholesale water providers and raw water conveyance systems producing greater than 10,000 MGD and water systems serving over 100,000 people will receive the majority of monitoring orders in Phase I. The State Water Board will evaluate findings from Phase I to determine sampling locations for Phase II. (SWRCB, 2021)

SWRCB has provided information on analytical methods:

- ATTACHMENT A – Non-exhaustive list of potential surrogate monitoring methods for microplastics
- ATTACHMENT B - Standard Operating Procedures for Extraction and Measurement by Infrared Spectroscopy of Microplastic Particles in Drinking Water
- ATTACHMENT C - Standard Operating Procedures for Extraction and Measurement by Raman Spectroscopy of Microplastic Particles in Drinking Water. (SWRCB, 2021)

FTIR versus Raman Spectroscopy. The most significant difference in the methods is the size of the particles that were extracted from the samples and analysed for composition identification. Studies using Fourier-transform infrared spectroscopy (FTIR), Raman spectroscopy (RM) were able to analyse particles down to 1 µm which significantly influenced the results. The degradation of MPs in the marine environment and the exponential increase of the number as the size decreases has been experimentally and mathematically explored. This would suggest that the same fragmentation pattern may also apply to other aquatic environments as well. On the other hand, only seven of the twelve studies reported the upper limit of the range in MP size. (Danopoulos et al., 2020)

Defining and Reporting the Size Range

The importance of defining and reporting the size range of the identified MPs has a double significance as follows. As a methodology parameter it is connected to the quantified MP content results. As a food contamination parameter, it is indicative of the potential health effects. MPs <1.5 µm are characterized as more dangerous since they are, in theory, capable of crossing the gut epithelium, further progressing into the human body and thus possibly causing an adverse health effect. (Danopoulos et al., 2020)

Sample Size. Differences in sample size were striking, ranging from 36 to 32000 L (per study) for tap water (TW) and 3 to (>)130 L for bottled water (BW). At the moment, methodological consensus concerning sample size does not exist. A recent review proposed a minimum of 1000 L for TW and 500 L for BW. In the first instance, sample size is dictated by the objectives and design of the study which in many cases are a function of the available resources. Sample size should be directly connected to the contaminant under examination. The volume of the samples as well as the sampling frequency can only be set when there is enough evidence to support what a meaningful MP content is. Meaningful being expressed in terms of food safety linked to human health and what is considered to be ‘wholesome and clean’ water intended for human consumption, which is the requirement of relevant European regulations and universal standards. (Danopoulos et al., 2020)

At the moment, there is not enough evidence to formulate an informed guideline for sampling sizes, nevertheless scientific experience points to larger sample sizes being more robust and reliable. Another area of importance is quality assurance of sampling and sample handling to avoid cross contamination via airborne MPs. In addition, only studies that employed blank procedural samples to account for this type of experimental error were included. (Danopoulos et al., 2020)

Commonalities between ENP and MP. Given their particulate nature, which significantly distinguishes both ENPs and MPs from dissolved contaminants and meanwhile represents their strongest commonality, it is clear that knowledge from ENPs fate research can be transferred to MPs based on their similarities. The advances made in ENP exposure assessment, both with respect to the tools and methods developed as well as the experience in handling particulate contaminants, can serve as a strong basis for developing exposure assessment approaches for MPs. With this example, the importance of interdisciplinary research teams becomes apparent. By omitting, or not actively seeking, a greater involvement of researchers from other related disciplines such as polymer/material, colloid/nano sciences and hydrology the MP research community would certainly be missing out on a significant contribution that could help to provide improved, faster, and more efficient MP environmental fate, exposure and risk assessment. Most recently, there have been first signs of explicit discussions on how knowledge of ENP research could be integrated into MP ecology, toxicity, environmental fate modeling, and food safety. (Hüffer et al., 2017)

Research Priorities. The most pressing research priorities in MPs exposure assessment to be addressed by interdisciplinary approaches can be summarized as (Hüffer et al., 2017):

- Investigation of fragmentation processes of macroplastics and rates of secondary MP formation under various natural conditions to account for relevant MP source and emission pathways and asses their environmental fate,
- Investigation of MP heteroaggregation to obtain MP specific attachment efficiencies and heteroaggregate breakup rates,
- Evaluation of the leaching of additives, and their effects on particle properties and ecosystems,
- Definition of particle size distribution range(s) and related biological and chemical relevance for the environment to facilitate the development of analytical methods and monitoring strategies,
- Establishment of an analytical framework, which sets analytical techniques for defined particle size fractions and analytical parameters (e.g., the use of FT-infrared microscopy for screening of larger MPs and, if positive, analysis of smaller sizes by Raman microscopy),
- Definition of protocols for stable MP dispersions accounting for the large variety of MP particle properties and sizes to design representative and comparable laboratory experiments. (Hüffer et al., 2017)

Analytical Method Selection. The broad size range of MPs ranging over 3 orders of magnitude or more requires the use of a variety of techniques in order to cover the entire range of sizes. For MPs the development of analytical strategies has so far been focusing on larger size particles (micrometer range and above), where techniques such as sieving, optical microcopy and laser obscuration in combination with Raman or Fourier transformed infrared spectroscopy or thermoanalytical techniques to determine particle composition (polymer type) were applied. Besides particle size and composition, additives in the polymer might be of interest in the discussion of MP analysis. The listed techniques which are known from material science are considered as most promising to meet the challenges (particle size and composition, i.e., polymer type) for analysis of MPs in the size range >50 µm in aquatic environmental samples. For MP size fractions <50 µm similar challenges (selectivity and sensitivity) as for ENPs arise for the development of analytical methods, where knowledge from ENPs could be integrated. The possible existence of nanoplastic particles may lead to a further increase in similarities as encountered for the detection of ENPs. For particle size determination, FFF or liquid chromatography techniques might be adapted, but will be challenged by particles >1 µm. This is particularly evident from the broad variety of concentration units in which the occurrence of MPs in aqueous systems is reported. For marine surface samples, these range from mass-based “grams per m3” to number-based “particles per m3” as well as to surface area normalized concentrations “grams per m2” and “particles per m2”. (Hüffer et al., 2017)

The development and refinement of analytical methods is the most prevalent and important area of microplastics research, and thus rapid improvement is expected. These advancements will subsequently facilitate the implementation of broader and more reliable occurrence and treatability studies. Sufficient understanding of human toxicology may require considerably more time, which could largely preclude any potential adoption of state or federal drinking water standards for many years. However, any future regulations requiring sampling and associated public notification could motivate utilities to take proactive action to remove microplastics well in advance of any established maximum contaminant level. (Alspach and Spinelli, 2020)

Sampling Setup and Analytical Technique at a Study in Sweden. Proper MP assessment requires quality assurance is in place and demonstrated, an adequate volume of drinking water is assessed, and that differences in analytical methods are understood. This study presents a systematic and robust approach where MP down to 6.6 µm were assessed in potable water distribution systems in terms of quantity, size, shape, and material. For the first time, sub-samples were analysed by two of the most validated and complementary analytical techniques: µFTIR imaging and Py-GCMS. (Kirstein et al., 2021) At each sampling station, triplicates of drinking water samples were filtered in parallel through 5 µm stainless steel filters (Haver & Boecker OHG, Germany), that were placed in custom modified stainless steel filter holders (Sterlitech Corporation, United States) attached via stainless steel pipes. The inlet tube was attached directly to a water tap at the pipe or to a hydrant. The water flow was adjusted to approximately 10 L/min. A flowmeter (Zenner International GmbH & Co. KG, Germany) was connected to each of the outlet tubes of the stainless steel filtration units to determine the volume of filtered water of each replicate. At each sampling position, the complete setup was primed for ten minutes prior to applying filters. Between 200 and 1100 L of drinking water were filtered. We aimed for 1 m3 sample size, and the filtration was stopped earlier when stainless steel filters clogged, which led to a significant reduction of the water flow. After completion, the filters were transferred to muffled glass Petri dishes, covered with 70% ethanol and stored frozen at −20 °C until further processing. (Kirstein et al., 2021)

The amount and chemical composition of the extracted MPs from drinking water was determined using a Focal Plane Array (FPA) –based Fourier Transformation Infrared Spectroscopy (FTIR) imaging technique. After investigation via µFTIR, the remaining sub-samples were submitted to Py-GCMS analysis. For MPs, identification via µFTIR imaging has proven efficient. This technique allows scanning of large areas of filters or windows for the presence of MP and has been successfully applied down to 10 µm MP particles. In the present study, we further decreased this size limit by applying a 25x Cassegrain objective producing 3.3 µm pixel resolution, which allowed us to determine particles down to 6.6 µm. This imaging technique also allows the automatisation of MP identification and has been proven as a reliable tool for MP analysis. While single-point FTIR or Raman spectroscopy for the larger particles and µFTIR or µRaman imaging spectroscopy for the smaller particles allow high-quality microplastic quantification, the techniques are time-consuming and require advanced analytical equipment. (Kirstein et al., 2021)

Both methods successfully determined low contents in drinking water. However, µFTIR and Py-GCMS identified different polymer types in samples with overall low MP content. With increasing concentration of a given polymer type, the values determined by the techniques became more comparable. Most detected MPs were smaller than 150 µm, and 32% were smaller than 20 µm. Our results indicate a potential annual uptake of less than one MP per person, suggesting that drinking potable water produced at a high-performance drinking water treatment plant represents a low risk for human health. (Kirstein et al., 2021)

Time transformations of plastics. A newly produced consumer product made from conventional plastic will have well-defined characteristics, including a known monomeric and polymeric composition, a known size, geometry and porosity, a known internal chemistry of additives (e.g., phthalate-based plasticizers), and a known external surface chemistry of characteristic coatings (e.g., antimicrobials, flame retardants, etc.). Time spent in the environment changes all of this. The size of the plastic will change from macroplastic (>5 mm diameter) to microplastic (>1 µm to <5 mm) to nanoplastic (<1 µm), but our knowledge on the corresponding rate of change remains limited. Macroscopic meshworks of polymerized monomers break apart and become fragmented, releasing internal additives while becoming ground into small pieces of unpredictable number, size and shape by mechanical stress from human use, from macrobiotic and microbial assault, and from environmental stress caused by soil, sediment, wind, surf, and wave action. Plastic monomers, plasticizers, and uncharacterized degradation products are further released, while fragments scavenge pollutants, nutrients and microbes from the environment and accumulate them on their surfaces. With increasing environmental residence time, environmental chemicals accumulate on the polymeric surfaces and all components are subject to further significant and mostly unpredictable changes. The end result is a shuttling and unloading of plastics-associated chemical and biological agents into new and unexpected locations and hosts, including a broad spectrum of biota and human populations worldwide. By changing the nature of plastic debris over time, this fosters an increasing uncertainty of latent hazards, exposure doses, and associated risks of the ecological and human exposures incurred. (Halden et al., 2021)

HEALTH

Studies conducted in recent years have shown strong evidence that humans are exposed to nanoplastics (NPs; size range <1 µm) and microplastics (MPs; size range 1 µm - 5 mm) dispersed ubiquitously in the environment. Currently, there are insufficient hazard and exposure data, as well as insufficient conceptual approaches, to perform a meaningful human health risk assessment of nano- and microplastics (NMPs). MPs originate from consumer products intentionally containing micron-sized plastic particles and fibres (primary MPs; e.g. cosmetic products, cleaning products, paints, textiles, etc.) and from gradual degradation and fragmentation of larger plastic items (secondary MPs). It is likely that a significant source of NPs derives from the further fragmentation of MPs, as demonstrated by plastic degradation studies, and the fact that environmental concentrations of NPs are increasing. (Noventa et al., 2021)

While MPs have been studied mostly in the context of the marine environment, there is growing evidence of their presence and accumulation in terrestrial, freshwater, and atmospheric compartments. Widespread NMP pollution makes humans vulnerable to daily exposure via several routes, in particular oral and respiratory. Hence, there is an urgent need to assess the potential detrimental impacts on human health. (Noventa et al., 2021)

The potential impact of NMPs on human health has only recently emerged as a concern, despite a growing body of evidence showing intake and adverse effects on other organisms. Accumulation of plastic debris from different natural environments has been demonstrated for many species, and in vivo and in vitro ecotoxicological studies have demonstrated the potential of NMPs to elicit toxicological activity (e.g. oxidative stress via free radical generation, immunological responses, alteration of gene expression, genotoxicity, endocrine disruption, neurotoxicity, reproductive abnormalities, transgenerational effects, and behavioural abnormalities). In contrast, many aspects related to the behaviour, fate and effects of NMPs in the human body (e.g. adsorption across membranes, translocation to secondary tissues and organs, accumulation, acute and long-term effects, and elimination) remain largely unknown. (Noventa et al., 2021)

Insufficient evidence on NMP risks for human health.

Prompted by growing public concerns over this issue, as well as requests from national health authorities, several organisations (i.e., World Health Organization (WHO), European Food Safety Authority (EFSA), Science Advice for Policy by European Academies (SAPEA)) have carried out their first expert evaluations of the overall state-of-the-art knowledge and risk characterization in relation to single exposure sources (i.e., drinking water, seafood). According to their reports, it seems that the available evidence does not highlight specific issues or concerns with respect to the existence of a widespread risk to human health. However, they make us aware that quantitative information regarding NMP exposure and toxicity is too scarce to allow for definitive conclusions on NMP risks for human health, both at present and in the future, where NMP pollution is expected to rise. (Noventa et al., 2021)

Possible human health risks associated with microplastics in drinking-water

The human health risk from microplastics in drinking-water is a function of both hazard and exposure. Potential hazards associated with microplastics come in three forms: the particles themselves which present a physical hazard, chemicals (unbound monomers, additives, and sorbed chemicals from the environment), and microorganisms that may attach and colonize on microplastics, known as biofilms. Based on the limited evidence available, chemicals and microbial pathogens associated with microplastics in drinking-water pose a low concern for human health. Although there is insufficient information to draw firm conclusions on the toxicity of nanoparticles, no reliable information suggests it is a concern. (WHO, 2019)

Physical Hazards. Particle toxicity is dependent on a range of physical properties, including size, surface area, shape and surface characteristics, as well as the chemical composition of the microplastic particle. The fate, transport and health impacts of microplastics following ingestion is not well studied and no epidemiological or human studies on ingested microplastics have been identified. However, microplastics greater than 150 µm are not likely to be absorbed in the human body and uptake of smaller particles is expected to be limited. Absorption and distribution of very small microplastic particles including nanoplastics may be higher, however the database is extremely limited and findings demonstrating uptake in animal studies occurred under extremely high exposures that would not occur in drinking-water. The limited number of toxicology studies in rats and mice on ingested microplastics are of questionable reliability and relevance, with some impacts observed only at very high concentrations that would overwhelm biological clearance mechanisms and that therefore do not accurately reflect potential toxicities that could occur at lower levels of exposure. (WHO, 2019)

> Based on this limited body of evidence, firm conclusions on the risk associated with ingestion of microplastic particles through drinking-water cannot yet be determined; however, at this point, no data suggest overt health concerns associated with exposure to microplastic particles through drinking-water. (WHO, 2019)

Chemical Hazards. Polymerization reactions during plastic production do not generally proceed to full completion, resulting in a small proportion of monomers such as 1,3-butadiene, ethylene oxide and vinyl chloride, that can leach into the environment. Residual monomers may also arise as a result of biodegradation and weathering of plastics. However, the extent to which this occurs is uncertain. It is likely that unbound monomers resulting from these scenarios would leach into the environment, resulting in extremely small concentrations in drinking-water sources. (WHO, 2019)

Additives. Additives such as phthalate plasticizers and polybrominated diphenyl ether flame retardants are, for the most part, not covalently bound to the polymer and can more easily migrate into the environment. Migration can also be impacted by the molecular weight of additives, with small, low molecular weight molecules generally migrating at a faster rate than larger additives. Aging and weathering are likely to strongly influence migration, the overall impact of which is not well understood. However, relative to other emission routes of additives to the environment, it is anticipated that leaching from microplastic will be relatively small. (WHO, 2019)

> If microplastics are ingested through drinking-water, the relative potential for the additives to leach from microplastics in the gastrointestinal tract is also poorly understood, with conflicting information reported in the limited number of available studies. It should be noted, however, that following the introduction of regulations limiting the use of many additives-of-concern from plastics, exposure is expected to become lower over time, although these substances can be present in older plastics which may degrade into microplastics in the environment. (WHO, 2019)

The hydrophobic nature of microplastic implies that they have the potential to accumulate hydrophobic persistent organic pollutants (POPs), such as polychlorinated biphenyls, polycyclic aromatic hydrocarbons and organochlorine pesticides. POPs indiscriminately sorb to organic carbon in the environment and therefore, the fraction of POPs sorbed to microplastics will be small relative to other environmental media such as sediment, algae and the lipid fraction of aquatic organisms. If microplastics are ingested through drinking-water, the relative potential for POPs to leach from microplastics is not well understood and will depend on a variety of factors, including the relative size of the particle, mass of chemical accumulated, relative level of contamination within the gut, and the gastrointestinal residence time of the particle. (WHO, 2019)

Potential Health Risks Assessment by WHO

To assess potential health risks associated with exposure to chemicals associated with microplastics, WHO developed a conservative exposure scenario, assuming high exposure to microplastics combined with high exposure to chemicals and applied a margin of exposure (MOE) approach. Chemicals included in the assessment have been detected in microplastics, are of toxicological concern and have adequate or accepted toxicological point of departures to derive a MOE. MOEs were derived for each chemical by comparing the estimated chemical exposure for a very conservative exposure scenario to a level of exposure at which no or limited adverse effects were seen. A judgement of safety could then be based on the magnitude of this MOE. MOEs derived from the risk assessment were found to be adequately protective, indicating a low health concern for human exposure to chemicals through ingestion of drinking water, even in extreme exposure circumstances. (WHO, 2019)

Biofilm Hazards. Biofilms in drinking-water are formed when microorganisms grow on drinking-water pipes and other surfaces. Although most microorganisms in biofilms are believed to be non-pathogenic, some biofilms can include free-living microorganisms and pathogens such as Pseudomonas aeruginosa, Legionella spp., and Naegleria fowleri. Biofilm-forming microorganisms attach faster to hydrophobic nonpolar surfaces, such as plastics, than to hydrophilic surfaces. Environmental conditions can also influence biofilm formation on plastics and microplastics. A limited number of occurrence studies in fresh water indicate the possibility that microplastics could enable the long-distance transport of pathogens and increase the transfer of antimicrobial resistant genes between microorganisms. (WHO, 2019)

However, there is no evidence to suggest a human health risk from microplastic-associated biofilms in drinking-water. The risk is considered far lower than the well-established risk posed by the high concentrations and diversity of pathogens in human and livestock waste in drinking-water sources. Further, the relative concentration of microplastics in fresh water is significantly lower than other particles that pathogens can adhere to in fresh water. For microplastics that are not removed during drinking-water treatment, the relative significance of microplastic-associated biofilms is still likely negligible due to the much larger surface area of drinking-water distribution systems and their subsequent ability to support more biofilms, compared to microplastics. (WHO, 2019)

Although human health effects are still under examination, lessons from toxicology inform us that the effects will be dose dependent. Determining exposure levels is key in formulating a risk assessment framework for this emerging environmental contaminant. Health effects will be caused by: their physical attributes, the chemical properties of the polymers, the plasticisers, or other chemicals added in the manufacturing process, and the chemicals they can absorb in nature as well as the microbes that can grow on their surface. (Danopoulos et al., 2020)

Exposure through Food. One of the major nano and microplastic entry points into the human system is represented by the ingestion of contaminated food estimated at 0.44 MP/g of nano and microplastics were found in sugar, 0.11 MP/g were found in salt, 0.03 MPs/g were found in alcohol, and 0.09 MP/g were found in bottled water. Humans could also assume an estimated intake of 80 g per day of microplastics via plants (fruits and vegetable) that accumulate MPs through uptake from polluted soil.

