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Drinking Water Crises in the United States Phase 2: Predictive Modeling

Final Report

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June 30, 2022

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Table of Contents

List of Figures

List of Tables

Overview

The Water Quality Research Foundation (WQRF) Drinking Water Crisis in the United States Phase 2 Predictive Modeling Study follows the Phase 1 effort to identify drinking water crisis which occurred in the United States between 2009-2019. The resulting Phase 1 data set includes nearly 250,000 qualified cases, defined by the following:

- The contamination event occurred between 2009-2019 in a public or private water supply
- The contaminant is known, or suspected, to cause adverse health effects (acute or chronic) in humans
- The contaminant could be federally regulated or unregulated
- The population served by the contaminated water supply was at least 100 people

The Phase 2 Predictive Modeling Study aims to meet the following objectives:

1. Collect and assess all available and relevant data to identify historical and current drinking water contamination events
2. Develop a qualitative model to describe likely future drinking water contamination events
3. Assess how POE and POU devices can be utilized to protect public health in the event of likely future drinking water contamination events

Methodology and Results

1: Review WQRF's Phase 1 Database

The Phase 1 Database (Wang & Chen 2020) includes two data sets, one for regulated contaminants and one for unregulated contaminants. The Phase 1 Regulated Contaminant data set includes data for the following:

- Health-based violations to the U.S. EPA's National Primary Drinking Water Regulations (NPDWR) for public water systems (PWSs) serving populations of 100 or greater that occurred between 2009 and 2019
    - Maximum contaminant level (MCL) or maximum residual disinfectant level (MRDL) violations
    - Treatment technique (TT) violations
    - Action level exceedances (ALE) for lead and copper
- Qualified cases from CDC's Waterborne Disease and Outbreak Reporting System (WBDOSS)
- Qualified cases from news/media occurrences

The Phase 1 unregulated contaminant data set includes data from EPA's Unregulated Contaminant Monitoring Rule (UCMR), including UCMR2, UCMR3, and UCMR4, as well as qualified cases from a news/media search.

Regulated Contaminants: Health-based NPDWR violations

The Phase 1 Regulated Contaminants data set includes NPDWR health-based violations for four violation categories, including MCL violations, MRDL violations, TT violations, and ALE occurrences. Table 1 provides a summary of the health-based violations by violation category, ordered by number of violations. The summary table and subsequent summary tables for health-based violation data include the number of violations, the duration of the violation in days, the number states with PWSs with violations, the number of PWS with violations, the total population served by the PWSs with violations, and the average of the median household incomes for populations served by the PWSs with violations as reported by the Phase 1 Regulated Contaminants data set. Note that some drinking water contaminants may not affect the entire population served by a PWS with a violation. For example, a PWS may have one well where a contaminant was found above the MCL (i.e., nitrate, arsenic, total coliform, etc.), and that well may only serve a portion of the PWS's distribution system. Another example is for disinfection byproducts (DBPs), which can continue to form within the distribution system when a disinfectant residual is present. As a result, only a portion of the distribution system may have occurrences of DBPs exceeding the MCL. Yet another example is lead and copper as lead and copper levels at a customer's tap can depend on service line materials and even in-home plumbing, as well as water quality. Lead and copper levels at a customer's tap vary from one home to the next.

There were approximately 76,000 MCL violations for DBPs, inorganic contaminants, organic contaminants, and radionuclides. MCL violations can be caused by a single sample result above the MCL or based on an average of several sample results above the MCL depending on the contaminant and violation type. These violations were widespread, occurring in all 50 states and the District of Columbia and in approximately 17,000 PWSs. MCL violations account for the greatest number of health-based violations compared to other violation categories. The ten contaminants that each account for more than 10,000 violations are summarized in Table 2, ordered by number of violations. While not included in the table, coliform bacteria violations under the Revised Total Coliform Rule (RTCR) accounted for 770 violations, which could be grouped together with the Coliform violations under the Total Coliform Rule (TCR) that account for the greatest number of MCL violations. The contaminants listed in table below are the highest priority for the predictive model based on MCL violations. Other contaminants not shown in Table 2 will still be considered for the predictive model.

Three disinfectant types, including chloramines, chlorine dioxide, and chlorine, led to a total of 83 MRDL violations. The MRDL violations are summarized in Table 3, ordered by number of violations. While maintaining a disinfectant residual in drinking water provided to consumers is critical to protect against pathogen growth, a MRDL violation identifies occurrences of disinfectant residuals exceeding the highest level allowed in drinking water. The MRDL violations occurred in only 42 PWSs located across 16 states and the District of Columbia. Compared to the other violation categories, MRDL violations account for the least number of health-based violations. These violations are specific to treatment through the application of disinfectants and are not a priority concern for the predictive model of drinking water crises.

There were almost 16,000 TT violations, which are a result of a failure in a required process intended to reduce the level of a contaminant in drinking water. TT violations occurred in all but one state as well as the District of Columbia and in over 6,000 PWSs. Table 4 summarizes the TT violations included in the Phase 1 Regulated Contaminants data set, ordered by number of violations. Overall, TT violations are widespread and have occurred in several thousands of PWSs. For the purposes of the predictive model, the TT violations can be used to understand the extent of drinking water issues that may be caused by operational, treatment, and/or managerial problems.

The Lead and Copper Rule (LCR) requires that 90% of lead and copper samples for a PWS in each compliance period must be below the corresponding action level (AL). There were over 10,000 ALEs for lead and copper in all 50 states and in over 5,000 PWSs. Table 5 provides a summary of the ALEs in the Phase 1 Regulated Contaminants data set, ordered by number of violations. Lead ALEs have occurred in over 3,000 PWSs across all 50 states, and copper ALEs in over 2,000 PWSs in 49 states. Due to the widespread ALEs, lead and copper are both identified as contaminants of concern for the predictive model.

Table 1 NPDWR health-based violations by violation category

Violation Category	No. of Violations	Average Duration of Violation (days)	No. of States* w/ Violations	No. of PWSs w/ Violations	Total Population Served by PWSs w/ Violations	Average Reported MHI
Maximum Contaminant Level (MCL)	76,017	455	51	17,202	253,687,004	$46,770
Treatment Technique (TT)	15,839	215	50	6,191	85,499,841	$46,417
Action Level Exceedance (ALE)	10,533	466	50	5,162	50,175,703	-
Maximum Residual Disinfectant Level (MRDL)	83	435	16	42	312,119	$47,816

MHI = Median Household Income reported in Phase 1 database
- = Data not available
*States include the 50 states and the District of Columbia

Table 2 Summary of MCL violations for contaminants with over 10,000 violations

Contaminant	No. of Violations	Average Duration (days)	No. of States*	No. of PWSs	Total Population Served	Average Reported MHI
Coliform (TCR)	22,885	206	51	12,343	63,508,615	$51,623
TTHM	18,029	457	49	2,513	79,839,352	$40,718
Arsenic	10,292	751	43	934	23,248,474	$48,078
HAA5	7,469	428	45	1,430	34,675,419	$40,532
Nitrate	4,796	650	33	842	5,308,850	$48,129
Combined Radium (-226 & -228)	3,045	619	34	335	15,109,507	$45,958
Gross Alpha	2,135	584	30	243	11,837,967	$45,534
Uranium	2,032	722	25	186	2,084,894	$47,211
Fluoride	1,794	829	23	104	5,261,929	$45,651
Total nitrate and nitrite	1,078	491	12	162	841,781	$43,578

*States include the 50 states and the District of Columbia

Table 3 Summary of MRDL violations

Contaminant	No. of Violations	Average Duration (days)	No. of States*	No. of PWSs	Total Population Served	Average Reported MHI
Chlorine Dioxide	38	324	10	24	281,581	$42,271
Chlorine	38	537	9	15	28,108	$51,278
Chloramines	7	404	4	4	3,810	$68,577

*States include the 50 states and the District of Columbia

Table 4 Summary of treatment technique (TT) violations

Description of Violation	Rule Violated	Contaminant Impacted	No. of Violations	Average Duration (days)	No. of States*	No. of PWSs	Total Pop. Served	Avg. Reported MHI
Failure to Address Deficiency	LT2ESWTR, GWR	*Cryptosporidium*, Fecal bacteria	4,344	515	37	1,774	7,045,164	$44,520
Treatment Technique	LT2ESWTR, GWR, SWTR	*Cryptosporidium*, Fecal bacteria, Other pathogen	4,205	34	44	1,314	39,176,056	$48,364
Monthly Turbidity Exceedance	LT1ESWTR	*Cryptosporidium*	1,810	30	35	560	9,230,443	$41,140
Startup Procedures	RTCR	*E.coli*	1,471	261	32	1,112	412,370	$50,601
Level 1 Assessment	RTCR	*E.coli*	1,050	189	40	960	1,177,644	$51,914
No Certif. Operator	DBP Stage 1	DBP	934	307	27	521	1,988,925	$41,646
Single Turbidity Exceedance	LT1ESWTR	*Cryptosporidium*	856	29	37	400	11,547,674	$40,876
Failure to Filter	LT2ESWTR, GWR, SWTR	*Cryptosporidium*, Fecal bacteria, Other pathogen	404	652	24	184	3,479,382	$43,831
Level 2 Assessment	RTCR	*E.coli*	401	183	24	314	449,319	$61,151