The presence of microplastics in marine species for human consumption (fish, bivalves and crustaceans) is now well-known. As an example, in Mytilus edulis and Mytilus galloprovincialis of five European countries, the microplastic number has been found to fluctuate from 3 to 5 fibers per 10 g of mussels. (Campanale et al., 2020)

Therefore, following exposure via diet, uptake in humans is plausible, as evidenced by the capacity for synthetic particles smaller than 150 μm to cross the gastrointestinal epithelium in mammalian bodies, which causes systemic exposure. However, scientists speculate that only 0.3% of these particles are expected to be absorbed, while a lower fraction (0.1%) that contains particles that are bigger than 10 μm should be capable of reaching both organs and cellular membranes and passing through the blood–brain barrier and placenta. Exposure concentrations are predicted to be low, although data about micro and nanoplastics into the environment are still limited due to the analytical and technical complications to extract, characterize, and quantify them from environmental matrices. Once ingested, particles smaller than 2.5 μm can enter the gastrointestinal tract through endocytosis by M cells (specialized epithelial cells of the mucosa-associated lymphoid tissues) of Peyer's patches. M cells transport particles from the intestinal lumen to the mucosal lymphoid tissues or through the paracellular persorption. Persorption consists of mechanical kneading of solid particles through gaps that are located in the single-layer epithelium at the villus tips of the gastrointestinal tract (desquamation zones) and into the circulatory system. The resulting toxicity is via inflammation due to the persistent nature of microplastics, as well as their unique properties such as hydrophobicity and chemical composition, and it is supposed to have an accumulative effect that is dependent on dose. This assumption, regarding levels of microplastics in men at a gastro-intestinal level, was further confirmed by the finding of microplastics into human stools: Twenty plastic particles, mostly PE and PP (ranging in size between 5 and 500 mm), were found for every 10 g of stool. Indeed, the human excretory system should be responsible for removing up to 90% of micro and nanoplastics ingested. (Campanale et al., 2020)

Exposure through Inhalation. Another microplastics entry point to the human body is through inhalation. The ingestion of synthetic fibers from mussel consumption is less than that inhaled from domestic dust during the same meal. The authors of reported finding 18 fibers and four fragments/L of rain during precipitation events. Microplastics are carried by the wind or from atmospheric depositions and could also result from the erosion of agricultural and fertilized lands, dried sludges, and products from wastewater treatment, synthetic clothes fabric, industrial emissions, road-dust, marine aerosol. This spread could lead to respiratory distress, cytotoxic and inflammatory effects, and autoimmune diseases in men. Moreover, the human lung has a quite wide alveolation surface of ca. 150 m2, with a very thin tissue barrier that is smaller than 1 µm and which could allow nanoparticles to penetrate the bloodstream and all human body. Polystyrene particles of the size 50 nm have led to genotoxic and cytotoxic effects on pulmonary epithelial cells and macrophages (Calu-3 and THP-1). More widely, the response to inhaled particles, depending on differences on individual metabolism and susceptibility, may be expressed as immediate bronchial reactions (asthma-like), diffuse interstitial fibrosis and granulomas with fiber inclusions (extrinsic allergic alveolitis, chronic pneumonia), inflammatory and fibrotic changes in the bronchial and peribronchial tissue (chronic bronchitis), and interalveolar septa lesions (pneumothorax). For example, similar effects have been registered in workers of the textile industry in close contact to nylon, polyester, polyolefin and acrylic fibers. The low deterioration of microfibers has been found in patients suffering from pulmonary cancer as a confirmation of the bio-persistence of these synthetic particles. In addition to bio-persistence, fiber size has an impact in their toxicity; for example, fibers of 15-20 µm cannot be successfully removed from macrophages to the lungs. Additionally, the toxicity of smaller-sized polystyrene nanoparticles (25 nm in diameter), which induced lower cell viability […] was demonstrated. Not to be overlooked is the potential transmission of microorganisms through the microplastics that are present in the air. By attaching to microplastic surfaces in order to be protected from UV radiation, microorganisms could reach the lung and become another threat of infections to human health. (Campanale et al., 2020)

Exposure through Skin. The last exposure pathway of microplastics to the human body could be skin contact through water while washing or while using scrubs and cosmetics that contain micro and nanoplastics. However, the penetration of the corneous layer is limited to particles lower than 100 nm, so it is unlikely that microplastics absorption could occur through the skin; on the contrary, nanoplastics absorption is more probable. (Campanale et al., 2020)

Fate and Effect of Microplastics on Human Body is Not Known

Following the intake of microplastics into the human body, their fate and effects are still controversial and not well known. Only microplastics smaller than 20 µm should be able to penetrate organs, and those with a size of about 10 µm should be able to access all organs, cross cell membranes, cross the blood–brain barrier, and enter the placenta, assuming that a distribution of particles in secondary tissues, such as the liver, muscles, and the brain is possible. Not enough information is available to fully understand the implications of microplastics for human health; however, effects may potentially be due to their physical properties (size, shape, and length), chemical properties (presence of additives and polymer type), concentration, or microbial biofilm growth. (Campanale et al., 2020)

New and Fully Integrated Risk Assessment of NPM is Needed. To be able to assess the current and future risks of NMPs to human health, we argue that a new and fully integrated risk assessment framework tailored to NMP specific features is required, as well as more data on NMP exposure and toxicity. In fact, as already happened for other particulate chemicals (e.g. engineered nanomaterials) and highly diverse classes of contaminants (e.g. per- and polyfluoroalkyl substances), NMPs do not easily fit within traditional risk assessment frameworks because their extreme diversity (of size, shape, chemical properties associated with adsorbed/absorbed chemicals, biofilms) results in high levels of uncertainty in hazard and exposure. (Noventa et al., 2021)

Scientifically, NMP research has benefitted significantly over the last decade from the considerable effort spent to understand and tackle plastic pollution. Furthermore, NMP research has been informed by the transfer of knowledge from research on engineered nanomaterials (nanotoxicology), particle and fibre toxicology and particulate air pollution studies. The quantitative assessment of the human health risk associated with NMP exposure remains an ambitious research objective. (Noventa et al., 2021) The potential hazards of NMPs for human health come in three forms: 1) the particles themselves (i.e., physical hazard), 2) the chemicals that can leach from the polymeric core and surface (unbound monomers and additives, adsorbed and absorbed environmental pollutants; i.e., chemical hazard), and 3) microbiological elements, including associated microorganisms and pathogens colonising NMP surfaces, and their mobile genetic materials (MGMs; i.e., microbiological hazard).

The size of a particle when moving from micro-scale to nanoscale will impact upon these other hazard considerations; the leaching of chemical substances may increase with the increase in relative surface area, or the adsorption of substances to particle surfaces may increase, again with the increase in relative surface area. Likewise, nanoscale particles may be more likely to translocate than micron-sized particles and therefore present a more varied biodistribution.

With specific reference to the chemical hazard, recent evidence from environmental studies suggests the role of NMPs as vectors for environmental pollutants is minor compared to that occurring via natural carriers. This has been supported by laboratory studies which demonstrated that uptake of hydrophobic pollutants adsorbed to NMPs via ingestion was negligible when the same pollutants were also available in the aqueous phase and/or food. While experimental studies conducted with invertebrates are not necessarily directly relevant to human exposures, modelling studies of human exposure also suggest a similarly low level of risk, especially compared to other exposure pathways. For examples, human exposure predictions by EFSA, Food and Agriculture Organization (FAO) and WHO have independently concluded that the chemical risk of ingestible MPs for human health is likely to be small. (Noventa et al., 2021)

However, the available information does not currently allow for full understanding of the implications of NMP chemical proprieties for human health. Importantly, the situation may be different for the smallest particles of the plastic continuum, especially with reference to plastic additive chemicals. Plastic contains a wide array of additive chemicals (e.g., plasticizers, colourings, fillers, flame retardants, antioxidants, etc.) used by industry to create the countless types of plastic materials that are on the market today. In addition, plastics also contain a range of residual monomers, catalysing agents used in chemical processing and potentially non-intentionally added substances carried over from the raw materials (usually petroleum oil), none of which are chemically bound to the polymeric chains. Residual concentrations of these chemicals may reside in NMPs, and this would apply to NMPs in foodstuffs and inhaled air. These chemicals have the potential to leach from the core/surface of the material to the surroundings. Research has demonstrated that the leachates from a range of plastic and rubber materials can trigger toxicity in vitro and in vivo. There is also some evidence that environmental (UV) degradation can influence the toxicity of NMP leachates. This raises the question of whether degradation mechanisms associated with food processing/preparation practices can influence the chemical and physical hazard profiles of NMPs contained in food, an issue that has yet to be investigated to our knowledge. Humans mainly eat processed food, obtained through a variety of steps, from primary processing (e.g., grinding grain to produce raw flour), to secondary processing (i.e., food preparation, e.g., preparing bread), and to tertiary processing (e.g., generating highly transformed unhealthy foods in respect to human dietary needs, rich in sugar and salt but poor in fibre). Owing to this complexity, food processing is expected to modify the hazard profiles of NMPs originally contained in the natural/agricultural/farmed products, as well as representing a source of additional NMPs in the final product. For example, the most temperature sensitive plastic particles can be sensitive to heating practices, leading to consequences in terms of risk. (Noventa et al., 2021)

As regards the microbiological hazard, there is increasing evidence that NMPs provide favourable conditions for the establishment of microbial taxa that differ from those in the surrounding environment (water, natural aggregates or atmospheric particulate), thereby altering the structure and composition of environmental microbial communities. However, the available data is currently insufficient to confirm whether NMPs represent a preferential environment for the growth or survival of pathogens compared to other natural particles and act as a significant vector for transfer of biofilm and microbiological elements able to be embedded into human microbiota. Human microbiota (i.e. the microbial community residing in human mucosae, with particular reference to gastrointestinal tract and lungs) naturally interacts with any microbial community to which it comes into contact. This implies exchange of microorganisms between microbial communities, and genes between the relative microbiomes (i.e. the whole collection of microbial genes). The latter occurs by horizontal transfer and by ex vivo transfer of MGMs, and it is considered an effective mechanism for microorganisms to acquire new genetic skills, including antimicrobial resistance, pathogenicity and virulence. Harmful antimicrobial resistant bacteria, protozoa, viruses and MGMs can be found in any environmental compartment, and in particular in air and water systems receiving inputs from waste and sewage treatment plants, hospitals, pharmaceutical production, intensive farming and aquaculture, etc. Therefore, conceptually they can contaminate air, water sources and food webs, colonize particles therein, including NMPs, and expose humans to biological hazards through ingestion. Even when viable bacteria are not directly transported, bacterial compounds such as lipopolysaccharides, may remain on NMP surfaces and possibly trigger strong immunomodulatory effects. In this context, NMPs are thought to favour an increased permissiveness towards MGMs carrying antibiotic resistance genes and eventually other genes thus facilitating the establishment of novel traits in bacterial communities by evolutionary changes at the species level. (Noventa et al., 2021)

Impact on Animals. Adverse impacts of microplastics to animals are a concern, particularly given the global contamination of habitats and organisms. Microplastics have been reported in over 100 species of wildlife across all trophic levels, including in shellfish, and fish sold for human consumption. Both microplastics and associated chemicals can bioaccumulate in animals. (McDewitt et al., 2017)

PNPs may have lethal and sublethal toxicity effects for organisms from microbes and bivalves to fish and even humans. Chemical additives and byproducts are also known to leach from PNPs and may present their own toxicological hazards. Compounding the problems associated with the spread of plastic pollution, PNPs can interact with other environmental contaminants, including a variety of heavy metals and organic compounds like pesticides and pharmaceuticals. Due to their small size, PNPs have a high surface area-to-volume ratio and are therefore capable of adsorbing and accumulating significant amounts of these other chemical pollutants, and this adsorption may alter the mobility and toxicity of both the PNPs and the adsorbate. (Brewer et al., 2021)

The major source of organic contamination of wildlife is from prey they consume. A recent analysis of seabirds that feed along the surface of water, where MPs are more prevalent, provides further perspective. The study of northern fulmar seabirds off the coast of Norway found levels of hazardous organic pollutants in the birds had no correlation to the amount of plastic in their stomachs. Ingestion of hazardous chemicals is 21,000 times more likely from consumption of natural prey than from MPs. Desorption of chemicals from MPs was a minor and negligible exposure pathway, even without discounting the low numbers of particles likely consumed. (WE&RF, Burton, 2017)

Studies of rodents exposed to some types of microplastics through drinking water indicate potentially adverse effects, including on the reproductive system. However, more research is needed to understand potential human health implications and at what concentrations adverse effects may occur. (SWRCB, 2021)

Microplastics as vectors for cyanotoxins. The current study has, for the first time, demonstrated that at least three types of microplastics (PVC, PE, and PS) can act as vectors for MCs; an almost 40-fold concentration compared to the dissolved concentration was observed for some MC congener-microplastic combinations (e.g., MC-LF + PS). Adsorption of MCs to microplastic particles is a multifactor process. The current study demonstrated that the particle size of the microplastics, pH conditions, the type of polymer, and the MC congener affect adsorption. Even under environmentally relevant pH conditions (pH 7), MC-LF adsorbed to microplastic particles. A theoretical worst-case scenario demonstrated that the amount of MC adsorbed onto certain types of plastics, if desorbed, would constitute a lethal dose to daphnids. Furthermore, this study highlights that adopting MC-LR as a model for all MCs is a poor choice as the chemical diversity created by the two variable amino acids can lead to widely varying adsorption behaviors. This was demonstrated by the significantly greater adsorption of MC-LF compared to MC-LR under the same experimental conditions. Microplastics could act as a vector for MCs, highlighting an, as of yet, unexplored pathway for cyanobacterial toxins to enter the food web. (Pestana et al., 2021)

OCCURRENCE

Occurrence of microplastics in water

Microplastics are ubiquitous in the environment and have been detected in marine water, wastewater, fresh water, food, air and drinking-water, both bottled and tap water. Microplastics enter freshwater environments in a number of ways: primarily from surface run-off and wastewater effluent (both treated and untreated), but also from combined sewer overflows, industrial effluent, degraded plastic waste and atmospheric deposition. However, there are limited data to quantify the contribution of each the different inputs and their upstream sources. Further, the limited evidence indicates that some microplastics found in drinking-water may come from treatment and distribution systems for tap water and/or bottling of bottled water. (WHO, 2019)

Research conducted by State Water Board staff suggests there is a high probability for the occurrence of microplastics as large as 5,000 micrometers in length in surface waters, and that several commonly used drinking water treatment technologies incidentally remove microplastics larger than 20 micrometers in length. Additionally, groundwaters typically have low detection frequencies and surface waters typically have high detection frequencies of microplastics. Microplastics concentrations vary spatially and temporally and depend on a number of known and unknown factors. (SWRCB, 2021)

Lake Erie is the most MP contaminated water ever recorded with numbers exceeding 446,000 particles/km2 with beads comprising only 16% of MPs (and fibers/lines only 2%). This converts to 1 to 3 particles per 300 to 700 liters (~80-185 gallons). However, in that same lake water there are ~10,000 to 10 million algae per liter. This means there are a billion more algae than MP. The primary organism at risk from eating these small MPs are zooplankton and their primary food source is algae. (WE&RF, Burton, 2017)

Concentrations of Microplastics in Surface Water are Very Low

When viewed in the context of total MP loadings from WWTP effluents, the numbers (like surface water contamination) are extremely high and alarming to the public. Nevertheless, as discussed above in the conversions of MP values to surface water volumes, the numbers (if they are close to being correct) being discharged by WWTPs appear inconsequential from an ecological perspective.

Total suspended solids (TSS) may be a useful surrogate for MPs in terms of physical damage that can result in aquatic biota. There is much more literature on their occurrence and biological effects in aquatic systems. If we compare MP particle numbers to the adverse effect of TSS it becomes apparent that MP particles are insignificant, meaning microbeads are even less so. Fish are adversely affected by TSS at levels ranging from 30-160 mg/liter. At the worst sites for MP pollution, such as Lake Erie, their concentrations are from 10 to 1 million-fold lower than adverse TSS levels. (WE&RF, Burton, 2017)

Review of Microplastics in Freshwaters and Drinking Water. Among water types, reported microplastic concentrations differed widely, but the fact that studies target different size classes contributes to this variability. Despite the quality limitations, our analysis confirmed that microplastic is frequently present in freshwaters and drinking water. There is a high need to improve the analysis of very small microplastics, and to identify them in different water samples. Fragments, fibers, film, foam and pellets were the most frequently found microplastic shapes in surface water samples. Relative abundance of polymer types found across studies reflected plastic production and polymer densities. (Koelmans et al., 2019)

Conclusions on size comparisons among studies and water types are difficult to draw due to the aforementioned differences in targeted particle sizes. More studies are needed to better understand occurrence, shape, polymer types, and particle sizes, particularly for the small plastic particles. (Koelmans et al., 2019)

Global microplastic concentrations in different water types We reviewed the available literature on microplastics in drinking water, fresh water and wastewater. Monitoring has been conducted in multiple locations in Asia, Australia, Europe and North America. A selection of studies reporting particle number concentrations were used for a further analysis, if they reported means and/or raw data on a volume basis. These microplastic concentrations, reported as number of particles, spanned ten orders of magnitude (0.01 to 10^8 #/m3) across all individual samples and water types, also when excluding wastewaters. The number of microplastic particles in samples per water type was statistically different ($p < 0.05$) for all pairwise comparisons of water types, except for the comparisons between ground water and all other water types, WWTP effluent versus (untreated) DWTP and tap water, and WWTP influent versus (untreated) DWTP water As these concentration data relate to numbers, they do not distinguish between particle size, shape or material type; differences that will be discussed in the sections below. Studies often do not mention a lower nor an upper size limit, or only mention the targeted size class. The data include particles reported as microplastics, that is, we did not take out suspect non-polymer particles as identified either by authors themselves or based on our quality assessment discussed above. The range for 50% of the data per water type is 12 orders of magnitude, and quite similar for influent, effluent, lake, river and bottled water data. For canal and tap water only a few studies were available, which may have caused the variation to be much smaller. For bottled water, the number of studies was also low, however there were many samples (bottled water brands) for this water type available in these studies. The median concentrations per water type vary over four orders of magnitude. (Koelmans et al., 2019)

Some general patterns exist in the concentration data. Surface waters have the lowest concentrations of all water types, with, bottled water closer to the higher end. The lower concentrations observed in surface water, particularly compared to drinking water, is likely attributed to the fact that most surface water studies targeted only larger particles whereas smaller particles are more abundant. WWTP influent shows the highest concentrations based on the median and interquartile range of reported concentrations although WWTP studies generally did not monitor small particles. The high concentrations therefore reflect direct domestic inputs and inputs from those diffuse land-based sources that are routed via wastewater. WWTP effluent has a lower median compared to WWTP influent, which probably reflects the retention of microplastics in WWTPs. Similarly, untreated tap water has higher concentrations than treated tap water. Concentrations in bottled water are higher than in tap water, which may reflect the higher influx of airborne particles in the factories, which are inherently more locked in, wear from caps or bottle walls after production, or the fact that these studies also included smaller sized particles. For instance, Schymanski et al. (2018) used Raman microscopy and was thus able to identify down to > 5 mm, which also explains the high number concentrations. The general trends observed here still remain when only the studies that received highest quality scores are taken into account. Still, the generalities listed here should be interpreted with caution given the low number of bottled water (n=3), treated tap water (n = 2), (untreated) DWTP water (n = 2) and ground water studies (1), although as noted earlier, there were many bottled water samples available in the limited number of studies. (Koelmans et al., 2019)

Study of Microparticles in a Water System in Sweden. The DWTP Sydvatten AB supplies drinking water to 900,000 inhabitants in the south of Sweden (Skåne). The DWTP uses surface water originating from the Lake Vombsjön that undergoes artificial groundwater infiltration.