Description of Violation	Rule Violated	Contaminant Impacted	No. of Violations	Average Duration (days)	No. of States*	No. of PWSs	Total Pop. Served	Avg. Reported MHI
Corrective/Expedited Actions	RTCR	*E.coli*	296	188	24	193	110,708	$50,661
Failure to Submit Treatment Requirement Rpt	LT2ESWTR	*Cryptosporidium*	45	676	8	45	1,002,944	$39,649
Failure to Address Contamination	GWR	Fecal bacteria	16	333	6	15	4,611	$53,028
Uncovered Reservoir	LT1ESWTR, LT2ESWTR	*Cryptosporidium*	4	455	3	4	9,873,300	-
No Prior State Approval	LT1ESWTR	*Cryptosporidium*	3	877	2	2	1,301	$38,864

DBP = disinfection byproduct
DC = District of Columbia
GWR = Groundwater Rule
LT1ESWTR = Long Term 1 Enhanced Surface Water Treatment Rule
LT2ESWTR = Long Term 2 Enhanced Surface Water Treatment Rule
RTCR = Revised Total Coliform Rule
SWTR = Surface Water Treatment Rule
*States include the 50 states and the District of Columbia
- = Data not available

Table 5 Summary of action level exceedances (ALEs) for lead and copper

Contaminant	No. of Violations	Average Duration (days)	No. of States*	No. of PWSs	Total Pop. Served	Avg. Reported MHI
Copper	5,370	399	49	2,393	10,301,800	-
Lead	5,163	535	50	3,350	39,873,903	-

Regulated Contaminants: Qualified Cases from WBDOSS and News/Media

The Phase 1 Regulated Contaminants data set includes 76 data records identified as "WBDOS/NEWS". These data records include locational information including state, county or place, and zip code, but do not include a public water system ID (PWSID) to identify the PWS. They do include system specific information, though, including the system type, source water type, and population served. These records also include a contaminant name, but do not provide contextual information to understand the incident or occurrence of the contaminant leading to the identification of these qualified cases. As a result, it is not clear how to interpret these data records or how to incorporate them in the predictive model. Table 6 provides a summary of the qualified cases from WBDOSS and news/media from the Phase 1 Regulated Contaminants data set by contaminant with more than one case. In addition to the contaminants shown in the table, there are 17 contaminants each corresponding with one data record. Some of these could be grouped together, though, such as "DBP", "DBPs", "HAA5", Trihalomethanes", which each corresponded with one qualified case.

Table 6 Summary of qualified cases from WBDOSS and news/media by contaminant with more than one case

Contaminant	No. of Cases	No. of States w/ Cases	No. of Places w/ Cases
Nitrate	14	4	14
Lead	13	9	13
Norovirus	10	5	10
Radium	7	2	7
Cyanotoxin(s)	5	3	4
DBPs*	4	3	4
Arsenic	3	2	3
Uranium	3	3	3
Campylobacter	2	2	2
Cryptosporidium	2	2	2

*DBPs includes DBP, HAA5, and Trihalomethanes, which each corresponded with one qualified case

Unregulated Contaminants

The Phase 1 Unregulated Contaminants data set includes data records from EPA's Second Unregulated Contaminant Monitoring Rule (UCMR2), UCMR3, and UCMR4, along with data records from a media search. The EPA's UCMR is mandated under the 1996 Safe Drinking Water Act (SDWA) amendments that require EPA to issue a new list once every five years of no more than 30 unregulated contaminants to be monitored by PWSs.

UCMR2 required monitoring for 25 contaminants between 2008 and 2010. The 25 contaminants were broken up into two lists: 10 List 1 contaminants for Assessment Monitoring and 15 List 2 contaminants for a Screening Survey. All PWS serving more than 10,000 people and 800 representative PWSs serving 10,000 or fewer people were required to monitor for the List 1 contaminants. All PWSs serving more than 100,000 people, 320 representative PWSs serving 10,000 to 100,000 people, and 480 representative PWSs serving 10,000 or fewer people were required to monitor for the List 2 contaminants. A comparison was made between the Phase 1 data set for UCMR2 data and the UCMR2 data set publicly available for download from EPA's website (https://www.epa.gov/monitoring-unregulated-drinking-water-contaminants/occurrence-data-unregulated-contaminant#2) that verified the Phase 1 UCMR2 data set includes all detected results based on a collection date of January 1, 2009 or after. Table 7 summarizes the contaminants detected in UCMR2, ordered by the number of detections. Of the 10 List 1 contaminants, two were detected and included in the Phase 1 Unregulated Contaminants data set. Of the 15 List 2 contaminants, nine were detected and included in the Phase 1 Unregulated Contaminants data set. Aside from N-nitroso-dimethylamine (NDMA), the UCMR2 contaminants have relatively few detections. NDMA will be considered as a greater priority for a potential contaminant of concern for the predictive model as compared with other UCMR2 contaminants.