Raw water seeps slowly through the alluvium of gravel and sand to natural groundwater storage. The artificial groundwater is pumped and initially aerated to remove iron and manganese; further, calcium ions are removed by the addition of sodium hydroxide and sedimentation. Next, ferrous chloride coagulation takes place followed by sand bed filtration. Finally, the water is disinfected and pumped into the distribution network. (Kirstein et al., 2021)

The primary goal of our study was to determine quality and quantity, including very small MPs (< 20 µm), in drinking water. Through the combination of representative sample size, quality control and assurance together with state-of-the- art µFTIR imaging and Py-GCMS, MPs could be qualified and quantified in all analysed drinking water of the investigated distribution system. Average MPs concentrations were generally low (between zero and 0.022 ±0.019 MP/L) except one pumping station which had considerably higher MP numbers (0.809 ±0.688 MP/L). Hence, our results are within the range of MP numbers reported by other studies. (Kirstein et al., 2021)

We also assessed the potential differences in MP loads between two distribution pipes of different age (8 vs. 19 years). The investigated distribution pipes mainly consist of cement, stainless steel, cast iron, and PE. Considering the low numbers of PE detected in the samples, it can be concluded that ten years’ age difference had no significant impact on the MP loads in the distribution system. (Kirstein et al., 2021)

Conclusions from Study in Sweden

The few existing studies that quantified MPs in drinking water report numbers that vary by several orders of magnitude. This discrepancy indicates high variability of MP loads in drinking waters from different sources and countries. However, the studies are also hardly comparable due to different sampling, MP extraction, and identification methods, where MP identification represents one of the crucial pitfalls. Furthermore, MP numbers are commonly reported within size classes impeding the assessment of the "real" MP concentration and making it impossible to compare the data to analytical techniques quantifying the polymer mass. Previous work has demonstrated that both, ATR-FTIR and Py-GCMS successfully differentiate between plastic and non-plastic. (Kirstein et al., 2021)

Using µFTIR imaging followed by an automated image analysis enabled us to identify the size and shape of MPs down to 6.6 µm. Since accessible clean drinking water is one of the Sustainable Development Goals of the United Nations (WHO, 2017), it is of utmost importance to reliably investigate MPs and to determine numbers, concentration, and size, in order to understand and evaluate the potential risks related to human health. Considering that the annual estimated MP consumption ranges from 39,000 to 52,000 particles or 74,000 and 121,000 when inhalation is taken into account, the generally low MP numbers of 0.174 MP/L we found in the present study suggest that the consumption of drinking water, processed by a high-performance drinking water treatment plant, does not particularly add to potential risks to human health. (Kirstein et al., 2021)

Microplastics in Tap Water in Denmark. The analyses of microplastic in tap water performed on samples taken from 17 different locations in Denmark showed that:

- On average, the total number of visually determined MP-like particles > 100 µm were 15.6 (range 4-30) per 50 L sample. In 16 out of 17 (94 %) tap water samples, the amount of MP-like particles were below the limit of detection, which were 29 particles per 50 L sample, corresponding to 0.58 MP-like particles per L tap water.
- The specific plastic polymer types, which were verified as MP in the tap water samples were PET, PP, PS, ABS and PU. In the blank samples, MP particles of PET, PMMA, PA and EVA were observed. Since only 1-2 of each type of plastic polymers were observed in each of the tap water samples with verified MP content, no firm conclusions about the origin of the MP from tap water or contamination can therefore be made.
- This study finds that 94 % of Danish tap water samples contain MP below the Limit of detection of 0.58 MP particles per L water. This is significantly lower levels than reported in previous American and Danish studies from 2017, which were highly publicised by the media, but in line with the levels reported from a study of Norwegian drinking water in 2018. (Strand et al., 2018)

Microplastics and Microfibres in Drinking WTPs. There is a wide variety in the concentration MP, with values that go from 0 to 6614 MPs/L in the influent and from 0 to 930 MPs/L in the effluent, with an average value of 739 MPFs/L and 236 MPFs/L, respectively. MP concentrations found in influents and effluents of DWTPs are similar or even higher than those reported for WWTPs. The abundance of microfibres in most cases is much lower in the influents of DWTPs than those obtained in the influents of WWTPs. This is probably due to the origin of the water—i.e., in DWTPs the influent is obtained from different water sources (aquifers, reservoirs, etc.) (Sol et al., 2021)

MP concentration in tap water varies between 0 and 1257 MP/L, with percentages of microfibres that vary from 1% to 99%, so MPF concentrations are between 0 and 168 MPFs/L, with and average value of 10 MPF/L. It is noteworthy that, in general, MPF are the MP form most commonly found in tap water. Regarding MP analysis in tap water, the procedure is similar to that described for WWTP and DWTP. The most common way to obtain the samples involves a storage container and subsequent filtration or a direct filtration through sieves with different mesh size. In general, samples are oxidized, with H2O2 being the oxidizer agent most frequently used. Nevertheless, some authors employ acids (for example HCl) to degrade organic impurities of the samples. Finally, a visual sorting using the same techniques employed for wastewater samples is carried out. The World Health Organization (WHO) recommended that an adult person should drink 2 L of water per day. According to this recommendation, it can be estimated that an approximate average of 154 MP per day could be ingested by a person, i.e., 56,210 MP per year, which is a value much higher than the value estimated for an American citizen (4000 MPs per year). Additionally, microfiber intake would be 20 MPF per day (7519 MPF per year). Thus, a large amount of MP and microfibres (4.5×10^6 MPs and 6.0×10^5 MPFs, respectively) can be ingested only from tap water over a person's lifetime, considering a life expectancy of 80 years. According to the European Commission's Science Advice for Policy organ (SAPEA) and WHO-published reports, there is no evidence of the harmful effects of MP on humans. Certainly, as far as we know, there is not any published study that has directly examined the effects of these micropollutants on people. The only available studies that have been carried out have exposed cells or human tissues to MP or have used animals such as mice or rats. In these works, it has been reported that mice fed large quantities of MP showed inflammation in their small intestines. In addition, mice exposed to MP had a lowered sperm count and fewer, smaller pups, compared with control groups. Some of the in vitro studies on human cells or tissues also suggest toxicity. Hence, a precautionary approach is warranted to limit human exposure to plastic particles since the risk is uncertain but potentially serious. (Sol et al., 2021)

Wastewater Plants. Ryaverket is one of the largest WWTPs in Sweden handling wastewater from approximately 790,000 inhabitants as well as industries in the greater Gothenburg area.

Around 369,000 m3 of treated wastewater is discharged daily into the Kattegat Sea. The WWTP utilizes bar screens, sand and grease traps, primary settling, activated sludge, secondary settling, nitrifying trickling filters and nitrifying moving bed biofilm reactors, followed by post-denitrification, and, finally, tertiary mechanical filtration through disc filters with a mesh size of 15 µm. The identified plastics could be categorized into 22 polymer groups. The most diverse type of sample was digested sludge covering 18 polymer groups. The least diverse sample type was 20 mm bar screen material, covering only 7 polymer groups. Throughout all matrices, the most common polymer types in terms of mass, ranked by relative contribution, were: PE, PP, polyester, PVC, PS, PU, acrylic, alkyd, PA, acrylic paints, EVA, ABS, SAN, epoxy, PVA, PVAC, vinyl copolymer, polycarbonate, PAN, PU paints, phenoxy resin, and PLA. Of these, 97% of the total plastic mass were identified within the first six groups. Previous studies likewise reported PE, PP, polyester, PVC, PS and PU as polymer commonly found in WWTPS. (Rasmussen et al., 2021)

Mass Balance at Ryaverket WWTP. The total plastic mass removal efficiency, taking all sizes entering the plant into account, was 99.6%. Considering only the small MP <500 µm, the removal efficiency became 98.8%. The sludge retained 65.8%, while 11.6% were retained at the 2 mm bar screens, and 1.2% was found in the effluent. 21.4% were unaccounted for in this mass balance, a discrepancy believed caused by sampling and measuring uncertainties or fragmentation and degradation in the digester and process tanks. Masses of plastics >500 µm were determined by weighting, while the mass of the smaller microplastics was estimated from the imaging. The total plastic load on the plant was 202.2 kg/d, of which the two screens retained 73%. The remaining plastic mass was found in the sludge (13.6%) and the effluent (0.4%). The missing 12.7% could be caused by sampling and measuring uncertainties and potentially also fragmentation below the size detection limit of the analytical approach, or by degradation. (Rasmussen et al., 2021)

MP originating from in industrial and urban activities can be discharged into the sewage system and wastewater treatment plants (WWTPs). Even though these facilities can remove even more than 90% of MP from wastewater, still millions of MP are discharged to the environment in treated water each day. Although great variability of data has been reported, the MP concentration usually ranges between 6.10×10^2 and 3.14×10^4 particles/L in influent and 0.01 and 2.97×10^2 particles/L in effluent. At the household level, microfibres can originate from clothing and furnishing, whereas at the industrial level, microfibres come from the automotive sector and the construction and clothing industries, amongst others. The clothing industry generates around 42 million tonnes of microfibres annually. Microfibres originating in laundry contributes 35% of the global release of primary MP to the environment, and the vast majority of these microparticles found in wastewater come from households. For example, between 1.1×10^5 and 1.3×10^7 polyester and cotton fibres can be emitted in only one wash. Additionally, the use of garments also contributes to the emission of microfibres to the atmosphere due to wear and tear. For instance, in Paris it was reported that fallout deposits an average value of 106.2 microfibres/m^2 per day. (Sol et al., 2021)

Microplastics in Receiving Waters in China. China is the largest plastic producer and consumer in the world, accounting for 26% of the world's total plastic production, and China also has the largest output of plastic waste to the marine environment. The review by Tang et al. (2020) concluded as follows:

- Microplastics are widely distributed in China's water ecosystems, with fibers and polyethylene being their most common shape and composition. Microplastics pollution is more serious in estuaries, consistent with the conclusion that terrestrial activities seriously affect microplastics pollution.
- Research on microplastics has included seawater, sediments and organisms in China's water ecosystems, but the research methods are not consistent. The mesh size, sampling depth, sampling tools and detection methods will affect the research results.
- Effluent from sewage treatment plants still contains large amounts of microplastics, and tertiary treatment technology could be the solution to improve the microplastics removal efficiency. In current sewage treatment plants, MBR is an efficient technology for microplastics.

Occurrence of Microparticles in San Francisco Bay. Concentrations in surface water were higher in the Bay than outside, and within the Bay, the highest concentrations were in Central Bay. On the contrary, sediments from Lower South Bay contained the highest average concentration. This suggests that Lower South Bay sediments could be an important sink for locally discharged microdebris, reducing the level of transport to the rest of the Bay. Furthermore, in fish GI tracts, we found that the benthic species ingested higher concentrations of microdebris than the pelagic species. Additional studies of other species in the Bay should be undertaken to explore this trend. Stormwater runoff and wastewater effluent are important pathways for microdebris to the Bay, and mitigation strategies for reducing inputs should be assessed. On average, concentrations in stormwater were ∼140 times greater that in wastewater, making it a much larger overall input of microdebris to the Bay and a priority for emission prevention. In terms of specific sources, we observed relatively large amounts of polyethylene fragments, polystyrene foams, and polyester fibers in surface water; cellulose acetate fibers in stormwater; and black rubbery fragments in stormwater and sediment. The presence of these materials suggests that sources of microplastics to the Bay may include breakdown of plastic litter (e.g., water bottles and cigarette butts), the shedding of textiles, and tires. On the basis of these observations and the strong influence of stormwater, solutions for urban areas surrounding the Bay may involve reducing driving, investing in public transport, and exploring upstream solutions such as catch basin inserts to keep litter out of stormwater drains. Overall, strategies for filtering microdebris from stormwater runoff and wastewater before it reaches the Bay may be effective approaches. (Zhu et al., 2021)

Study of Stormwater Runoff in San Francisco Bay. Stormwater runoff was collected from 12 sites in the San Francisco Bay Area in California, USA, to quantify and characterize microplastics and other anthropogenic particles in stormwater. As a case study, we also sampled the inlet and outlet of a rain garden during three separate storm events to test the effectiveness of rain gardens in reducing microplastics in stormwater runoff discharged to an aquatic ecosystem. The rain garden is rectangular in shape (3.7 m × 1.7 m), and the surface ponding depth is 0.28 m. From bottom to top, the garden is composed of the following components: native soil, drain rock, and rain garden soil media. The drain rock (1.3 cm diameter) is located approximately 0.7 m below the surface. Within this is an underdrain, which was necessary because of the native soil's infiltration rate of 0−1.3 mm/h. This native soil is hydrologic soil with high clay content. The rain garden media is composed of engineered soil and native vegetation. This engineered soil has a minimum infiltration rate of 12.7 cm/h and is a mixture of sandy loam (70%), clay (10%), and composited organic matter (20%). The vegetation is drought tolerant. (Werbowski et al., 2021)

All stormwater runoff contained anthropogenic microparticles, including microplastics, with concentrations ranging from 1.1 to 24.6 particles/L. These concentrations are much higher than those in wastewater treatment plant effluent, suggesting urban stormwater runoff is a major source of anthropogenic debris, including microplastics, to aquatic habitats. The concentrations of anthropogenic particles observed in the stormwater in this study tend to be higher than other pathways, such as wastewater treatment plant (WWTP) effluent. For example, an average of 0.05 ± 0.024 microparticles/L of effluent, average of 0.21−1.5 microplastics/L of final effluent. Our concentrations also tend to be much higher than those in WWTP effluent discharged to our study region, San Francisco Bay. (Werbowski et al., 2021)

Fibers and black rubbery fragments (potentially tire and road wear particles) were the most frequently occurring morphologies, comprising ∼85% of all particles across all samples. This suggests that mitigation strategies for stormwater should be prioritized. As a case study, we sampled stormwater from the inlet and outlet of a rain garden during three storm events to measure how effectively rain gardens capture microplastics and prevent it from contaminating aquatic ecosystems. We found that the rain garden successfully removed 96% of anthropogenic debris on average and 100% of black rubbery fragments, suggesting rain gardens should be further explored as a mitigation strategy for microplastic pollution. (Werbowski et al., 2021)

With respect to particle morphology, fibers and rubbery fragments were most common at the 12 sites. Some samples were composed of as many as 97% fibers and others, 64% black rubbery fragments. Because of the spectroscopic difficulties with rubbery fragments, the latter were classified mostly based on appearance and compressibility. Combined, fibers and rubbery fragments represented ∼85% of all particles across all samples. Firm fragments, the next most common particle morphology, represented ∼12% of all particles. The other categories we found were spheres, foam, film, and fiber bundles, which together comprised only ∼2% of all particles. The large amount of rubbery fragments is consistent with current thinking that tire wear particles are a large source of microplastics into the environment. With respect to size, most particles in the samples were in the 125−355 μm range. There were more than 2.5 times as many particles in this size range than the second most common size range, >1 mm. The fewest particles were found in the 355−500 μm range. With respect to particle composition, microplastics were common, comprising ∼39% of all particles tested via spectroscopy. "Unknown" (i.e., unidentifiable) particles comprised ∼30%, and "anthropogenic (unknown base)" particles comprised ∼24%. The particle breakdown was as follows: natural particles, ∼3%; glass, ∼2%; paint, ∼1%; wool, ∼1%. Of the particles that were plastic, polyethylene (∼25%), polyethylene terephthalate/polyester (∼21%), polypropylene (∼13%), cellulose acetate (∼9%), and plastic copolymers (∼7%) were most common. All other plastic types comprised ∼5% or less of the plastic particles. Regarding the subsample of rubbery fragments (9 particles) that were tested with pyrolysis GC-MS, six were identified as styrene−butadiene rubber with natural rubber as a minor component and one particle appeared to have a petroleum origin. (Werbowski et al., 2021)

Comparison between Tap Water and Bottled Water. The inverse relationship between the size of MPs and their abundance is supported by the findings. All studies reported some level of MP contamination. Samples positive for contamination ranged from 24–100% in TW and 92–100% for BW. Comparing the results between the different water origins, specifically between the two studies that targeted similar MP sizes of minimum 1 μm, MP content was higher in BW (plastic and glass bottles) than TW. Therefore, current evidence suggests that there are higher rates of MP contamination in BW compared with TW, both in terms of frequency and quantity. (Danopoulos et al., 2020)

Study of Plastic and Paper Cups. MP count, size and morphology in 15 polylactic acid (PLA)-lined plastic cups and 15 PLA-lined paper cups were examined using Nile Red fluorescence tagging, microscopic photography, and morphology assessment and quantification. In the plastic cups, the count and area of MP fibers were found to be significantly higher compared with blanks ($p < 0.05$), but not MP particles or total MP. In paper cups, count or area was not significantly different in terms of MP particle, MP fibers or total MP. No interesting trend was observed in the distribution regarding the size of MP particles or fibers. These results indicate that selected paper cups and plastic cups could be considered as safe beverage containers. (Chen et al., 2021)

Particle Release from Bottle Opening. A student at Mission San Jose High School published a study of particle release during bottle opening and closing in Journal Water and Health. The caps of single use polyethylene terephthalate (PET) plastic water bottles were opened and closed 1, 5, 10, and 15 times before analyzing the number of particles generated per open-close cycle. Nile Red dye was used for the detection of microplastics >4.7 µm in size. Microplastic contamination levels in the water were found to increase as the bottle cap was opened and closed repeatedly. (Singh, 2021)

TREATMENT

Treatment technologies for removing microplastics from water.

Wastewater and drinking-water treatment systems—where they exist—are considered highly effective in removing particles with characteristics similar to those of microplastics. Properties relevant to removal in water treatment include size, density and surface charge. According to available data, wastewater treatment can effectively remove more than 90% of microplastics from wastewater, with the highest removals from tertiary treatment such as filtration. Although there are only limited data available on the efficacy of microplastic removal during drinking-water treatment, such treatment has proven effective in removing far more particles of smaller size and at far higher concentrations than those of microplastics. Conventional treatment, when optimized to produce treated water of low turbidity, can remove particles smaller than a micrometer through processes of coagulation, flocculation, sedimentation/flotation and filtration. Advanced treatment can remove smaller particles. For example, nanofiltration can remove particles >0.001 µm while ultrafiltration can remove particles >0.01µm. These facts combined with well-understood removal mechanisms point to the rational conclusion that water treatment processes can effectively remove microplastics. (WHO, 2019)

Another factor to consider is how treatment waste is handled. Plastics are not usually destroyed, but rather transferred from one phase to another. For this reason, water treatment waste needs to be considered as a potential source of microplastics contamination in the environment. There are currently limited data available on how treatment wastes are handled and the impact they may have on the environment. (WHO, 2019)

No MPs in the traditional size class of 300 to 500 microns would be expected to make it through modern day drinking water treatment plant that has filtration. A plant that can remove cryptosporidium oocytes which are 4 to 6 microns in size should remove most MPs. However, many MP may be closer to the nano-size is a potential concern that has not been addressed. (WE&RF, Burton, 2017)

Microplastics (MPs), and specifically microfibres (MPFs), are ubiquitous in water bodies, including wastewater and drinking water. In this work, a thorough literature review on the occurrence and removal of MPs, and specifically MPFs in WWTPs and DWTPs, has been carried out. When the water is treated, an average microfiber removal efficiency over 70% is achieved in WWTPs and DWTPs. These high percentages are still inefficient for avoiding the presence of a large number of microfibres in treated wastewater and also in tap water. RSF, DAF, oxidation ditch and CAS processes have been described as the most efficient treatments for eliminating MPFs from wastewater treatment. It is remarkable the wide range of the data reported on this topic; for example, treated wastewater contains between not detected and 347 MPFs/L, whereas tap water contains between not detected and 168 MPFs/L. Microfibres constitute more than half of the MPs found in treated wastewater and sewage sludge, whereas in DWTP effluents the percentage of MPFs is around 32%. Nevertheless, the relative amount of MPFs reported in tap water is notably higher (71%). Microfibres from WWTPs are discharged to the environment, being a source of MP pollution. Additionally, MPs released by DWTPs directly enter the drinking water lines, which constitute a direct route for MP human consumption, so that it has been estimated that an adult may ingest an average value of 7500 MPFs per year only via tap water. (Sol et al., 2021)

In general, DWTPs are less efficient in removing MPs and microfibres than WWTPS as a consequence of the usually simpler treatment carried out in the DWTPs. In fact, some WWTPs achieve removal efficiencies above 99%, whereas the highest MPF removal efficiency found in literature for a DWTP was 90.4%, and it was achieved in a DWTP that included coagulation–sedimentation, deep-bed filtration, ozonation and granular activated carbon. (Sol et al., 2021)

This study investigated the removal efficiency of four different sized polystyrene MP (10 - 90 µm in diameter) in bench experiments including coagulation/sedimentation with alum and ferric, sand filtration, and UV-based oxidation. The sequential process of coagulation/sedimentation and sand filtration could completely remove MP > 20 µm, whereas a small portion of the MP ≤ 20 µm passed through the sand media, suggesting the need for introducing processes, specifically targeted at MP < 20 µm in the conventional water treatment systems. During the UV-based oxidation process (UV photolysis and UV/H2O2), smaller-sized fragments were generated by photochemical weathering of MP, which was more evident in the UV/ H2O2-treated sample. Meanwhile, UV/H2O2 treatment substantially promoted the release of a mixture of low molecular weight organic compounds that might stem from radical–facilitated polymer chain scission, leading to an increase in bacterial toxicity in treated water. (Na et al., 2021)

RECOMMENDATIONS

Managing plastic and microplastic pollution in the Environment.

Irrespective of whether there are any risks to human health from ingestion of microplastics in drinking-water, there is a need to improve management of plastics and reduce plastic pollution to protect the environment and human well-being. Poorly managed plastic can contribute to sanitation-related risks and air pollution, and impact tourism and overall quality of life. If plastic emissions into the environment continue at current rates, there may be widespread risks associated with microplastics to aquatic ecosystems within a century, with potentially concurrent increases in human exposure. In response to concerns about the impact of plastic and microplastic pollution, public engagement and political commitment has increased. More than 60 countries are already taxing or banning single-use plastics, primarily plastic bags. (WHO, 2019)

Strategies to reduce the number of plastics released into the environment are critical to the effort to minimize adverse impacts of discarded plastics. Where simple, low cost actions can be taken to make even a small difference to plastic inputs to the environment, it would be sensible to implement them. Actions could include improving recycling programmes, reducing littering, improving circular solutions, reducing the use of plastics where possible and decreasing waste inputs into the environment by industry. Care must be taken, however, when considering mitigation strategies so that addressing one problem does not simply result in the creation of a new one. This is particularly important in view of the limited data on sources of different sizes and types of microplastics, including the very small particles that are currently not well quantified. The benefits of plastic must also be considered before introducing policies and initiatives. For example, single-use syringes play an important role in preventing infections. Priority management actions should be “no regrets,” in that they confer multiple benefits and/or that they are cost-effective. (WHO, 2019)

Routine monitoring of microplastics in drinking-water is not recommended

Routine monitoring of microplastics in drinking-water is not recommended at this time, as there is no evidence to indicate a human health concern. Concerns over microplastics in drinking-water should not divert resources of water suppliers and regulators from removing microbial pathogens, which remains the most significant risk to human health from drinking-water along with other chemical priorities. As part of water safety planning, water suppliers should ensure that control measures are effective and should optimize water treatment processes for particle removal and microbial safety, which will incidentally improve the removal of microplastic particles. (WHO, 2019)

However, for researchers, it would be appropriate to undertake targeted, well designed and quality-controlled investigative studies to better understand the sources and occurrence of microplastics in fresh water and drinking-water, the efficacy of different treatment processes and combinations of processes, and the significance of the potential return of microplastics to the environment from treatment waste streams including the application of sludge biosolids to agricultural land. Measures should also be taken to better manage plastics and reduce the use of plastics where possible, to minimize plastic and microplastic pollution despite the low human health risk posed by exposure to microplastics in drinking-water, as such actions can confer other benefits to the environment and human well-being. (WHO, 2019)

Given the current state of the science, there is no reason at this time for deep concern about public health issues from microplastics in drinking water. However, more research from the USEPA, WRF, the National Oceanic and Atmospheric Administration, plastic manufacturers, and others is needed for utilities to determine the extent of exposure, possible health effects, and reasonable strategies for identification and removal of microplastics, with special attention to those microplastics that are smaller than 300 µm. (Smith et al., 2019)

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10. Engineered Nanomaterials and Nanoparticles

Engineered nanomaterials (ENM) or nanoparticles (ENP) exhibit novel properties and consist of particles or physically discrete entities that (when not aggregated) are typically at or below 100 nanometers (nm) in one dimension (e.g., nanoplates or nanoflakes), two dimensions (e.g., nanofibers or nanotubes), or three dimensions (e.g., nanospheres or nanoparticles), (Good et al., 2016).

Engineered Nanoparticles Pose Low Risk during Ingestion

ENP are currently orders of magnitude less common than natural nanoparticles in waters that flow into drinking water treatment plants. Because such plants are designed to remove small-sized natural nanoparticles, they are also very good at removing ENP. Consequently, ENP concentrations in tap water are extremely low and pose low risk during ingestion. However, after leaving drinking water treatment plants, corrosion by-products released from distribution pipes or in-home premise plumbing can release incidental nanoparticles into tap water. The occurrence and toxicity of incidental nanoparticles, rather than ENPs, should therefore be the focus of future research. (Westerhoff et al. 2018)

Not included in this group are unintentionally (incidentally) produced ENM, such as diesel exhaust particles, or natural nanosized materials that occur in the environment (e.g., viruses or volcanic ash) (USEPA, 2007).

LOW PRIORITY FOR SFPUC

Because SFPUC source waters come from protected watersheds, occurrence of ENM is unlikely. Little is known about ENM occurrence in US drinking waters, health significance, and treatment effectiveness. These CECs are subjects of preliminary research. In general, concentrations of ENM in drinking water are likely to be extremely low, if even detectable.

This section presents: (1) Screening Evaluation Table and (2) Technical Review 2016-2021 of available scientific studies. No SFPUC Monitoring is available at this time.

Table 10-1. Screening Evaluation Table for Engineered Nanomaterials and Nanoparticles

GENERAL INFORMATION ON CEC	
Instructions	This Screening Evaluation may be applied to a CEC group or an individual CEC. The purpose of this section of the Evaluation is to develop background information on the CEC or CEC group.
CEC Name	**Engineered Nanomaterials (ENM) + Engineered Nanoparticles (ENP)**
CEC Description Is CEC a group? If individual CEC, which group is CEC part of?	This group includes engineered nanomaterials, not naturally occurring nanomaterials. There are many definitions of nanomaterials (or nanoparticles). One definition of ENM is engineered nanoscale materials that exhibit novel properties and consist of particles or physically discrete entities that (when not aggregated) are typically at or below 100 nanometers (nm) in one dimension (e.g., nanoplates or nanoflakes), two dimensions (e.g., nanofibers or nanotubes), or three dimensions (e.g., nanospheres or nanoparticles). ENM are used in a variety of industrial, chemical, and manufacturing applications, in consumer products such as textiles and electronics, but also personal care products. They are used in the agricultural, aerospace, automotive, construction, energy, environmental remediation and medical industries (Good et al., 2016). ENM are designed at the nanometer scale where novel or enhanced properties emerge. ENM are being developed and incorporated into products rapidly, while understanding of potential environmental and health effects is proceeding at a much slower pace. The novel properties of ENM may require a different approach than traditional risk assessment. (Resnik, 2019).
CEC Grouping What is the basis for grouping? *(Grouping factors are: common health effects, treatment, and analytical method, and/or compound co-occurrence)*	ENM are a group. The basis for the grouping is common chemical or physical properties (i.e., nanoscale design). USEPA organizes ENM into four types (USEPA, 2007): 1) carbon-based materials (e.g., spheres, tubes, fullerenes) 2) metal-based materials (e.g., quantum dots, nano silver, zero valent metals, metal oxides such as titanium dioxide) 3) dendrimers (nanosized branched polymers grown in a stepwise fashion) 4) composites (nanoparticles combined with other nanoparticles or with larger, bulk-type materials, e.g., nanosized clays added to auto parts or packaging products to enhance properties) Not included in this group are unintentionally (incidentally) produced ENM, such as diesel exhaust particles, or natural nanosized materials that occur in the environment (e.g., viruses or volcanic ash) (USEPA, 2007).

Examples and Indicators If group, what are notable examples? Are there possible indicator constituents? *(A suitable indicator occurs at quantifiable levels and may co-occur with other CEC, exhibit similar treatment and fate in environment)*	Examples: Carbon nanotubes, Buckyballs (Fullerene C-60), titanium dioxide, cerium oxide, nano-sized zero-valent iron (nano-Fe0), colloidal silver ENM is a diverse group with a range of properties. No suitable indicators have been identified.
Health Advisories Does CEC have a USEPA Health Advisory (e.g., DWEL) or California NL?	No
Regulatory Development Status Is CEC on USEPA CCL, UCMR, or California PHG lists?	No
CONTEXT OF CEC EVALUATION AT SFPUC	
Instructions	The purpose of this section is to report SFPUC experience with the CEC or CEC Group, including occurrence data for each source water if available.
Purpose Why is evaluation undertaken? What is new about the issue that is considered ‘emerging’ (e.g., new chemical, new effect)?	Despite the significant benefits from nanomaterials, ENP are a potential concern because (by design) they behave differently than other particles. In the “USEPA Nanotechnology White Paper” (February 2007), USEPA makes the following statements that summarize some of the issues: • “There is a significant gap in our knowledge of the environmental, health, and ecological implications associated with nanotechnology.” (pg. 52) • “Studies assessing the role of particle size on toxicity have generally found that ultrafine or nano size range (<100 nm) particles are more toxic on a mass-based exposure metric when compared to larger particles of identical chemical composition.” (pg. 54)

Customer Interaction Widespread public concerns? Media coverage?	With respect to drinking water, currently there are no widespread public concerns and no media coverage about specific impacts from nanomaterials.
Expected Outcomes What are the likely benefits of the investigation to SFPUC and its customers?	ENM are not expected to be a significant issue as SFPUC source waters are not impacted by treated wastewater or urban runoff. However, very little is known about the fate of ENM in the environment. This investigation will support tracking this field of study and development of a knowledge base. A better understanding of the issue by SFPUC should enhance communications and customer confidence.
Occurrence Data (US and SFPUC) What occurrence information is available? Have detections, if any, been confirmed by follow-up sampling and/or QA/QC review?	ENM may be detectable based on particle size but should be distinguished from naturally derived ultra-fine particles. For analysis in water samples, advanced tools are available for particle size, chemical, and morphological characterization (USEPA, 2017; Good et al., 2016). Because ENM are relatively new; they have not been a focus of environmental or drinking water studies, reliable analytical methods are not widely available. One study reported surface water concentrations of nano-titanium dioxide as high as 1.4 µg/L in recreational waters due to sunscreen (Good et al., 2016). More often researchers estimate surface water and drinking water concentrations of ENM based on their usage, release and transport in the environment and behavior during drinking water treatment. Wastewater effluent concentrations of different ENM in the San Francisco region have been estimated to be no more than 100 µg/L (Keller, 2013). Worst case predicted concentrations in drinking water could be in the low- to sub- µg/L level (Tiede et al., 2015; Good et al., 2016). No occurrence data are available for SFPUC source or drinking waters.
Supporting Information List key references.	Good K. D., et al., (2016). Implications of Engineered Nanomaterials in Drinking Water Sources. Journal AWWA, 108:1. http://dx.doi.org/10.5942/jawwa.2016.108.0013 USEPA (2007). Nanotechnology White Paper. EPA 100/B-07/001, Office of the Science Advisor, Science Policy Council, United States Environmental Protection Agency. USEPA (2017). Technical Fact Sheet – Nanomaterials, November 2017. Office of Land and Emergency Management, EPA 505-F-17-002.

DIAGNOSTIC QUESTIONS TO SUPPORT CEC PRIORITIZATION

Instructions	The purpose of the Diagnostic Questions is to determine whether the CEC or CECs Group are significant to SFPUC drinking water and whether they merit further evaluation and/or action. All answers require explanation except those clearly not applicable. The Diagnostic Questions are divided into Health, Occurrence, and Treatment sections. The more questions are answered with a "Yes", the higher the probability that the CEC is a high priority or that a proactive approach should be taken.

HEALTH EFFECTS FROM SCIENTIFIC STUDIES

Question	Answer	Explanation and Comments
Is scientific knowledge on CEC health effects well developed?	**Unknown**	There is very limited data on potential human toxicity of ENM. Risk evaluation is difficult because of the diversity and complexity of ENM, and the limitless potential uses (USEPA, 2007). Most toxicity studies have focused on respiratory exposure (Handy, 2007). In vitro studies have identified cell responses to carbon nanotubes and metal oxides including oxidative stress, inflammation responses, inhibited cell proliferation and down-regulation of cell growth genes. Studies have shown that ENM may pass the blood-brain barrier and the placenta; the cardiovascular system and liver have also been identified as target organs (US EPA, 2017; Bhattacharyya et al., 2017). Potential health-related impacts from ENM in drinking water have not been evaluated. Potential human exposures include occupational exposure, consumer products, and airborne industrial releases. Exposure from drinking water is also possible but not likely a major source (USEPA, 2007; Wiesner et al., 2006). The US National Nanotechnology Initiative (NNI) supports research in the fate and potential toxicity of nanomaterials (Wiesner et al., 2006).
Based on current scientific understanding, does the CEC pose potential health risk at the levels typically found in drinking water in the US?	**Unknown**	Neither occurrence in US drinking waters nor potential health-related impacts from drinking water have been evaluated. In general, however, concentrations of ENM in US drinking water would be expected to be very low from trace contamination by municipal or industrial wastewaters impacted by ENM (Tiede et al., 2015; Good et al., 2016). None of the ENM have both high production volumes and high ecotoxicity. (Arvidsson et al., 2018)

Question	Answer	Explanation and Comments
Adverse health impacts observed in other drinking water systems? Are public health studies documenting human health impacts (disease or outbreaks) available?	**No**	No adverse health impacts have been observed in other drinking water systems from ENM.
Existing regulations or guidelines outside of US (e.g., WHO, EU)?	**No**	No regulations or guidelines outside of the US are available for ENM in drinking water. In Europe, ENM have been regulated under the REACH initiative, which has required collection of environmental performance data prior to commercialization of ENM-enabled products; e.g., predicted or derived no-effect exposure levels for compounds produced above 10 metric tons per year and physicochemical properties, such as flash point or octanol–water partitioning coefficients for compounds produced above 1 metric ton per year. (Janković and Plata, 2019)
Existing US health advisories or CA notification levels?	**No**	No US health advisories or CA notification levels are available for ENM in drinking water.
Likely US regulation in the next 10 years? Is CEC on a regulatory development list, such as CCL? Is there a pending regulation or California PHG?	**No**	Because ENM are an emerging topic of study in environmental monitoring and human health risk, there is little information available on which to base regulation. Hence US regulation is not likely within the next 10 years.
SUMMARY – SIGNIFICANT TO PUBLIC HEALTH IN GENERAL? *(Based on above answers)*	**Unknown**	Potential health-related impacts from ENM in drinking water have not been evaluated in any risk assessment study to date.

OCCURRENCE

Question	Answer	Explanation and Comments
Is scientific knowledge on CEC sources/formation well developed?	**Yes**	Potential ENM sources to the environment are direct or indirect releases from the manufacture and processing of ENM, oil refining processes, chemical and material manufacturing, chemical clean-up activities, urban and agricultural runoff and releases from consumer products to municipal wastewater or recreational waters (USEPA, 2007; Wiesner et al., 2006; Good et al., 2016).
CEC presence reported in other water supplies? Are occurrence studies available?	**Unknown**	Only one study has reported concentrations of ENM in surface waters used for drinking water. Concentrations of nano-titanium dioxide as high as 1.4 µg/L have been observed in recreational waters due to release from swimmers' sunscreen (Good et al., 2016).
CEC present in SFPUC watersheds and/or surface waters? Are there complex issues involved in managing CEC ;e.g., point vs. non-point sources?	**Unknown**	ENM have not been monitored in SFPUC watersheds and source waters but are not expected to occur because watersheds and source waters are not impacted by wastewater discharges or urban runoff. Wiesner et al. (2006) notes that nonpoint sources such as long-range atmospheric transport of ENM to watersheds is possible, but this has not been evaluated. In general, concentrations of ENM in drinking water sources are likely to be in the low- to sub-µg/L level (Tiede et al., 2015; Good et al., 2016).
Is the CEC a potential groundwater contaminant?	**Yes**	Releases from chemical clean-up activities is a possible source of ENM (e.g., ENM used for environmental remediation of groundwater) (USEPA, 2007; Wiesner et al., 2006).
If the CEC is a potential groundwater contaminant, is it highly mobile in the subsurface? Is the CEC low-sorbing and resistant to microbial degradation?	**Yes** **and** **No**	Fate in soil and groundwater will vary depending on the ENM. For selected compounds, studies have shown variable mobility across ENM. In general, little information is available on environmental fate of ENM (USEPA, 2007; Wiesner et al., 2006). Most metal ENP are hydrophilic but have low solubility. Other hydrophobic materials, such as carbon nanotubes and fullerenes, do not dissolve as they form stabilized suspensions or aggregate. (Bhattacharyya et al., 2017b)

Question	Answer	Explanation and Comments
Precursor present in SFPUC source waters? *(Including surface waters and groundwaters)*	**No**	ENM, by definition, are engineered by humans and therefore there are no natural precursors.
Formed or added during current SFPUC treatment? If so, describe whether the formation or addition of CEC can be controlled.	**No**	ENM are not formed or added during SFPUC treatment.
Formed or added within SFPUC storage or distribution? If so, describe whether the formation or addition of CEC can be controlled.	**Unknown**	ENM are not formed or added within SFPUC storage or distribution.
Detected in SFPUC drinking water?	**Unknown**	ENM have not been monitored in SFPUC drinking water. They are unlikely to be present.
SUMMARY – OCCURRENCE IN SOURCE AND DRINKING WATER? *(OR SIGNIFICANT POTENTIAL TO OCCUR)* *(Based on above answers)*	**No**	Though there is no data available on ENM occurrence in US drinking waters, occurrence is not expected for SFPUC waters because watersheds and source waters are not impacted by potential sources of ENM such as wastewater discharges, industrial discharges, or urban runoff.

TREATMENT

Question	Answer	Explanation and Comments
Is scientific knowledge on CEC treatment/removal well developed?	**Yes**	Coagulation, flocculation, sedimentation and filtration have been found to reduce metal, metal oxide and carbon ENM concentrations by 80% or greater (Good et al., 2016). ENM form aggregates with NOM that are anticipated to form larger, more easily filterable particles. Although membrane pores are larger than the nano scale, advanced filtration (MF or UF) exhibited good removal of metal oxide ENM at the lab-scale due to aggregation (Good, 2016; Floris, 2017). ENM may be removed by conventional and advanced drinking WTPs, but it is likely that removals of 3- to 4-log (like bacteria or viruses) will not be possible. Chlorine oxidation may impact the properties and behavior of some ENM (Good et al., 2016).
Likely to pass through current treatment for Hetch Hetchy Supply? Describe any complex issues for treatment/removal of CEC.	**Unknown**	Tesla Water Treatment Facility provides treatment via primary disinfection using chlorine and UV treatment. Because there is no conventional filtration, ENM are likely to pass through, if present. The extent to which chlorine or UV may transform or degrade ENM has not been evaluated. ENM are not expected to occur because watersheds are not impacted by wastewater discharges or urban runoff.
Likely to pass through current treatment at SVWTP? Describe any complex issues for treatment/removal of CEC.	**No**	SVWTP has a conventional treatment process (i.e., coagulation, flocculation, sedimentation, and deep bed anthracite/sand filtration), primary disinfection with free chlorine, followed by monochloramine. ENM will be removed during conventional treatment, based on technical studies (Good et al., 2016; Floris, 2017). NOM and coagulation pH are important parameters; both for alum and ferric coagulants the removal was better at neutral pH than at pH 9.

Question	Answer	Explanation and Comments
Likely to pass through current treatment at HTWTP? Describe any complex issues for treatment/removal of CEC.	**No**	HTWTP has a direct filtration treatment process (i.e., flocculation and deep bed anthracite/sand filtration), preceded by pre-ozone oxidation, and followed by primary disinfection with free chlorine and chloramination. (See also information above)
Likely to pass through current treatment for groundwater? Describe any complex issues for treatment/removal of CEC.	**Yes if Present**	Groundwater treatment will include chlorination or chloramination and other chemical addition steps. Because there is no filtration, ENM are likely to pass through, if present.
SUMMARY – LIKELY TO PASS (NOT REMOVED BY) CURRENT TREATMENT? *(Based on above answers)*	**No**	Knowledge about treatment performance for specific ENM in water is still developing, but current evidence suggests that many ENM will be removed in filters during water treatment. Not all SFPUC treatment plants have filtration. ENM are not expected to occur because watersheds are not impacted by wastewater discharges or urban runoff.

CEC PRIORITIZATION – CURRENT ASSESSMENT	
Instructions	This section prioritizes the CEC based upon the information developed in the above Diagnostic Questions as well as in the background information. For high and medium priorities, develop monitoring and/or mitigation measures as appropriate. For low priorities, maintain current measures, track regulatory developments, health/technical studies and reevaluate priority when needed.
Could CEC occur in SFPUC drinking water at levels of possible health significance? *(Based on above Diagnostic Questions)*	**UNKNOWN.** ENM are unlikely to occur in SFPUC surface water or groundwaters because the watersheds and source waters are not impacted by significant industrial or wastewater discharges or urban runoff. In general, concentrations of ENM in drinking water are likely to be extremely low, if even detectable.
CEC Prioritization for SFPUC High, Medium, or Low. Provide explanation. *(A high number of "Yes" answers to the Diagnostic Questions indicates a higher priority, and "No" or very few "Yes" answers indicates a lower priority.)*	**LOW PRIORITY FOR SFPUC** Because SFPUC source waters come from protected watersheds, occurrence of ENM is unlikely. Little is known about ENM occurrence in US drinking waters, health significance, and treatment effectiveness. These CECs are subjects of preliminary research. In general, concentrations of ENM in drinking water are likely to be extremely low, if even detectable.
Implemented Actions Indicate the progress and results of action items, implemented in previous cycles of CEC review. Evaluate whether changes to the action plan are required.	• Maintained source water protection and optimized multibarrier water treatment and distribution system operation. • Conducted technical literature reviews. • No other actions have been taken. Analytical methods are not widely available.

Recommended Actions Does the situation merit investing additional resources or has the information gathered so far fulfilled due diligence? Actions could include monitoring and other measures (specified by source water, if necessary).	• Benchmark through national or state surveys when appropriate. • Maintain source water protection and optimized multibarrier water treatment and distribution system operation. • Track federal and state regulatory developments. • Track peer-reviewed publications.

This evaluation was prepared based on available information (peer-reviewed literature and occurrence data) with the purpose of prioritizing work and informing the public on unregulated CEC. This evaluation will be updated every 6 years or when significant new research or occurrence data on CEC become available that may warrant changing priority and recommendations.

Water Quality Division, Technical Review 2016 – 2021

Contaminants of Emerging Concern (CEC) in Drinking Water

Engineered Nanomaterials and Nanoparticles

Nanotechnology offers the promise of new materials and technologies through manipulation of physical and chemical properties and system behaviors that are controlled by size— very small particles behave differently from larger ones. Engineered nanomaterials (ENM) are those that have at least one dimension in the nanoscale (approximately 1 to 100 nm), and this feature alters their biogeochemical behavior. Nanomaterials are abundant and ubiquitous, naturally occurring in many global processes (e.g., from volcanic eruptions); incidentally formed in human activities (e.g., from diesel exhaust emissions); and engineered for specific purposes (i.e., designed and tailored for novel applications such as drug delivery, antifouling coatings, or improvements to mechanical strength). (Good et al., 2016)

What are Engineered Nanomaterials and Nanoparticles?

A nanometer (nm) is one-billionth (10^{-9}) of a meter and is approximately 100,000 times smaller than the diameter of a human hair. Nanomaterials (ENM) have one dimension less than 100 nm in length, and nanoparticles (ENP) are nanomaterials with at least two dimensions less than 100 nm in length. The unique phenomena associated with nanoparticles result from surface area and particle size. At the physical scale of a nanometer, or the nanoscale, quantum effects control particle properties. By controlling the particle size, it is possible to control the properties of the material. An example of this is demonstrated by the antimicrobial characteristics of nano size silver, which is far less effective when aggregated into larger silver particles. Nanoparticles (NP) are everywhere and may include engineered nanomaterials and those occurring naturally (e.g., clays) or incidentally created (e.g., combustion products). They are produced from forest fires (and other combustion processes), volcanic ash, dust storms, and ocean spray, and have been found in pottery glazes from the ninth century in Mesopotamia. (Bhattacharyya et al., 2017a)

Good et al. (2016) provides an overview of current first-generation ENM types and includes examples of the properties for which they are designed, examples of products and uses, and example methods for detection in water. While quantifying ENM production volumes is challenging, those that are currently estimated to have the highest volume of production, generally range from tens to hundreds of tons per year globally.