Table 7 Summary of UCMR2 detected contaminants included in Phase 1 Unregulated Contaminants data set

Contaminant	Contaminant Type	No. of Detections	No. of States w/ Detection	No. of PWS w/ Detection
N-nitroso-dimethylamine (NDMA)	List 2 (Nitrosamine)	1,283	40	236
N-nitroso-diethylamine (NDEA)	List 2 (Nitrosamine)	32	8	17
Metolachlor ethane sulfonic acid (ESA)	List 2 (Acetanilide Degradate)	30	9	14
N-nitroso-di-n-butylamine (NDBA)	List 2 (Nitrosamine)	6	3	4
N-nitroso-pyrrolidine (NPYR)	List 2 (Nitrosamine)	5	3	4
Metolachlor	List 2 (Parent Acetanilide)	3	3	3
Alachlor ethane sulfonic acid (ESA)	List 2 (Acetanilide Degradate)	2	2	2
N-nitroso-methylethylamine (NMEA)	List 2 (Nitrosamine)	2	2	2
Terbufos sulfone	List 1 (Insecticide)	1	1	1
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)	List 1 (Explosive)	1	1	1
Acetochlor ethane sulfonic acid (ESA)	List 2 (Acetanilide Degradate)	1	1	1

*DBPs includes DBP, HAA5, and Trihalomethanes, which each corresponded with one qualified case

UCMR3 required monitoring for 30 contaminants (28 chemicals and two viruses) between 2013 and 2015. All PWSs serving more than 10,000 people and 800 representative PWSs serving 10,000 or fewer people monitored for 21 List 1 Assessment Monitoring contaminants. All PWSs serving more than 100,000 people, 320 representative PWSs serving 10,001 to 100,000 people, and 480 representative PWSs serving 10,000 or fewer people monitored for seven List 2 Screening Survey contaminants. Additionally, EPA selected 800 representative PWSs that serve 1,000 or fewer people, do not disinfect, and have wells located in areas of karst or fractured bedrock to monitor for two List 3 viruses. Overall, the UCMR3 data set includes 44 contaminants due to indicators (total coliforms, *E.coli*, *Enterococci*, bacteria phages – somatic phage and male specific phage, and aerobic spores) for PWS monitoring for List 3 contaminants, two methods for Enteroviruses (Enterovirus cell culture and Enterovirus RT-qPCR), three methods for Noroviruses (Norovirus genogroup I with RT-qPCR primer set A, Norovirus genogroup I with RT-qPCR primer set B, and Noroviruses genogroup II).

A comparison was made between the Phase 1 data set for UCMR3 data and the UCMR3 data set publicly available for download from EPA's website (https://www.epa.gov/monitoring-unregulated-drinking-water-contaminants/occurrence-data-unregulated-contaminant#3) to verify that the Phase 1 UCMR3 data set includes all detected results. The Phase 1 UCMR3 data set includes 89,423 detected results for 44 contaminants, while the UCMR3 data set downloaded from the EPA website includes 253,259 detected results for 40 contaminants. There were 4 contaminants that did not have any detected results, including equilin, estrone, sec-butylbenzene, and tellurium, which are included in the Phase 1 UCMR3 data set. It's also noteworthy that both the Phase 1 UCMR3 data set and the downloaded UCMR3 data set include data records for sec-butylbenzene, n-propylbenzene, germanium, manganese, and tellurium, which are not listed as part of UCMR3 based on EPA's list of contaminants (https://www.epa.gov/dwucmr/third-unregulated-contaminant-monitoring-rule). The Phase 1 UCMR3 data set includes 61,584 data records where the Analytical Results Sign is equal to "<" indicating a non-detect result. Based on the documentation describing the Phase 1 UCMR data collection, only detected results should be included as qualified cases. The other main discrepancy between the Phase 1 UCMR3 data set and the downloaded UCMR3 data set is that the Phase 1 UCMR3 data set contains data records for systems in only 33 states and Puerto Rico, as opposed to the downloaded UCMR3 data set which contains data records for detected contaminants in systems in all 50 state plus 16 territories, tribal nations, or EPA regions. The states missing from the Phase 1 UCMR3 data set appear to be due to an alphabetical cut off, as they start with letters from A-L. Based on the results of this comparison, the summary provided in Table 8 are based on detected results from the downloaded UCMR3 data set for systems in the 50 US states and the District of Columbia (DC). Table 8 orders the UCMR3 contaminants by number of detections. The UCMR3 contaminants with the most widespread detections are the metals, i.e., strontium, chromium-6, vanadium, and chromium, as well as chlorate. Additionally, there were numerous detections of the VOCs, inclusive of 1,2,3-trichloropropane, which will be of interest for the predictive model due to specific state regulations. There were also over 4,000 detections of 1,4-dioxane. The PFAS detections were limited due to relatively high method reporting limits, but we know now that PFAS occurrences are more widespread than UCMR3 data suggests due to better analytical methods and more recent state and system specific sampling programs.