ENP or ENM are typically incorporated in consumer products or industrial applications to fulfill a specific purpose or are intentionally applied to the environment, for example as nanopesticides or nanofertilizers in agriculture and for contaminant remediation purposes. The ENP produced in the largest volumes typically consist of metals or metal oxides. Several mass-flow modeling studies provided emission estimates into different environmental compartments during their lifecycle (e.g., air, water, soil) at global and regional scales. These emission estimates are mainly based on data or estimates of production volumes or market penetration of ENP-containing products and applications, release rates during use and transfer factors between various life-cycle stages (e.g., retention in wastewater treatment). (Hüffer et al., 2017)

Engineered Nanoparticles Pose Low Risk during Ingestion

ENP are currently orders of magnitude less common than natural nanoparticles in waters that flow into drinking water treatment plants. Because such plants are designed to remove small-sized natural nanoparticles, they are also very good at removing ENP. Consequently, ENP concentrations in tap water are extremely low and pose low risk during ingestion. However, after leaving drinking water treatment plants, corrosion by-products released from distribution pipes or in-home premise plumbing can release incidental nanoparticles into tap water. The occurrence and toxicity of incidental nanoparticles, rather than ENPs, should therefore be the focus of future research. (Westerhoff et al. 2018)

Regulatory Developments

USEPA's Safe Drinking Water Act does not include any ENM, but it would be equipped to regulate them in drinking water if warranted by exposure and occurrence data. USEPA's recently proposed one-time reporting and recordkeeping requirement for nanomaterials in the marketplace under Section 8(a) of the Toxic Substances Control Act. (Good et al., 2016)

Minimizing and Managing Risks from Engineered Nanomaterials

The central ethical and policy issue with respect to minimizing and managing the risks of ENM is whether existing legal frameworks are sufficient to protect public health and the environment. Proponents of new regulations argue that ENM are so different from existing substances and pose such far-reaching and poorly understood risks to public health and the environment that new forms of government oversight, such as regulations that address ENM as a class, are needed. (Resnik, 2019)

One could argue that since the risks of ENM—and strategies for minimizing them—are poorly understood at this point, policymakers should (1) use existing laws to regulate ENM and the best available evidence to set regulation levels without creating new laws or an overarching system to regulate ENM and (2) support additional research on the risks of ENM. These and other precautions can offer a way to minimize and manage the public health and environmental risks of ENM without sacrificing their potential medical, social, and economic benefits. (Resnik, 2019)

In Europe, ENM have been regulated under the REACH initiative, which has required collection of environmental performance data prior to commercialization of ENM-enabled products; e.g., predicted or derived no-effect exposure levels for compounds produced above 10 metric tons per year and physicochemical properties, such as flash point or octanol–water partitioning coefficients for compounds produced above 1 metric ton per year. (Janković and Plata, 2019)

In the United States, while no such restrictions were placed on commercial applications of ENM, the National Science Foundation (NSF) and USEPA jointly sponsored two major research networks ($77.4m to date to the University of California's Center for the Environmental Implications of Nanotechnology (UC CEIN) and Duke University's Center for the Environmental Implications of Nanotechnologies (CEINT)) to address questions related to the unintended implications of ENM, their ecotoxicity, and their environmental fate. In addition, the EPA-sponsored project Lifecycle of Nanomaterials (LCNano) was aimed at understanding the relationships between nanomaterial properties and exposure or hazard, through lifecycle considerations. (Janković and Plata, 2019)

From a global perspective, nanomaterial markets make up relatively small proportions of in-use materials. This implies that ENM, when distributed in the environment or over the globe, would have a negligible effect compared to their natural analogs. it's worth noting that the toxicity of some ENM is dramatically distinct from their natural analogs (e.g., CNTs, where morphology presents unique respiratory toxicity beyond that of spherical or agglomerated black carbon soots). The same urgency may not exist for metal and metalloid nanomaterials, which may lack the feature of nano-specific toxicity or environmental impact (e.g., Ag) or are identifiable as industrially sourced (e.g., QDs). For example, QDs will have toxicity related to their metal constituents, but also contain elemental ratios that are sufficiently unique from natural minerals to potentially identify them in the environment (until the atoms dissociate). Considering the implicit toxicity of some QDs and the rapid anticipated market growth, research to understand the environmental fate of these materials is justified. (Janković and Plata, 2019)

Probing the nanomaterial space en masse, one can prioritize EHS research by element type and suggest the following:

- For metals, current and future markets are expected to remain minor relative to other anthropogenic uses. QDs provide an exception with rapid anticipated growth and few other technologies that rely on those most common QD elements (Cd, Se, and Te).
- For metal oxides, the nanomaterial markets are substantial and represent the largest proportion of any ENM in a material's use phase (e.g., 3–25% of the total Si market). They also have some of the highest anticipated growth rates in the coming years. Thus, metal oxide ENM may have the greatest environmental abundance on a mass basis.
- For carbonaceous nanomaterials, especially nanocellulose and graphene, there is strong anticipated growth of the industries with many diverse applications (i.e., and corresponding exposure routes). Further, the synthetic efficiencies for some of these processes tend to be extremely low. Therefore, EHS research should continue to work to improve industrial processing for carbonaceous ENM in order to mitigate the geochemical impact of these emergent technologies. (Janković and Plata, 2019)

Analytical Considerations

In case of particulate contaminants such as ENP the characterization and quantification in laboratory settings, technical products and natural environments has to go beyond total mass quantification toward a more detailed analysis to reveal information on particle size (distribution), possible coatings, shape and aggregation state. For ENP continuous developments and improvements in terms of sensitivity and selectivity of microscopic, chromatographic and spectroscopic instruments have led to the identification of promising approaches, which however often require a combination of complementary analytical techniques, to elucidate the ENP characteristics. For example, particle size and particle composition of inorganic ENP can be determined with a hyphenation of field flow fractionation (FFF) and element selective detectors such as inductively coupled plasma mass spectrometry (ICP-MS). Further prominent methods to determine ENP size (distribution) include electron microscopy (EM), light scattering and, most recently, single particle (sp-) ICP-MS. A particular challenge is associated with the fact that the ENP of primary concern are those smaller than 10 nm, which are also the most difficult to analyze since most of the analytical methods used are based on the detection of mass. The mass scales with the third order to particle size, therefore a 50% reduction in particle size (for spheres) reduces the mass (and hence the signal detected) by 87.5%. (Hüffer et al., 2017)

Most Used Analytical Methods

Inductively coupled plasma mass spectrometry (ICP-MS) provides elemental identification and can be run in single-particle counting mode or combined with other methods (e.g., field-flow fractionation [FFF]) to focus detection on ENM. Single-particle ICP-MS shows promise as a detection method for quantifying and sizing ENM in environmental samples in concentrations in the ng/L to µg/L range. Thus, while detection methods are being improved, current monitoring technologies used at DWTPs are inadequate for detecting and quantifying ENM. To determine source or finished water concentrations of ENM, samples would need to be sent to research laboratories for characterization, where techniques for detecting ENM in environmental samples are still under development. (Good et al., 2016)

For ENP, no final agreement on concentration metrics has been found, but the discussion has resulted in an increased awareness of the challenges associated with reporting properties of particulate contaminants. (Hüffer et al., 2017)

Several technologies have been developed to characterize either bulk nanomaterials or individual NPs (including the subset of materials termed “quantum dots”). While the list of potential physical and chemical properties is expansive, a short list of most commonly sought properties includes (1) size distribution, (2) shape, (3) composition, (4) physiochemical structure, and (5) agglomeration state. (Bhattacharyya et al., 2017b)

Recently nanomaterial characterization has seen considerable growth by application of inductively coupled plasma–mass spectrometry (ICP–MS) to analyze single particles (sp–ICP–MS). The benefit of this approach is a simplified sample preparation or even a direct, dilute and-shoot approach. After in-line dilution, sp–ICP–MS can be used to analyze each separate NP as it is aerosolized and ionized in the plasma, resulting in a signal intensity that is directly proportional to particle size. The mass-to-charge ratio of resulting ions can subsequently be used to provide elemental analysis. Taken together, the analysis from an sp–ICP–MS can therefore provide elemental composition of most nanomaterials (although only a single isotope can be determined at a time), size distribution, and concentration of the nanomaterial in the test solution. The typical lower size limit of detection for sp–ICP–MS is 20 nm. (Bhattacharyya et al., 2017b)

Nanomaterial-enabled sensors are being designed for high-efficiency, multiplex-functionality and high-flexibility sensing applications. Many existing nanosensors have the inherent capacity to achieve such goals; however, they require further development into consumer- and operator-friendly tools with the ability to detect analytes in previously inaccessible locations, as well as at a greater scale than heretofore possible. (Vikesland, 2018)

HEALTH

Common environmental and industrial nanomaterials that may accumulate in humans include TiO2, associated with neurological lesions, CuO, associated with kidney and liver lesions, TiO2/ZnO/CeO2, associated with oxidative stress, and cadmium selenide/zinc sulfide, associated with acute toxicity. In the latter case, not only is the nanomaterial itself toxic, but any solubilized cadmium that leaches from the nanomaterial is also toxic. Morphology of the nanomaterial is also a significant characteristic— smaller NPs are generally more toxic than larger ones, and the more aspherical NP are more toxic than spherical. Thus, in developing a clinical assessment for nanomaterials in specimens, one needs to focus on composition and morphology as well as the presence of dissolved toxic elements. (Bhattacharyya et al., 2017b)

The USEPA has led research on the environmental transformation and fate of several types of nanomaterials and has concluded that common disinfectants are a significant source of potentially toxic nanomaterials in the environment. The rise in use of nanomaterials and their potential toxic effects stresses the urgency for a nanomaterial biomonitoring effort. (Bhattacharyya et al., 2017b)

Possible Health Outcomes Based on Laboratory Studies

Ingestion of NPs via drinking water may pose a direct human health threat or an indirect risk resulting from release of metal ions from the NP. Exposure to metal NP or metal ions derived from NPs via ingestion can result in adverse effects including kidney damage, elevated blood pressure, gastrointestinal inflammation, neurological damage, and cancer. Cell uptake, cytotoxicity, and DNA damage in theCaco-2 human intestinal cell line have been reported after in vitro NP exposure. NP exposure via drinking water ingestion tested using in vivo animal studies has revealed adverse effects. Rats and mice that ingested metal NP had increased metal concentrations in their liver, kidneys, brain, and blood compared with controls. histological evidence of inflammation, as well as increased liver enzymes related to necrosis and inflammation, in rats and mice in response to Ag and ZnO NP in drinking water. Ingestion of metal NP has also been reported to lead to DNA damage. The consequences of increased metal burdens, DNA damage, and liver toxicity are not fully understood. However, these studies indicate that ingestion of NPs can lead to NP or metal ions in systemic circulation with potentially adverse health consequences. Future routine monitoring of NP in public water systems (source and finished water) by available analytical methods in the public health laboratories would allow timely identification and estimate concentration, as well as facilitate risk assessment and intervention strategies for NP exposure related to human, plant, and animal health. (Bhattacharyya et al., 2017a)

Proxy Measures of Environmental Risk. The overcomplexity of the natural environment, [may lead to a conclusion] that the environment cannot be described in a deterministic way. In particular, the risk of chemical substances is therefore difficult to model with any accuracy. As an alternative intended to reduce the complexity of the assessment, it has been proposed to use the proxy measures, which are observable indicators or variables. Proxy measures thus reflect environmental threat rather than actual environmental risk. Proxy measures have been proposed as a low data option for simplified assessment of environmental threat given the high complexity of the natural environment. In total, 18 potential proxy measures were identified and evaluated regarding their link to environmental risk, an aspect of relevance, and data availability, an aspect of practice. They include socio-technical measures (e.g., ENM release), particle-specific measures (e.g., particle size), partitioning coefficients (e.g., the octanol−water coefficient), and other fate-related measures (e.g., half-life) as well as various ecotoxicological measures (e.g., 50% effect concentration). (Arvidsson et al., 2018)

Conclusions from Proxy Analysis

For most identified proxy measures, the link to environmental risk was weak and data availability low. Two exceptions were global production volume and ecotoxicity, for which the links to environmental risk are strong and data availability relatively decent. As proof of concept, these were employed to assess seven ENM: titanium dioxide, cerium dioxide, zinc oxide, silver, silicon dioxide, carbon nanotubes, and graphene. The results show that none of the ENM have both high production volumes and high ecotoxicity. (Arvidsson et al., 2018)

Debate on Size Ranges Associated with Increased ENM Toxicity. It is often suggested that a material must have at least one dimension in the 1−100 nm range in order to qualify as a nanomaterial. However, a review has shown that many other size ranges have also been suggested for defining nanomaterials, including less than 200 nm, less than 300 nm, less than 500 nm, and less than 1000 nm. Although particle size is often mentioned as a parameter of importance for ENM toxicity and fate, the exact causality between the parameter and environmental risk is unclear. Some studies point at a wider size range than 1−100 nm being of environmental interest. For example, the screening risk assessment method called the Precautionary Matrix differentiates between ENP smaller than 500 nm and larger particles, where the former are assumed to be more hazardous to the environment. "There is little reason not to suppose that some materials may exhibit abrupt changes in behavior above 100 nm". Other studies suggest that a narrower size range than 1−100 nm should be in focus from an environmental point of view. Although there seems to exist particle size threshold levels for environmentally relevant physio−chemical properties of ENM, these thresholds are often below 100 nm. More specifically, inorganic particles larger than 30 nm typically do not show physio−chemical properties that imply different environmental effects than their bulk material counterparts. These conflicting views on which sizes lead to environmental risk limit its usefulness as a proxy measure. Regarding data availability, particle sizes vary between products and are typically only available for a limited number of ENM products. (Arvidsson et al., 2018)

OCCURRENCE

Potential release pathways for ENM into surface waters include (a) discharge of municipal wastewater effluent containing ENM from personal care products and other products that could enter municipal sewage; (b) agricultural runoff containing ENM from land-applied biosolids or from nanomaterial plant protection and fertilizer products; urban runoff, (c) stormwater runoff containing ENM from exterior facades, fuel additives, or other products; (d) combined or sanitary sewer overflows containing ENM from municipal sewage; and (e) direct releases from recreational activities. There could also be unplanned releases into surface waters, including (f) discharges from ENM manufacturing facilities, (g) discharges from other industrial facilities that use ENM, and (h) accidental spills or leaks of ENM at manufacturing/industrial facilities or during transportation. (Good et al., 2016)

Transformations in Water and Wastewater. Physical processes (e.g., aggregation, sedimentation) and chemical/biological processes (e.g., dissolution, ligand exchange, biotic and abiotic redox reactions, and photolysis) alter the properties of ENM from their original forms and affect their persistence in the environment. These transformations will therefore also affect ENM concentrations in source waters. In general, environmental transformations increase the tendency of ENM to aggregate, increasing sedimentation and filtration potential. (Good et al., 2016)

Possible Concentrations of ENM in Surface Waters and Wastewater

Average ENM concentrations in surface waters at current production and release rates are expected to be very low (<<1 µg/L). ENM concentrations above 1 µg/L are likely to be rare, because even predicted concentrations of ENM in wastewater effluent at a regional scale (e.g., San Francisco, Calif.) are estimated to be less than 100 µg/L, depending on the ENM, and would be further diluted once discharged. (Good et al., 2016)

It is difficult to identify ENM among the natural and incidental nanoparticles commonly observed in natural waters. There are currently no published studies that sample drinking water intakes and report ENM concentrations, and there is only one study that sampled and reported ENM concentrations in surface water, with results suggesting a 1.4-µg/L increase in TiO_2 in summer months from swimmers' sunscreen in a recreational lake They estimated that the ENM most likely to be found in the highest concentrations in drinking water are TiO_2^-, ZnO^-, and SiO_2-based ENM. (Good et al., 2016)

Transformations in Soil and Sediment. When released to the soil environment, ENM may sorb to soil particles, may become transformed through biotic and abiotic processes, and in some cases may be transported back to water bodies through runoff, leaching, and discharge from agricultural fields. Nanotubes, fullerols, fullerenes, and polyurethane nanoparticles have been found to strongly sorb to soil particles and are thus removed from the water. Coating, aging, and previous contact with sewage sludge were observed to affect behavior and transport of Ag nanoparticles in soils. ENM in soil also demonstrate uptake into surrounding plants and bacteria. Aerated soils can provide oxidizing environments that may result in relatively insoluble oxide coatings on metal ENM. (Good et al., 2016)

Possible Impacts of ENM in Environment

Most metal ENP are hydrophilic but have low solubility. Other hydrophobic materials, such as carbon nanotubes and fullerenes, do not dissolve as they form stabilized suspensions or aggregate. The predictions concerning toxicity and water interactions are complicated further when accounting for surface coatings. Nanomaterials likely affect all levels of aquatic organisms from coating algae to accumulating in the respiratory systems of vertebrates. Additionally, untreated nanomaterials are likely to accumulate in benthic sediments. (Bhattacharyya et al., 2017a) Most materials are more toxic in aquatic systems than in terrestrial environments. (Bhattacharyya et al., 2017b)

TREATMENT

Nanotechnology holds great potential in advancing water and wastewater treatment to improve treatment efficiency, as well as to augment the water supply through safe use of unconventional water sources. (Bhattacharyya et al., 2017a)

The presence of sub-micron particles (e.g., colloids, viruses, clays) in natural waters is well known. Specific technologies within drinking water systems are designed to remove these particles, some of which are naturally occurring at the nanoscale. Thus, existing regulations already indirectly cover some natural nanomaterials—e.g., turbidity and disinfection. Conventional drinking water treatment processes are designed to remove contaminants in source waters, including small particles, and thus can also be expected to remove some ENM. Four main treatment steps—coagulation, flocculation, sedimentation, and filtration—have been found to remove metal and metal oxide nanoparticles. Coagulation, flocculation, and sedimentation are used extensively in surface water treatment to remove NOM since NOM can lead to taste and odor problems in finished water and to increased formation of disinfection by-products (DBPs). NOM can increase the stability of nanoparticles in solution; thus, its removal is important for removal of ENM at WTP. Multiple studies have found that the use of the coagulant alum can remove ENM, including metal, metal oxide, and carbonaceous species (80% removal of metal oxide ENM with a 20-mg/L alum dose). (Good et al., 2016)

Peak removal of C60 at 97% using 100 mg/L alum at neutral pH. However, a more moderate alum dose of 10 mg/L was still able to achieve close to 80% removal of C60 at neutral pH. Filters can be effective in removing larger ENM aggregates on the micron scale and aggregation of ENM is expected in surface waters and during coagulation/ flocculation. Advanced filtration techniques, such as with UF and MF membranes, have been shown to be suitable for ENM removal. Although neither MF nor UF membranes have nano-sized pores that are capable of removing individual nanoparticles, aggregation of nanoparticles before filtration enables the high level of removal observed. Sodium hypochlorite and ozone reduced concentrations of polyvinyl alcohol– coated silver nanoparticles by oxidative dissolution, leading to increased silver ion concentration; i.e., the silver was still present but in ionic, not nanoparticle, form. Presence of polyvinylpyrrolidone-coated silver nanoparticles led to minor changes in the composition of DBPs formed during sodium hypochlorite disinfection, and only at the relatively high concentration of silver nanoparticles (1 mg/L). Only the citrate-coated silver nanoparticles significantly increased DBP (chloroform) formation using silver nanoparticle concentrations of 1, 10, and 20 mg/L, which again are high relative to expected concentrations of silver nanoparticles in drinking water sources, and postulated that the citrate coating played an important role in the observed increase in DBP formation. (Good et al., 2016)

Possible Concentrations of ENM in Drinking Water

While the effects of drinking water disinfection reactions on other ENM have not yet been studied extensively, reaction conditions (e.g., pH, presence of NOM) and ENM coating appear to be important parameters for future study. ENM may be present in tap water in the ng/L to µg/L range under a worst-case scenario. (Good et al., 2016)

Removal of nC_{60} Fullerene ENP during Coagulation and Flocculation, Activated Carbon Filtration and Micro- and Ultrafiltration Membrane Processes. Almost complete nC_{60} removal was achieved by membrane with an average pore size smaller (approx. 18 nm) than tested ENP, but also for similar/larger (approx. 200 nm) than the ENP size, while membrane with an average size larger than the ENP (approx. 500 nm) showed very low removal (10%). The ratio of nC_{60} particle size to membrane pore size played very important role in the removal mechanism. Low pressure membrane processes, specifically microfiltration, are solid barriers to remove nC_{60} in natural surface water with different NOM compositions 0.7 – 3.2 mg/L DOC, 11 – 75 mg/L Ca^{2+} and < 0.5 mg/L Mg^{2+}. (Floris, 2017)

The removal of nC_{60} ENP by coagulation/flocculation/sedimentation with ferric chloride varied from 85% at low pH (pH < 6) due to charge neutralization and destabilization by hydrolysis products of Fe^{3+}, and drastically decreased to 34% at basic conditions (pH 9 and 15 mg/L ferric dose) where concentration of Fe^{3+} hydrolysis products decreased. The removal on nC_{60} was correlated with the removal of NOM, which suggests the coprecipitation of nC_{60} and NOM. The presence of Ca^{2+} and Mg^{2+} cations improved the removal on nC_{60} both at acidic and basic conditions. The presence of divalent cations increased the removal of nC_{60} to 90% at pH 9 overcoming the NOM stabilization effects. (Floris, 2017)

Adsorption efficiency by activated carbon depended on the pore size. PAC was able to remove up to 100% nC_{60} ENP (48 hours contact time) whereas removal by GAC was much less effective (20% after 6 weeks contact time). These removals were based on equilibrium results. (Floris, 2017)

RECOMMENDATIONS

The lack of regulatory aspects for the of use of nanotechnology demands partnering among researchers, communities, and industry in public and private sectors to encourage and support novel research and innovative applications, develop positions for related policies, and develop appropriate business models to sustainably exploit the potential in the field of nanotechnology. (Bhattacharyya et al., 2017b)

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Acronyms and Abbreviations

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ABS	Poly (Acrylonitrile Butadiene Styrene)
ACC	American Chemistry Council
ACGIH	American Conference of Governmental Industrial Hygienists
ADI	Acceptable Daily Intake
ADMA	Allyldimethylamine
ADWG	Australian Drinking Water Guidelines
AdV	Adenovirus
AE	Alameda East Portal
AER	Anion exchange resins
AFFF	Aqueous Film-Forming Foam
AiV	Aichi virus
AIX	Anion Exchange
AIDS	Acquired Immunodeficiency Syndrome
AK	Acanthamoeba keratitis
AMR	Antibiotic Residues, Antimicrobial Resistance
AMMP	Algae Monitoring and Mitigation Plan
AOP	Advanced Oxidation Process
AOX	Adsorbable Organic Halides
ARB	Antibiotic Resistant Bacteria
ARG	Antibiotic Resistant Genes
ATP	Adenosine triphosphate
AWWA	American Water Works Association
B(a)P	Benzo(a)pyrene
BBP	Benzyl butyl phthalate
BCAA	Bromochloroacetic acid
BCAN	Bromochloroacetonitrile
BCIM	Bromochloroidomethane

BCNM	Bromochloronitromethane
BDCAA	Bromodichloroacetic acid
BDCAL	Bromodichloroacetaldehyde
BDCNM	Bromodichloronitromethane
BDIM	Bromodiiodomethane
BCYE	Buffered Charcoal Yeast Extract
BPA	Bisphenol A
BTEX	Hydrocarbons: benzene (B), toluene (T), ethylbenzene (E), and p -xylene (X)
BV	Bed volumes
BW	Bottled water
CA	California
CA	Cluster analysis
CAC	SFPUC Citizens Advisory Committee
CCL	USEPA Contaminant Candidate List
CCL3	Third Contaminant Candidate List
CCL5	Fifth Contaminate Candidate List
CCR	Consumer Confidence Report
CDC	Centers for Disease Control and Prevention
CDPH	California Department of Public Health
CEC	Contaminants of Emerging Concern
CERC	CDC’s Crisis and Emergency Risk Communication
CFU	Colony Forming Unit
CEINT	Duke University’s Center for the Environmental Implications of Nanotechnologies
CHS	College Hill System
CL	Free chlorine
CLM	Chloramine
CNCL	Cyanogen chloride
CNX	Cyanides

CoV	Coronavirus
COVID	Coronavirus Disease
CPF	California Cancer Potency Factor (OEHHA)
Cr (VI)	Hexavalent Chromium
CRT	Coast Range Tunnel
CW	Constructed wetland
DADMAC	Diallyldimethyl ammonium chloride
DALY	Disability adjusted life years
DBAN	Dibromoacetonitrile
DBCAA	Dibromochloroacetic acid
DBCAL	Dibromochloroacetaldehyde
DBIM	Dibromoiodomethane
DCAA	Dichloroacetic acid
DCAcAm	Dichloroacetamide
DCAL	Dichloroacetaldehyde
DCAN	Dichloroacetonitrile
DCIM	Dichloroiodomethane
DBCNM	Dibromochloronitromethane
DBP	Disinfection By-products
DBP	Di-nbutyl phthalate
DCP	Dichloropropanone
DDW	SWRCB's Division of Drinking Water
DEET	N,N-Diethyl-meta-toluamide
DEHP	Di (2-ethylhexyl) phthalate
DL	Detection Limit
DMA	Dimethylamine
DO	Dissolved Oxygen
DOD	Department of Defense

DON	Dissolved Organic Nitrogen
DNA	Desoxyribonucleic Acid
DSOP	Distribution System Optimization Program
DWEL	Drinking Water Equivalent Level
DWS	Drinking Water System
DWTP	Drinking Water Treatment Plant
DXAA	Dihalogenated HAA
EBRPD	East Bay Regional Park District
ECHA	European Chemicals Agency
EDC	Endocrine-Disrupting Chemicals (Endocrine Society)
EDSP	USEPA Endocrine Disruptor Screening Program
EfOM	Effluent Organic Matter
EFSA	European Food Safety Authority
EHEC	Enterohemorrhagic E. Coli
ELISA	Enzyme-linked Immunosorbent Assay
EM	Electron microscopy
ENM	Engineered Nanomaterials
ENP	Engineered Nanoparticles
EPA	Environmental Protection Agency
EPTDS	Entry Points to the Distribution System
ER	Extended release
ES	Executive Summary
EU	European Union
EV	Enterovirus
EVA	Ethylene Vinyl Acetate Copolymer
EWG	Environmental Working Group
FAO	Food and Agriculture Organization
FBR	Fluidized bed bioreactor

FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FFDCA	Federal Food, Drug, and Cosmetic Act
FFF	Field Flow Fractionation
FLA	Free-living amoebae
FP	Formation potential
FPA	Focal Plane Array
FTIR	Fourier-transform infrared spectroscopy
GAC	Granular Activated Carbon
GAE	Granulomatous Amoebic Encephalitis
GenX	Azane;2,3,3,3-tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy) propanoic acid
GI	Gastrointestinal
GV	Guideline Value
GDWQ	WHO Guidelines for Drinking-Water Quality
HA	Health Advisory
HAA	Haloacetic acids (HAA5)
HAA6Br	Brominated Haloacetic acids
HAA9	Chlorinated and brominated HAA
HAB	Harmful Algal Blooms
HAL	Haloacetaldehydes
HAN	Haloacetonitriles
HAM	Halo acetamides
HAV	Hepatitis A Virus
HBCD	Hexabromocyclo-dodecane
HDPE	High-density polyethylene
HFPO-DA	Hexafluoropropylene oxide dimer Acid
HIV	Human Immunodeficiency Virus
HK	Haloketones
HNM	Halo nitromethanes

HOS	Hypolimnetic Oxygenation System
HCoV	Human Coronavirus
HHWP	Hetch Hetchy Water and Power
HPC	Heterotrophic plate count
HPS	Hunters Point System
HRL	Health Risk Limit
HTWTP	Harry Tracy Water Treatment Plant
IARC	International Agency for Research on Cancer
ICP-MS	Inductively coupled plasma mass spectrometry
I-DBP	Iodinated-DBPs
IRV	Irvington Portal
IVM	Integrated Vegetation Management
IX	Ion Exchange
LC-PFCA	Long-chain perfluorocarboxylic acids
LC/MS/MS	Liquid Chromatography/Tandem Mass Spectrometry
LCS	Lower Crystal Springs Reservoir
LCNano	Lifecycle of Nanomaterials
LD	Legionella Disease
LDPE	Low-density polyethylene
Li	Lithium
LVW	Las Vegas Wash
MAC	Mycobacterium Avium Complex
MAC	Maximum Acceptable Concentration (Canada)
MAHC	CDC Model Aquatic Health Code
MAV	Maximum Allowable Value (New Zealand)
MBAA	Monobromoacetic acid
MBAN	Bromoacetonitrile
MC	Microcystin

MCAA	Monochloroacetic acid
MCL	Maximum Contaminant Level
MDL	Method Detection Limit
MERS	Middle East Respiratory Syndrome
mg/L	Milligram per Liter
µg/L	Microgram per liter
MIB	2-methylisoborneol
MIBK	Methyl-isobutyl ketone
MMS	Merced Manor System
Mn	Manganese
MOA	Memorandum of agreement
MOE	Margin of exposure
MPF	Microplastic fibres
MRL	Method Reporting Level
MRSA	Methicillin-resistant Staphylococcus aureus
MP	Microplastics
MPF	Microfibres
MST	Microbial Source Tracking
N	Nitrogen
NA	Not Applicable
NASEM	National Academies of Sciences, Engineering, and Medicine
ND	Non-Detect
NDBA	N-Nitorsodi-n-butylamine
NDEA	N-Nitrosodiethylamine
NDMA	N-Nitrosodimethylamine
NDPA	N-Nitorsodi-n-propylamine
NDPhA	N-Nitrosodiphenylamine
NF	Nanofiltration

ng/L	Nanogram per Liter
NIEHS	National Institute of Environmental Health Sciences
NIOSH	National Institute for Occupational Safety
NL	Notification Level
nm	Nanometer
NMEA	N-Nitrosomethylethylamine
NMOR	N-Nitrosomorpholine
NMP	N-Methyl-2-Pyrrolidone
NMP	Nano and Microplastics
NNI	US National Nanotechnology Initiative
NOAEL	No-observed Adverse Effect Level
NOM	Natural Organic Matter
NoV	Norovirus
NPDWR	National Primary Drinking Water Regulation
NPIP	N-Nitrosopiperidine
NPYR	N-Nitrosopyrrolidine
NRLMD	SFPUC Natural Resources and Land Management Division
NSAID	Nonsteroidal anti-inflammatory drugs
NSF	National Science Foundation
NSF 61	National Sanitation Foundation Standard 61
NTM	Non-tuberculous Mycobacterium
NTP	National Toxicology Program
NTU	Nephelometric Turbidity Unit
NWRI	National Water Research Institute
OEHHA	California Office of Environmental Health Hazard Assessment
OPFR	Organophosphate flame retardant
OPPP	Opportunistic pathogens reported in premise plumbing
OSHA	Occupational Safety and Health Administration, US Department of Labor

OSP	Oceanside Water Pollution Control Plant
P	Phosphorous
PA	Polyacrylate, Polyamide (Nylon)
PAC	Powdered Activated Carbon
PAH	Polycyclic Aromatic Hydrocarbons
PAM	Polyacrylamide
PAM	Primary Amoebic Meningoencephalitis
PAN	Polyacrylonitrile
PBAT	Poly (butyleneadipate-co-terephthalate)
PBDE	Polybrominated diphenyl ethers
PCA	Principal component analysis
PCCL	Preliminary CCL
PC	Polycarbonate
PCA	Pest Control Advisor
PCB	Polychlorinated Biphenyls
PCE	Perchloroethylene
PCR	Polymerase-Chain Reaction
PE	Polyethylene
PET	Polyethylene Terephthalate
PFAA	Perfluoroalkyl Acids
PFAS	Per- and Poly- Fluoroalkyl Substances
PFBA	Perfluorobutyrate
PFBS	Perfluorobutane Sulfonic Acid
PFC	Perfluorinated Chemicals
PFHpA	Perfluoroheptanoic acid
PFHxS	Perfluorohexanesulfonic acid
PFNA	Perfluorononanoic acid
PFOA	Perfluorooctanoic Acid

PFOS	Perfluorooctane sulfonic Acid
PFLA	Pathogenic Free Living Amoebae
PHG	Public Health Goal
PLA	Polylactic acid
PMMA	Polymethylmethacrylate (aka acrylic, plexiglass)
PNEC	Predicted No Effect Concentration
PNP	Plastic nanoparticles
POP	Persistent organic pollutants
PP	Polypropylene
PPCP	Pharmaceuticals and Personal Care Products
PS	Polystyrene
PSW	Partnership for Safe Water
PTT	Polytrimethylene Terephthalate
PU	Polyurethene
PVA	Poly vinyl alcohol
PVAC	Poly (Vinyl Acetate)
PVC	Polyvinyl chloride
PWS	Public Water System
Py-GCMS	Pyrolysis gas chromatography mass spectrometry
QA	Quality Assurance
QD	Quantum Dot
QC	Quality Control
QMRA	Quantitative microbial risk assessment
qPCR	quantitative Real-time Polymerase Chain Reaction
REACH	Registration, Evaluation, Authorization, and Restriction of Chemicals
REE	Rare Earth Elements
RM	Raman spectroscopy
RNA	Ribonucleic acid

RO	Reverse Osmosis
R-PET	Recycled PET
RTCR	Revised Total Coliform Rule
RWQCB	Regional Water Quality Control Board
SAN	Poly(Styrene Acrylonitrile)
SAPEA	Science Advice for Policy by European Academies
SAR	Santa Ana River
SARS	Severe Acute Respiratory Syndrome
SDWA	Safe Drinking Water Act
SFDPH	San Francisco Department of Public Health
SFPUC	San Francisco Public Utilities Commission
SFRWS	San Francisco Regional Water System
SFWS	San Francisco Water System
SOCs	Semi-volatile Organic Chemicals, Synthetic Organic Compounds
SPE	Solid Phase Extraction
SaV	Sapovirus
Sr	Strontium
SRT	Solid Retention Time
STEC	Shiga toxin-producing E. coli
STX	Shiga toxin
SUTS	Sutro System
SVWTP	Sunol Valley Water Treatment Plant
SWRCB	California State Water Resources Control Board
SWTR	Surface Water Treatment Rule
T.	Toxoplasma
TB	Trip blank
TBAA	Tribromoacetic acid
TBBPA	Tetra-bromobisphenol A

TBD	To Be Determined
TC	Total Coliform
TCAA	Trichloroacetic acid
TCAcAm	Trichloromoacetamide
TCAL	Trichloroacetaldehyde
TCAN	Trichloroacetonitrile
TCE	Trichloroethylene
TCNM	Chloropicrin (trichloronitromethane)
TCP	Trichloropropanone
TCR	Total Coliform Rule
TCEP	Tris(2-carboxyethyl)phosphine
TCPP	Tris(chloropropyl) phosphate
TCIPP	Tris (1-chloro-2-propyl) phosphate
TDCPP	Tri (1,3-dichloropropyl) phosphate
TDCIPP	Tris (1,3-dichloro-2-propyl) phosphate
TDI	Tolerable Daily Intake
TDS	Total Dissolved Solids
TIM	Iodoform (triiodomethane)
TM	Technical Memorandum
TTHM	Total Trihalomethanes (THM4)
T&O	Taste and Odor
TOBr	Total Organic Bromine
TOC	Total Organic Carbon
TOI	Total Organic Iodine
TON	Total Organic Nitrogen
TOX	Total Organic Halide
TSS	Total Suspended Solids
TTF	Tesla Treatment Facility

TXAA	Trihalogenated HAA
TW	Tap water
UC CEIN	University of California's Center for the Environmental Implications of Nanotechnologies
UCMR4	USEPA Unregulated Contaminant Monitoring Rule 4
UCMR5	USEPA Unregulated Contaminant Monitoring Rule 5
UF	Ultrafiltration
UMS	University Mound System
US or U.S.	United States
USEPA	US Environmental Protection Agency
USGS	US Geological Survey
UV	Ultraviolet
V	Vanadium
VBNC	Viable but Non Culturable
VOCs	Volatile Organic Compounds
WDS	Water Distribution System
WERF	Water Environment & Reuse Foundation
WHO	World Health Organization
WQD	SFPUC Water Quality Division
WQRA	Water Quality Research Australia
WRF	Water Research Foundation
WSP	Water Safety Plan
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant
VTEC	Verotoxigenic E. coli

Resources

Summary of CECs Monitored in SFPUC Drinking Water, 2016 – 2021, with Detects

DRAFT Monitoring Plan for CECs, SFRWS and SFWS for 2022 – 2025

Olson G., Wilczak A., Boozarpour M., DeGraca A., Weintraub J., 2017. *Evaluating and Prioritizing Contaminants of Emerging Concern in Drinking Water*, Journal AWWA, 109(12), 54-63

Summary of CECs Monitored in SFPUC Drinking Water, 2016 – 2021 with Detects

Group	Contaminant (s) Monitored and Guideline Values if Available	Number of Samples or Monitoring Events	Number of Detects Above Drinking Water Guidelines or MDL	Comment	Number of Monitoring Locations
Emerging Microbial Waterborne Pathogens	Not monitored in 2016 - 2021				
PFAS (monitored 2019 - 2021)	29 compounds	2 sample rounds	0	All results below MDL (<2 ng/L)	15
DBPs, nitrosamines (monitored 2018- 2021)	6 nitrosamines, NDMA , CA NL 0.01 µg/L	90	21 NDMA detects, but below CA NL	NDMA detected at Alameda E, SVWTP EFFX12, IRV Portal, UMS#1,9, CHS#8,13. All other nitrosamines were below MDL (<2 ng/L)	10
DBPs, other (monitored 2018 - 2021)	Bromochloroacetic Acid, HAA	8	8 detects above MDL Results range from 0.4 - 1.7 µg/L	UMS#01, 02, 03, HPS, SSO#7	5
	Bromodichloroacetic Acid, HAA	6	3 detects above MDL Results range from 0.5 – 0.9 µg/L	Detects above MDL (<0.5 µg/L) : FOREST_K_HPS_1, SUTS#03	4
	Chlorodibromoacetic Acid, HAA	7	3 detects above MDL Results range from 0.3 - 0.7 µg/L	Detects above MDL (<0.3 µg/L): HPS, UMS#01	5
	Tribromoacetic Acid, HAA	5	0	(MDL <2.0 µg/L), UMS#01, 09, Forest_K_HPS_1, MT-Davidson_TK	4
	Chlorate, CA NL 800 µg/L	133	2 detects above CA NL	Chlorate detected above CA NL at SVWTP TWR EFF, detected above MDL (<10 µg/L) at SVWTP TWR EFF, HTWTP Post, Alameda East	11
	Methylene chloride, CA MCL 5 µg/L	27	0	Detected in groundwater above MDL (<0.5 µg/L), but below CA MCL	6
Algal Toxins (monitored 2018 - 2021)	Total Microcystin USEPA HA 0.3 µg/L	163	0	Results below MDL (<0.15 µg/L).	2

Group	Contaminant (s) Monitored and Guideline Values if Available	Number of Samples or Monitoring Events	Number of Detects Above Drinking Water Guidelines or MDL	Comment	Number of Monitoring Locations
Inorganics (monitored 2016 – 2021)	10 contaminants monitored Cr (VI), MCL 10 µg/L (reproposed), PHG 0.02 µg/L	766	0	Cr (VI) is observed in groundwater above proposed MCL of 10 µg/L (n = 462, 50 % = 14 µg/L, 90 % = 25 µg/L, Max = 35 µg/L). *	11
	Manganese, CA NL 500 µg/L	1247 (includes process runs)	0	Mn is observed in groundwater close to CA NL of 500 µg/L (n= 267, 50% = 2 µg/L, 90% = 25 µg/L, Max = 452 µg/L). *	26
Organics monitored for SOC, VOC, Industrial Chemicals, Pesticides (monitored 2016 – 2021)	Quinoline	UCMR4 monitoring (2018 -2019), n= 44, 2019 monitoring, n=42	UCMR4 Monitoring - 11 detects above MDL 2019 Monitoring - 5 detects above MDL.	(MDL<0.02 µg/L), Detected at SSL_Baden, LMPS Sutro Disch, SSO#1 N, SSO#2, MMS#02, UMS#08, SUTS#03, Southfield turnout tap. Caused due to leaching from old coal tar pipe linings.	24
	Fluoranthene	11	1 above MDL	(MDL<0.04 µg/L), Detected at Outlet SSO#2	12
	Carbon Tetrachloride, CA MCL 0.5 µg/L	27	0	Detected only in ground water above CA MCL. * SFPUC is approved for blending by SWRCB. The wells in which it is detected are currently not in operation.	7
	Tetrachloroethylene, CA MCL 5 µg/L	39	0	Detected only in ground water above CA MCL. * SFPUC is approved for blending by SWRCB. The wells in which it is detected are currently not in operation.	7
Pharmaceuticals/EDC (monitored 2020 – 2021)	Propylparaben	3	1 Detect at 14 ng/L, above MDL	(MDL <5 ng/L), Detected in Alameda East. Also detected in groundwater. *	3
	Iohexal	3	0	(MDL <10 ng/L), Detected in groundwater. *	3
	Sucralose	3	0	(MDL <100 ng/L), Detected in groundwater. *	3
	1,7-Dimethylxanthine	3	0	(MDL <5 ng/L), Detected in groundwater. *	3
	N,N-Diethyl-meta-toluamide (DEET)	3	0	(MDL <10 ng/L), Detected in groundwater. *	3
	Sulfamethoxazole	3	0	(MDL <5 ng/L), Detected in groundwater. *	3
	Thiabendazole	3	0	(MDL <5 ng/L), Detected in groundwater. *	3
Microplastics and Nano-plastics	Not monitored in 2016 - 2021				
Engineered Nanomaterials and Nanoparticles	Not monitored in 2016 - 2021				

* Groundwater is not served directly before blending/treatment.

Notes:

CHS-College Hill System

Forest_K_HPS – Forest Knoll

HPS – Hunters Point System

HTWTP Post – Harry Tracy Plant treated water

LMPS_SUTRO_DISCH – Lake Merced Pump Station Sutro Discharge

MMS – Merced Manor System

MT_DAVIDOSN_TK – Mount Davidson Tank

SSL_BADEN – Sunset Line Baden

SSO – Sunset Reservoir Outlet

SUTS: Sutro System

SVWTP_EFF_X12 – Sunol Plant Treated Water – San Anton Pump

SVWTP+TWR_EFF – Sunol Plant Treated Water

UMS – University Mound System

Draft Monitoring Plan for CECs, San Francisco Regional Water System and San Francisco Water System for 2022 -2025

CEC Group **[Priority]**	**Monitoring Recommendations[a], Contaminant (MRL)**	**Locations***	**Frequency**
Microbial Waterborne Pathogens **[High]**	TBD	TBD CCL5 is in a draft stage and there is a possibility of changes.	TBD
PFAS **[Medium]**	**Monitor for the UCMR5 compounds (29 PFAS compounds). List Attached. See notes [f]**	UCMR5 locations – see notes[b]	UCMR5 frequency –see notes[c] Repeat groundwater monitoring for PFAS in six years
DBPs - Nitrosamines **[Medium]**	**Continue semi-annual nitrosamines monitoring.** **Collect total chlorine, free ammonia, pH, nitrite, temperature and conductivity along with nitrosamine samples. See note (e).** Nitrosamines (1 thru 6 listed in Draft CCL5): *1)* *N*-Nitrosodimethylamine, NDMA (2 ng/L) *2)* *N*-Nitrosodiethylamine, NDEA (2 ng/L) *3)* *N*-Nitrosodi-n-butylamine, NDBA (2 ng/L) *4)* *N*-Nitrosodi-n-propylamine, NDPA (2 ng/L) *5)* *N*-Nitrosopyrrolidine, NPYR (2 ng/L) *6)* N-Nitrosodiphenylamine NDPhA *7)* *N*-Nitrosomethylethylamine, NMEA (2 ng/L) *8)* N-nitrosomorpholine, NMOR	Plant Effluents: SVWTP EFFX12, HTWTP Eff Post Distribution System: Alameda E, Irvington Portal 1 & 2, CS#2 Baden, UMS#1, UMS#2, College Hill #8, College Hill #13. Consider adding locations after boosting and nitrification	Semi-annual monitoring. Listed in Draft CCL5.

CEC Group [Priority]	**Monitoring Recommendations[(a)], Contaminant (MRL)**	**Locations***	**Frequency**
DBPs Other than nitrosamines **[Medium]**	Chlorate (20 µg/L)	AE, SVWTP Effluent, and HTWTP Effluent	Monthly and Annual (with Title 22 monitoring). Also listed in Draft CCL5. Continue with current frequency
	UV254	Surface water, groundwater	
	Total Organic Carbon (TOC)		
	HAA9	HAA9 – part of routine analysis	
	Bromide (Br^-)	Br^- at surface water and other water sources under development and consideration. Br- monitored at SVWTP and HTWTP effluents.	Br^- monitored annually Title 22 Br^- SVWTP raw – weekly
	Iodide (I^-)	I^-at surface water and other water sources under development and consideration.	
	Total Organic Nitrogen (TON)	TON at surface water and other water sources under development and consideration.	
	Total Organic Halides (TOX)	Plant Effluents, Distribution System	TOX - Same as DBP compliance
	HANs, HALs, HAMs, HNMs	Plant Effluents, Distribution System	HAN5 – monitoring in 4 seasons. HAL, HAM, HNMs. Conduct targeted monitoring after events of interest, including wildfires, and algal blooms.
	Listed in Draft CCL5: Haloacetonitriles Haloacetic acids Halonitromethanes Iodinated trihalomethanes Formaldehyde	TBD. Listed in draft CCL5.	TBD

CEC Group [Priority]	**Monitoring Recommendations[(a)], Contaminant (MRL)**	**Locations***	**Frequency**
Algal Toxins **[Medium]**	**OEHHA Notification Level Recommendation (May 2021)** **OEHHA's Interim Recommended NLs** Total Microcystin (interim 0.03 µg/L) Saxitoxin (interim 0.6 µg/L) Anatoxin-a (4.0 µg/L) Cylindrospermopsin (interim 0.3 µg/L) Temperature[(d)] pH[(d)]	Reservoirs, and influent and effluent of treatment plants. Also, part of CCL5.	Continue with current frequency: Total MC – biweekly in listed locations (San Andreas, HTWTP Raw, HTWTP Eff, Calaveras, San Antonio, SVWTP RAW, SVWTP Eff). Total MC at LCS - Monthly Monitor for toxins listed in CCL5 at LCS Reservoir, San Andreas Reservoir, Calaveras Reservoir, SVWTP Raw, SVWTP EFF, HTWTP Raw, HTWTP EFF Post – Quarterly.
Inorganics **[Medium]**	**Continue monitoring following metals.** Consider additional monitoring at lower DLR for metals consistent with SWRCB plans to reduce DLR limits. See note[(e)]		
	Strontium (0.3 µg/L)	Surface water, groundwater, and treated drinking water	Strontium - annually with ongoing frequency (part of 2016 Title 22 monitoring).
	Germanium (0.3 µg/L)	TBD (completed as part of UCMR4)	Germanium – TBD
	Manganese (0.4 µg/L)	Reservoirs, groundwater, distribution system, Treatment plants. Mn is also listed in CCL5	Annually- Title 22 requirement. SVWTP Raw- biweekly
	Chromium (VI)	Groundwater monitoring, reservoirs receiving blended groundwater	Follow current frequency
	Monitor for the following UCMR5 metal: **Lithium**	Groundwater, UCMR5 locations – see notes[(b)] Also listed in Draft CCL5.	UCMR5 frequency –see notes[(c)]

CEC Group **[Priority]**	**Monitoring Recommendations$^{(a)}$,** **Contaminant (MRL)**	**Locations***	**Frequency**
Organics **[Medium]**	**Monitor for VOCs and SOCs per EPA Methods 524 and 525, respectively, and other contaminants when warranted. See note (e).** For as-needed sampling, see SFPUC Manual of Procedures, Disinfection/Dechlorination and Related Tasks (2011).	As needed to confirm new or significant construction practices	As needed to confirm new or significant construction practices
	Pesticides, SOC and VOC	Surface Water, Groundwater, and Drinking Water	Routine T22 monitoring.
	Pesticides listed in Draft CCL5: Chlorpyrifos (0.03 µg/L) Ethoprop (0.03 µg/L) Oxyfluorfen (0.05 µg/L) Profenofos (0.3 µg/L) Tebuconazole (0.2 µg/L) Tribufos (0.07 µg/L)	TBD – Pesticides listed in Draft CCL5.	Draft CCL5 – TBD
	Industrial Chemicals	Listed in Draft CCL5 -TBD	Draft CCL5 - TBD
Pharmaceuticals & Personal Care Products (PPCPs), EDC Hormones **[Low]**	**Monitor every 6 years if not covered by national/state surveys**	Source Waters and Treated Waters Any new considered water source should be monitored for CEC	Every 6 years
Microplastics **[Low]**	**New emerging contaminant**	Drinking Water	Evaluation of participation by SFPUC WQD in a SWRCB pilot to monitor microplastics in our system. Summer 2022 - State Board will issue monitoring orders for Phase 1 monitoring. In Phase 1 selected utilities will have to monitor for microplastics occurring in drinking water that are larger than 20 um length
Nanomaterials **[Low]**	**Benchmark through national and state surveys, when appropriate.**	TBD	TBD

__Notes__

*Detailed location can be found in the report, where applicable.

"Low" priority CEC groups do not require monitoring per SFPUC CEC approach, but monitoring may be indicated in above table if required by UCMR5.

(a) In addition to above monitoring plan, participate in national and state CEC surveys and conduct special monitoring for any breaking CEC issue (new research study findings, etc.), when appropriate.
(b) UCMR5 locations: TBD - Entry points to the Distribution System (EPTDS).
(c) UCMR5 frequency: TBD - Quarterly for one year.
(d) Temperature and pH are indicator parameters and must be measured at the same time as cyanotoxin sample collection.
(e) Evaluate if DLRs are sufficient to satisfy future MCL regulations for NDMA.
(f) UCMR5 PFAS lists:

11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	Perfluoro-4-methoxybutanoic acid (PFMBA)	Perfluorooctanesulfonic acid (PFOS)	1H, 1H, 2H, 2H-perfluorodecane sulfonic acid (8:2 FTS)
Perfluorobutanesulfonic acid (PFBS)	Perfluorooctanoic acid (PFOA)	1H, 1H, 2H, 2H-perfluorohexane sulfonic acid (4:2 FTS)	Perfluorobutanoic acid (PFBA)
Perfluoropentanesulfonic acid (PFPeS)	1H, 1H, 2H, 2H-perfluorooctane sulfonic acid (6:2 FTS)	Perfluorodecanoic acid (PFDA)	Perfluoropentanoic acid (PFPeA)
4,8-dioxa-3H-perfluorononanoic acid (ADONA)	Perfluorododecanoic acid (PFDoA)	Perfluoroundecanoic acid (PFUnA)	9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid (9Cl-PF3ONS)
Perfluoroheptanesulfonic acid (PFHpS)	n-ethyl perfluorooctanesulfonamidoacetic acid (NEtFOSAA)	hexafluoropropylene oxide dimer acid (HFPO-DA) (GenX)	Perfluoroheptanoic acid (PFHpA)
n-methyl perfluorooctanesulfonamidoacetic acid (NMeFOSAA)	nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	Perfluorohexanesulfonic acid (PFHxS)	Perfluorotetradecanoic acid (PFTA)
Perfluoro (2-ethoxyethane) sulfonic acid (PFEESA)	Perfluorohexanoic acid (PFHxA)	Perfluorohexanoic acid (PFHxA)	Perfluorotridecanoic acid (PFTrDA)
Perfluoro-3-methoxypropanoic acid (PFMPA)	Perfluorononanoic acid (PFNA)		

CCL5 = Contaminant Candidate List

CEC = contaminants of emerging concern

DBPs = disinfection by-products

MRL = Minimum Reporting Level

NA = not applicable

SFRWS = San Francisco Regional Water System

SFWS = San Francisco Water System

TBD = To Be Determined

TC = Total Coliform

UCMR5 = Proposed Unregulated Contaminant Monitoring Rule 5

WRF = Water Research Foundation

Feature Article

Photo credit: O' Shaughnessy Dam at Hetch Hetchy Reservoir in Yosemite National Park, Gary Saxe/Shutterstock.com

GREGG OLSON, ANDRZEJ WILCZAK, MANOUCHEHR BOOZARPOUR,
ANDREW DeGRACA, AND JUNE M. WEINTRAUB

Evaluating and Prioritizing Contaminants of Emerging Concern in Drinking Water

THE SAN FRANCISCO PUBLIC UTILITIES COMMISSION'S WATER QUALITY DIVISION USES A SYSTEMATIC, DATA-RICH SCREENING PROCESS TO MONITOR UNREGULATED CONTAMINANTS OF EMERGING CONCERN IN ITS DRINKING WATER SYSTEM.

An approach was developed for evaluating and prioritizing contaminants of emerging concern (CECs) in drinking water to determine the need, if any, for further action such as water quality monitoring. In addition to setting priorities, the approach provides a mechanism for documenting CEC information and engaging the public and stakeholders on CEC issues. This approach has been used by the San Francisco Public Utilities Commission (SFPUC) Water Quality Division in California since 2011 and is currently part of a triennial review, conducted in parallel with California Public Health Goals (PHGs) Reports (SFPUC 2016).

BACKGROUND ON EMERGING CONTAMINANTS

CECs comprise a large group of compounds with limited health, occurrence, and treatment information. Because of advances in analytical technology, CECs that were previously nondetectable in the range of parts per million to parts per billion (milligrams per liter to micrograms per liter) can now be detected at trace levels in the parts-per-trillion (nanograms-per-liter) range. CECs are an important consideration for drinking water utilities in their aim to (1) provide safe drinking water; (2) maintain public confidence in the water supply; and (3) prepare for future regulations with potentially additional monitoring, treatment optimization, and/or other mitigation measures. As demonstrated by the Associated Press articles in 2008 on trace detections of pharmaceuticals in US drinking water supplies (Donn et al. 2008), public concerns can develop rapidly when trace CEC detections are reported. It is likely that public concerns over CECs will increase with future advances in analytical technology, so utilities need a platform for systematic CEC evaluations and public engagement.

FIGURE 1 Regulated contaminants versus CECs

Regulations = organized

- Small number (≈100 limits)
- Targets (MCLs)
- Treatment techniques
- Monitoring requirements
- Reporting requirements
- Communication requirements

CECs = unorganized

- Large number (≈100,000 registered chemicals, plus microbials)
- Analytical, occurrence, health, and treatment research ongoing
- Unknown health effects
- Few and unclear targets
- Few monitoring and communication recommendations

CECs—contaminants of emerging concern, MCL—maximum contaminant level

As summarized in Figure 1, there are significant differences between regulated contaminants and CECs. The number of regulated contaminants is large but manageable. In the United States, there are fewer than 100 contaminants regulated by maximum contaminant levels (MCLs) (USEPA 2009). Federal and state drinking water regulations establish clear direction with respect to health targets, monitoring frequency, and communication approaches.

CECs, on the other hand, number in excess of 100,000 chemicals (Muir & Howard 2006), making their management and understanding very challenging on a contaminant-by-contaminant basis. Without regulations or guidance, there is a lack of direction on health targets, monitoring frequency, and communication approaches. A systematic approach to address CECs can help fill these voids by providing a means to identify, organize, and prioritize CECs as well as a basis for communicating with the public. While regulatory programs for well-known contaminants are quantitative (i.e., set-specific numeric limits for specific parameters), CECs may need to be qualitatively grouped or rely on additional indicators.

BACKGROUND ON SAN FRANCISCO'S WATER SYSTEM

SFPUC provides water to 2.7 million people. This includes retail customers within the city of San Francisco and wholesale customers in the San Francisco Bay Area (27 water systems). Approximately 85% of SFPUC's drinking water supply comes from Hetch Hetchy Reservoir in Yosemite National Park in Northern California (see the photograph on page 56). This reservoir, fed mainly by snowmelt in a pristine watershed, is actively protected by the National Park Service and meets the US Environmental Protection Agency's (USEPA's) filtration avoidance requirements under the Surface Water Treatment Rule. The Hetch Hetchy supply receives pH adjustment, fluoridation, ultraviolet irradiation, free chlorination, and chloramination for a secondary disinfectant.

The remaining 15% of SFPUC's water supply is drawn from two protected watersheds in the Bay Area. These watersheds have some minor agricultural and recreational uses (cattle grazing and a golf course) but are generally not impacted by wastewater, industrial discharges, or urban runoff. The Alameda watershed source water is treated by a conventional filtration plant, chlorination, and chloramination. The Peninsula watershed source water is treated by ozonation, direct filtration, chlorination, and chloramination.

NEED FOR CEC APPROACH

In 2006, SFPUC participated in the AWWA Research Foundation (AwwaRF) project, *Toxicological Relevance of EDCs and Pharmaceuticals in Drinking Water*, which involved the monitoring of 62 compounds in source and treated waters of 19 utilities in the United States (Snyder et al. 2008). The study found trace concentrations of a wide range of pharmaceuticals and personal care products (PPCPs) and endocrine disrupting compounds (EDCs) in source waters throughout the country. Although levels were far below those anticipated to cause health issues in humans, detection of these contaminants in the nation's drinking water sources generated national news articles and raised public awareness of CECs (Donn et al. 2008). It also highlighted a need for utilities to get organized in addressing CECs.

In 2008, following the news articles on CECs in drinking water, San Francisco's then-mayor Gavin Newsom directed SFPUC to develop a San Francisco Water Quality Protection Plan. An action item from the plan was to "clarify and revise the monitoring framework for emerging contaminants" (SFPUC 2008).

CEC EFFORTS IN THE UNITED STATES

Activities by the regulators. As the federal authority for US drinking

Hetch Hetchy Reservoir supplies the majority of San Francisco Public Utilities Commission's drinking water. *Photo courtesy of Gregg Olson*

water regulations, the USEPA conducts significant activities to understand CECs. USEPA's Contaminant Candidate List (CCL) establishes a list of parameters that may warrant future regulation. In October 2009, the third CCL (CCL 3) involved an initial screening of approximately 7,500 contaminants, narrowing them down to a final list of 116 contaminants, which included 104 chemicals and 12 microbial contaminants (USEPA 2012a). CCL 4 was finalized by USEPA in November 2016 and includes 97 chemicals or chemical groups and 12 microbial contaminants (USEPA 2016a). USEPA also implements the Unregulated Contaminant Monitoring Rule (UCMR), which requires utilities to monitor 30 CECs every five years (USEPA 2012b). UCMR 4 monitoring will be conducted from 2018 to 2020 and includes algal toxins, pesticides, disinfection byproducts, and two metals (USEPA 2016b).

At the state level, California's Office of Environmental Health Hazard Assessment develops PHGs as a first step before MCLs are developed by the State Water Resources Control Board (SWRCB). PHGs are entirely health based, without including economic and technical (treatment or analytical) feasibility (OEHHA 2014). Though most contaminants with PHGs have MCLs, some contaminants with PHGs are still unregulated (e.g., *N*-nitrosodimethylamine [NDMA]). SWRCB also has California notification levels for 30 unregulated parameters (SWRCB 2015). When these levels are exceeded, SWRCB recommends that utilities notify consumers. Finally, SWRCB has adopted CEC monitoring requirements for projects that recharge aquifers with recycled water (SWRCB 2013). These monitoring requirements include chemicals found in recycled water, such as caffeine, triclosan, DEET, and some pharmaceuticals (e.g., gemfibrozil, iopromide).

Research organizations and drinking water utilities. In 2004, Parkin et al. published an AwwaRF report titled *Risk Communication for Emerging Contaminants*, which provides tools for communicating about CECs (Parkin et al. 2004). One tool used a list of diagnostic questions to determine when to communicate on CECs by defining strategic versus nonstrategic concerns. SFPUC adopted this concept for its CEC approach and used diagnostic questions to organize the broad universe of CEC information, prioritize CECs, and communicate CEC priorities.

In 2012, Daniel and Bywater published a Water Research Foundation (WRF) online tool called the Water Utility Tool for Responding to Emerging Contaminant Issues (AwwaRF changed its name to the Water Research Foundation in 2009). This tool provides worksheets for evaluating an emerging contaminant. It also provides PPCP and EDC references (Daniel & Bywater 2012). Chowdhury and Sinha described a computer model that uses flow data, water quality data, and wastewater and drinking water treatment assumptions (Chowdhury & Sinha 2013); this model determines the most cost-effective measures for reducing PPCPs and EDCs in drinking water.

Spiesman and Speight presented an approach to prioritize all types of contaminants including regulated, aesthetic, and CECs (Spiesman & Speight 2014). The authors applied the approach to the Washington aqueduct in Washington, D.C., and were able to narrow a list of over 700 compounds to a list of 12 priority contaminants.

CEC APPROACH FOR SAN FRANCISCO'S DRINKING WATER SYSTEM

In 2011, the SFPUC Water Quality Division developed an approach for evaluating and prioritizing unregulated CECs. As detailed in Figure 2, the approach organizes CECs into groups (currently 12) that are then screened using a detailed evaluation form. The screening evaluations for each CEC group are then reviewed by experts and stakeholders. Priorities are established and, if warranted, special CEC efforts are initiated.

In California, utilities prepare PHG reports every three years and present the reports at public hearings. For SFPUC, CEC updates have been attached to the PHG public process for efficiency and to establish a systematic schedule for updates. SFPUC also updates CEC screening evaluations and priorities as needed, following new, significant information derived from monitoring data, scientific literature, or regulatory developments.

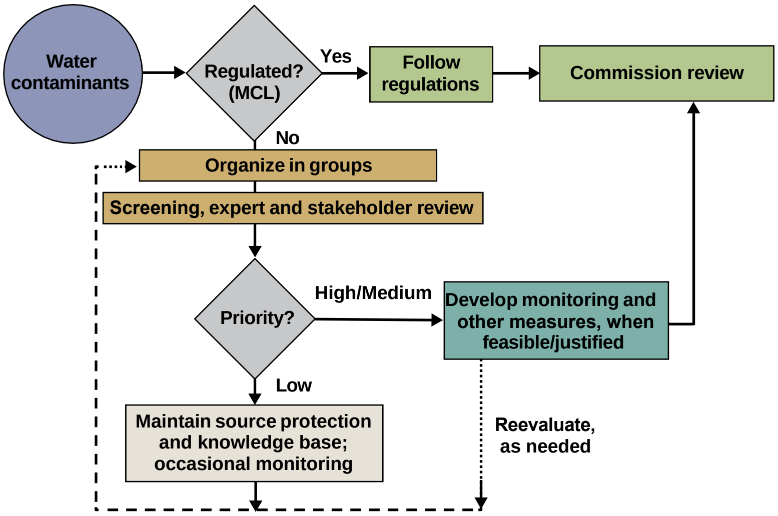
Grouping. If a contaminant is not regulated, it will fall into a group of CECs with similar properties and/or common routes of entry into the water system. SFPUC's current CEC groups are summarized in Table 1. The CEC groupings SFPUC uses are further defined by three categories on the basis of how the CECs enter the water cycle: (1) naturally, (2) through the water treatment process, or (3) by human-induced contamination. This categorization is related to the potential sources of the contaminants and helps identify mitigation activities.

Screening evaluations. Each CEC group is screened to determine its significance to SFPUC using a screening evaluation form. The first section of the screening evaluation includes general information, such as a CEC description, grouping rationale, indicator parameters, applicable health advisories, and the regulatory development status of the group. If indicators are not detected or are found at very low levels, it is likely that other parameters in the group would also not be detected or found at very low levels. For example, if the most commonly applied pesticides for a particular watershed are not detected, it is likely that other pesticides with no or very limited use within the watershed would also not be found.

The second section of the screening evaluation covers the context of the review (i.e., SFPUC's experience with the CEC group). This section summarizes any customer concerns, occurrence data for SFPUC's water sources, and an identification of key literature that SFPUC has reviewed on the group.

The third section of the screening evaluation includes diagnostic questions on health, occurrence, and treatment. This section tries to demonstrate whether the group is significant to public health in general, if the group is anticipated to occur in SFPUC's source water or distribution system water, and if SFPUC's existing treatment systems will remove the contaminants.

FIGURE 2 Flowchart of SFPUC CEC approach for the drinking water system



CEC—contaminant of emerging concern, MCL—maximum contaminant level, SFPUC—San Francisco Public Utilities Commission

TABLE 1 Current CEC groups for SFPUC drinking water system

General Categories	CEC Group (*n* = 12)
Naturally occurring contaminants	Microbial waterborne pathogens Algal toxins Inorganics Hormones
Treatment/distribution byproducts	DBPs (nitrosamines) DBPs (other than nitrosamines) Leachate from materials (e.g., liners, gaskets)
Human-induced contaminants	Halogenated flame retardants Industrial and commercial chemicals Nanomaterials Pesticides Pharmaceuticals and personal care products

CEC—contaminant of emerging concern, DBP—disinfection byproduct, SFPUC—San Francisco Public Utilities Commission

The appendix to this article provides an abbreviated version of the screening evaluation for algal toxins, which serves as an example of an analysis conducted for one group of CECs. All of the questions are included, but the responses have been abbreviated as presented here. Standardized questions are asked, followed by yes/no responses and a short narrative that explains the yes/no response by pointing at key literature and guidelines.

With algal toxins, as shown in the appendix, the evaluation summarizes the USEPA health advisories, issued in June 2015, for total microcystins and cylindropermopsin (USEPA 2015) and discusses the placement of

TABLE 2 CEC priorities for 2013–2022, SFPUC drinking water system

Priority	CEC Group, 2013-2016	CEC Group, 2016-2022
High	Microbial waterborne pathogens DBPs (nitrosamines) Inorganics (CrVI only)	Microbial waterborne pathogens
Medium	Algal toxins DBPs (other than nitrosamines)	Algal toxins DBPs (nitrosamines) DBPs (other than nitrosamines)
Low	Inorganics (other than CrVI) Halogenated flame retardants Industrial and commercial chemicals Leachate from materials (e.g., liners, gaskets) Nanomaterials Naturally occurring hormones Pesticides PPCPs	Inorganics Halogenated flame retardants Industrial and commercial chemicals Leachate from materials (e.g., liners, gaskets) Nanomaterials Naturally occurring hormones Pesticides PPCPs

CEC—contaminant of emerging concern, CrVI—hexavalent chromium, DBP—disinfection byproduct, PPCPs—pharmaceuticals and personal care products, SFPUC—San Francisco Public Utilities Commission

algal toxins (cyanotoxins) on the CCL 4 as a group (USEPA 2016a). The evaluation summarizes the latest algal toxin monitoring results in SFPUC reservoirs and assesses the treatment effectiveness for algal toxins. Specifically, the evaluation notes that filtration at SFPUC's water filtration plants would contribute to the removal of intracellular toxins and that free chlorination would oxidize approximately 80% of extracellular toxins. The unfiltered Hetch Hetchy water treatment system will not remove algae; however, algal toxins are unlikely to occur in concentrations of health significance in the oligotrophic Hetch Hetchy Reservoir.

Finally, the assessment for algal toxins concludes that, on the basis of monitoring in 2007, 2010, and 2015/2016, the vulnerability of SFPUC water supplies to algal toxins is low to medium. A medium priority was ultimately assigned to algal toxins by SFPUC because, though rare, adverse health impacts from algal toxins in drinking water associated with severe algal blooms have been reported by other water systems, and it is also recognized that algae levels and algal toxin concentrations could change over time as a result of climate change or other environmental factors.

Expert and stakeholder review: priorities and follow-up actions. The next step in assessing CECs (Figure 2) involves expert and stakeholder reviews of the screening evaluations and the development of priorities based on these evaluations. For high and medium priorities, the team develops monitoring and/or mitigation measures if feasible and justified. For low priorities, the CEC group will not warrant active monitoring; however, SFPUC will continue its source protection efforts and track new information on the group.

Expert reviews were conducted in 2011, 2013, and 2016 by the SFPUC Water Quality Division and San Francisco Department of Public Health. In 2013 and 2016, external reviews were conducted by Kennedy/Jenks Consultants. Stakeholders include wholesale customers (San Francisco Wholesale Customers Water Quality Committee) and the SFPUC Citizens Advisory Committee, which includes representatives from nongovernmental organizations such as Clean Water Action.

SFPUC CEC priorities for 2013–2022. SFPUC's CEC priorities for 2013 to 2022 are summarized in Table 2. In 2013, the high priorities were microbial waterborne pathogens, nitrosamines, and hexavalent chromium (CrVI). Since the only inorganic concern was CrVI, the inorganics group was separated into two groups: inorganics (CrVI only) and inorganics (other than CrVI).

The microbial waterborne pathogens group was ranked a high priority because of the inherent risk associated with any microbial pathogens. Before its regulation by the Enhanced Surface Water Treatment Rule, *Cryptosporidium* would have been considered a microbial CEC. *Legionella* and enteroviruses and noroviruses (addressed by UCMR 3) are examples of current microbial CECs. Nitrosamines were a high priority because of the occurrence of nitrosamines in SFPUC's finished water (detections typically between 2 and 5 ng/L), California notification levels of 10 ng/L for three nitrosamines (NDMA, *N*-nitrosodiethylamine, and 2-nitrodiphenylamine), and the likelihood of future regulations. CrVI was a high priority because of a proposed California regulation and the presence of CrVI in groundwater (a new water source for SFPUC) that required blending considerations by SFPUC.

In 2016, SFPUC identified one CEC group as a high priority—i.e., microbial waterborne pathogens. The nitrosamines group was reduced from a high priority to a medium priority on the basis of 2013–2016 monitoring data demonstrating optimized treatment with respect to nitrosamines. CrVI was removed from the CEC program because California adopted an MCL for CrVI in 2014 (although the CrVI MCL was invalidated on May 31, 2017).

In addition to nitrosamines, the 2016 CEC review identified algal toxins and disinfection byproducts other than nitrosamines (e.g., chlorate) as medium priorities. The other groups are low priorities for SFPUC, mainly because of its watershed protection program.

CONCLUSIONS

The development of an approach to better understand CECs led to the organization of a large amount of information. The documentation of health, occurrence, and treatment information (available from AWWA, WRF, and other sources), as well as utility-specific rationales for CEC priorities, provided a platform to address questions internally at the utility and externally with customers and stakeholders, such as the SFPUC Citizens Advisory Committee. Teaming up with the San Francisco Department of Public Health brought the perspectives of health professionals to the original assessments conducted by engineers. Because of ongoing developments in our understanding of CECs, this approach is a living document that needs consistent updates and revisions as new information becomes available. Establishing a three-year review cycle with the option to revise as needed is the schedule SFPUC incorporated to ensure all CEC information is up-to-date and ready to be used if needed.

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Appendix

Screening evaluation for the prioritization of contaminants of emerging concern (CECs) in San Francisco Public Utilities Commission (SFPUC) drinking water

General Information on CEC	
CEC name	Algal toxins
CEC description	Algal toxins, or cyanotoxins, are a diverse group of chemical substances produced from cyanobacteria, also called blue–green algae. Blue–green algae are photosynthetic bacteria that grow in both fresh and marine water and have been linked to human and animal illness around the world. There are many strains of blue–green algae. Types of cyanotoxins produced by blue–green algae include neurotoxins (affecting the nervous system), hepatotoxins (affecting the liver), and others (CDC 2010, USEPA 2015a).
CEC grouping	Algal toxins are a group. The basis for the grouping is common source (blue–green algae) and compound co-occurrence.
Examples and indicators	Examples of algal toxins include microcystins and cylindrospermopsin, which are hepatotoxins (i.e., liver toxins), and anatoxin-a and saxitoxin, which are neurotoxins. Microcystins and anatoxin-a are the most commonly detected algal toxins in California source waters (SWRCB 2008).
Health advisories Does CEC have a US Environmental Protection Agency health advisory (e.g., drinking water equivalent level [DWEL]) or California notification level?	Yes. The USEPA has issued 10-day drinking water health advisories for microcystins and cylindrospermopsin (USEPA 2015b). The health advisory for total microcystins is 0.3 μg/L for those younger than six years old and 1.6 μg/L for all others. The health advisory for cylindrospermopsin is 0.7 μg/L for those younger than six years old and 3.0 μg/L for all others. The USEPA published a health effects support document for anatoxin-a, but concluded there was not adequate information available to support a health advisory for this toxin.
Regulatory Development Status Is CEC on USEPA Candidate Contaminant List (CCL), Unregulated Contaminant Monitoring Rule (UCMR) list, or California Public Health Goal (PHG) list?	Yes. Algal toxins (cyanotoxins), as a group, are on the Candidate Contaminant List 4 (CCL 4). CCL 4 algal toxins include, but are not limited to, anatoxin-a, cylindrospermopsin, microcystins, and saxitoxin. USEPA has included 10 algal toxins on the Unregulated Contaminant Monitoring Rule 4 (UCMR 4) list, including total microcystins, microcystin variants (LA, LF, LR, LY, RR, YR), nodularin, anatoxin-a, and cylindrospermopsin. In 2016, Ohio EPA adopted a regulation for algal toxins (Ohio EPA 2016).

Context of CEC Investigation at SFPUC	
Customer interaction Widespread public concerns? Media coverage?	There have not been widespread public concerns or media coverage about algal toxins in the SFPUC drinking water system; however, there have been emergency shutdowns of drinking water supplies in other parts of the country, such as Toledo, Ohio, in August 2014 (USEPA 2015c). In the San Francisco Bay Area, during the summer of 2015, East Bay Regional Park District closed six recreational lakes due to elevated algal toxins (microcystins).
Occurrence data Are reliable analytical methods available? What occurrence information is available? Have detections, if any, been confirmed by follow-up sampling and/or QA/QC review? List laboratory information management system (LIMS) occurrence data.	Preliminary algal toxin sampling was conducted at major SFRWS source water reservoirs and treatment plants in 2007 and 2010. Most measurements in raw waters were low or nondetect, far below international health advisories. SFPUC did not detect toxins in finished drinking waters. From 2010 to 2015, phytoplankton levels (mainly blue–green algae) at Calaveras Reservoir increased approximately tenfold. This increase in phytoplankton levels could be related to drought and warmer temperatures and/or due to an ongoing dam improvement project at Calaveras Reservoir requiring low water levels. Since 2015, algal toxin monitoring at Calaveras Reservoir has included four toxins, including microcystins, cylindrospermopsin, anatoxin-a, and saxitoxin. Monitoring is conducted every two weeks in coordination with routine limnology profiles. SVWTP influent and effluent are monitored when the plant is online. Analyses are conducted with ELISA test kits with occasional split samples sent to a laboratory for LC/MS/MS analyses. During fall 2015, total microcystins were measured up to 6.9 μg/L in Calaveras Reservoir surface samples. Cylindrospermopsin and anatoxin-a have not been detected and saxitoxin has either not been detected or detected near the detection level. Toxins have not been detected in SVWTP effluent samples (Olson et al. 2016).
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Diagnostic Questions to Support CEC Prioritization

Health

Question	Answer	Explanation and Comments
Is scientific knowledge on CEC health effects well developed?	Yes	Types of cyanotoxins produced by blue–green algae include neurotoxins (affecting the nervous system), hepatotoxins (affecting the liver), and others (CDC 2010). Health effects range from mild skin rash to serious illness or death (USEPA 2012). Young children are more susceptible because they consume more water relative to their body weight (USEPA 2015b).
Based on current scientific understanding, does the CEC pose greater than a de minimis risk (i.e., insignificant risk) at the levels typically found in drinking water in the US?	Yes	Although the most common exposures to algal toxins occur during recreational activities in contaminated waters (USEPA 2012), the risk associated with drinking water is not negligible.
Adverse health impacts observed in other DW systems? Are public health studies documenting human health impacts (disease or outbreaks) available?	Yes	Relatively few incidents of adverse health impacts to humans from drinking water have been reported (Health Canada 2008, USEPA 2015a). Young children exhibit greater sensitivity; during one disease outbreak associated with cylindrospermopsin in drinking water, 93% of the 148 reported cases were children (USEPA 2015a).
Existing regulations or guidelines outside of US (e.g., WHO, EU)?	Yes	WHO developed a provisional, health-based guideline of 1 µg/L (based on lifetime of daily exposure) for microcystin-LR in drinking water (2003) and has plans to consider cylindrospermopsin in future guideline revisions. Several countries have set national standards or guidelines for microcystin in drinking water based on the WHO guideline, including Australia, Brazil, Canada, the Czech Republic, France, Poland, and Spain (USGS 2008).
Existing US health advisories or California notification levels?	Yes	In June 2015, USEPA issued 10-day health advisories for total microcystins and cylindrospermopsin of 0.3 µg/L and 0.7 µg/L, respectively.
Likely US regulation in the next 10 years? Is CEC on a regulatory development list, such as CCL? Is there a pending regulation or PHG?	No	Algal toxins, as a group, are on the CCL 4. The USEPA has included 10 algal toxins in the UCMR 4 (listed above).
SUMMARY: Significant to public health in general? *(Based on above answers)*	Yes	Algal toxins may occur in drinking water at significant concentrations during episodes of algal blooms. Algal toxins, as a group, are on the CCL 4 and 10 have been placed on UCMR 4. Though rare, adverse health impacts to humans from drinking water have been reported.
Occurrence		
Is scientific knowledge on CEC sources/formation well developed?	Yes	The source of algal toxins is understood to be blue–green algal blooms that most often occur in late summer or early fall in warm, slow-moving water that is rich in nutrients and organic matter (Paerl & Otten 2013). Watersheds with strong agricultural influences are the most impacted (Beaver et al. 2014). Microcystins and anatoxin-a are the most commonly detected algal toxins in California source waters (SWRCB 2008).

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CEC presence reported in other water supplies? Are occurrence studies available?	Yes	A study of 33 US water supplies indicated microcystin-LR levels were below the WHO guideline of 1 µg/L in treated waters (AWWA 2007). A recent study of microcystins in Egypt reported levels in finished drinking water from 1.1 to 3.6 µg/L (Mohamed 2015).
CEC present in SFPUC watersheds and/or source waters? *(Including surface waters, i.e., Hetch Hetchy and local watersheds, and groundwaters)* Are there complex issues involved in managing the CEC in the watersheds (e.g., point versus nonpoint sources)?	Yes	During fall 2015, a 10-week algal bloom resulted in measurement of total microcystins concentrations up to 6.9 µg/L in Calaveras Reservoir surface samples. Cylindrospermopsin and anatoxin-a have not been detected and saxitoxin has either not been detected or detected near the detection level of 0.02 µg/L, far below international health advisories.
Is the CEC a potential groundwater contaminant?	No	Algal toxins are expected only in surface waters where algal blooms can occur (requires sunlight).
If the CEC is a potential groundwater contaminant, is it highly mobile in the subsurface? (i.e., is the CEC generally low-sorbing and resistant to microbial degradation?)	NA	
Precursor present in SFPUC source waters? *(Including surface waters and groundwaters)*	Yes	Low levels of nutrients (derived from plants and animals), as well as low levels of blue–green algae, are naturally present in watersheds. Nutrients are precursors to algal blooms.
Formed or added during current SFPUC treatment? If so, describe whether the formation or addition of CEC during treatment can be controlled.	Possible	Algal toxins are not produced during treatment; however, cells can be broken (lysed) by prechlorination, increasing the dissolved toxin fraction. Strategy is to discontinue prechlorination during significant cyanotoxin blooms. In addition, WTP recycle may need to be monitored to ensure toxins do not re-enter treatment process.
Formed or added within SFPUC storage or distribution? If so, describe whether the formation or addition of CEC during storage or distribution can be controlled.	No	Algal toxins are not produced during storage or distribution.
Detected in SFPUC finished drinking water? If so, are detections supported with QA/QC data?	No	Based on the 2007, 2010, and 2015/2016 studies described above, algal toxins have not been detected in SFPUC finished drinking water.
SUMMARY: Occurrence in source water or distribution system? (or significant potential to occur) (Based on above answers)	Yes	Although low levels of blue–green algae and algal toxins are generally expected in source waters (surface waters), the vulnerability of SFPUC water supplies to algal toxins is low. To date, toxins have not been detected in SVWTP effluent samples.
Treatment		
Is scientific knowledge on CEC treatment/removal well developed?	Yes	Conventional drinking water treatment (coagulation, flocculation, sedimentation, and filtration) is effective at removing algal cells and therefore algal toxins confined within the cells (USEPA 2015c). The best treatment approach is to remove the cells, intact and without damage, such as by filtration (WQRA 2010). Chlorination or ozonation prior to filtration can cause cell lysis and release of cell-bound toxins (USEPA 2015b, Fan 2014). For extracellular toxins (not cell-bound), free chlorine (post-filtration) will remove >80% of extracellular mycrocystins, but is ineffective for anatoxin-a (USEPA 2015b). A study of 33 US water supplies indicated that existing water treatment processes were generally effective for microcystin removal (AWWA 2007).
Likely to pass through current treatment for Hetchy supply? Describe any issues involved with the treatment/removal of CEC.	Yes	Tesla Water Treatment Facility provides treatment via primary disinfection using chlorine and UV treatment. There is no filtration. However, Hetch Hetchy reservoir does not experience blue–green algal blooms.
Likely to pass through current treatment at SVWTP? Describe any complex issues involved with the treatment/removal of CEC.	No	SVWTP has a conventional filtration treatment process, primary disinfection with free chlorine. Removal of algal cells by sedimentation/filtration and approximately 80% extracellular toxin removal by free chlorination, would be expected.

Likely to pass through current treatment at HTWTP? Describe any complex issues involved with the treatment/removal of CEC.	No	HTWTP has ozonation followed by a direct filtration treatment process and primary disinfection with free chlorine.
Likely to pass through current treatment for groundwater? Describe any complex issues involved with the treatment/removal of CEC.	NA	Algal toxins are not expected to occur in groundwater.
SUMMARY: Likely to pass (not removed by) current treatment? **(Based on above answers)**	No	Filtration at SVWTP and HTWTP should provide removal of algal cells and free chlorination should reduce extracellular toxins by approximately 80%. The unfiltered Hetchy system will not remove algae; however, blue–green algae (and associated cyanotoxins) are not present in Hetchy supply.
CEC Prioritization: Current Assessment		
Could CEC occur in SFPUC treated drinking water at levels of possible health significance? *(Based on above Diagnostic Questions)*	Based on monitoring conducted by SFPUC, it appears that the vulnerability of SFPUC water supplies to algal toxins is low to medium. Algal toxins could occur in SFPUC local source water at levels of possible health significance during significant algal blooms.	
CEC Prioritization for SFPUC High, Medium, or Low. Provide explanation.	**Medium.** Though rare, adverse health impacts to humans from algal toxins in drinking water associated with severe algal blooms have been reported elsewhere (though not for SFPUC). Algae types and levels and algal toxin concentrations could change over time due to climate change or other environmental factors.	
Recommended actions Does the situation merit investing additional resources or is the information gathered so far sufficient to have fulfilled due diligence? Actions could include monitoring and other measures (specified by source water, if necessary).	• Continue addressing recommendations identified in sanitary surveys completed in December 2015 for Alameda watershed and Peninsula watershed. • Continue coordination with the SFPUC Natural Resources Division (SFPUC-NRD) as they regularly conduct limnology profiles and algae species characterization, maintain hypolimnion oxygenation system (HOS), and conduct algae treatment as needed. • Complete year-long algal toxin monitoring (8/2015 to 8/2016) at Calaveras Reservoir (and other source waters, as needed) with SFPUC-NRD. Use this monitoring program to develop an overall program for monitoring and evaluating algal toxins. • Develop response plan for algal toxin occurrence (e.g., source water change, treatment optimization, blending, notification). • Perform UCMR 4 mandatory monitoring for 10 algal toxins and two indicator parameters, 2018–2020. • Maintain source water protection and optimized multi-barrier water treatment and distribution system operation. • Track information, peer-reviewed publications, and any federal and state regulatory developments.	
Name(s) of reviewer and affiliation	SFDPH: June M. Weintraub SFPUC: Andrew DeGraca, Manouchehr Boozarpour, Andrzej Wilczak, Gregg Olson Kennedy/Jenks Consultants: Jean Debroux, Janel Grebel	
Date of review	5/5/2016	

Because this table is an abbreviated version, not all information is included.

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