Table 8 Summary of UCMR3 detected contaminants

Contaminant	Contaminant Type	No. of Detections	No. of States* w/ Detection	No. of PWS w/ Detection
Strontium	List 1 (Metal)	61,466	51	4,815
Chromium-6	List 1 (Metal)	46,435	51	4,303
Vanadium	List 1 (Metal)	36,661	51	3,528
Chlorate	List 1 (Oxyhalide Anion)	33,994	51	3,323

Contaminant	Contaminant Type	No. of Detections	No. of States* w/ Detection	No. of PWS w/ Detection
Chromium	List 1 (Metal)	30,928	51	3,579
Molybdenum	List 1 (Metal)	25,195	51	2,510
1,4-Dioxane	List 1 (SOC)	4,180	45	1,066
1,1-Dichloroethane	List 1 (VOC)	830	38	241
Cobalt	List 1 (Metal)	828	35	245
Chlorodifluoromethane (HCFC-22)	List 1 (VOC)	810	37	280
Bromochloromethane (Halon 1011)	List 1 (VOC)	646	39	303
Perfluorooctanoic acid (PFOA)	List 1 (PFAS)	377	27	116
Aerobic spores	List 3 Indicator	317	15	252
Chloromethane	List 1 (VOC)	278	23	133
Perfluorooactanesulfonic acid (PFOS)	List 1 (PFAS)	275	24	91
1,2,3-Trichloropropane	List 1 (VOC)	247	13	62
Perfluorohelptanoic acid (PFHpA)	List 1 (PFAS)	228	22	82
Perfluorohexanesulfonic acid (PFHxS)	List 1 (PFAS)	191	22	52
Bromomethane	List 1 (VOC)	115	12	49
4-Andostene-3,17-dione	List 2 (Hormone)	99	28	75
Testosterone	List 2 (Hormone)	68	25	61
Total coliforms	List 3 Indicator	57	10	53
Enterococci	List 3 Indicator	41	8	41
Perfluorononanoic acid (PFNA)	List 1 (PFAS)	19	7	14
Perfluorobutanesulfonic acid (PFBS)	List 1 (PFAS)	17	4	7
Bacteriophage - male specific phage	List 3 Indicator	14	5	14
Enteroviruses (RT-qPCR)	List 3 (Virus)	6	3	6
Bacteriophage – somatic phage	List 3 Indicator	5	3	5
17-alpha-ethynylestradiol (ethinyl estradiol)	List 2 (Hormone)	4	4	4
Noroviruses GIA	List 3 (Virus)	4	3	4
Noroviruses GII	List 3 (Virus)	4	3	4
17-beta-estradiol	List 2 (Hormone)	3	1	1
16-alpha-hydroxyestradiol (estriol)	List 2 (Hormone)	3	2	3

Contaminant	Contaminant Type	No. of Detections	No. of States* w/ Detection	No. of PWS w/ Detection
E.coli	List 3 Indicator	3	2	3
Noroviruses GIB	List 3 (Virus)	2	1	2
Enteroviruses (cell culture)	List 3 (Virus)	2	2	2
1,3-Butadiene	List 1 (VOC)	1	1	1

PFAS = Per- and polyfluoroalkyl substances
SOC = synthetic organic compound
VOC = volatile organic compound
*States include the 50 states and the District of Columbia

UCMR4 required monitoring for 30 contaminants (10 cyanotoxins and 20 additional chemicals) between 2018 and 2020. All surface water (SW) and groundwater under direct influence of surface water (GWUDI) PWSs serving more than 10,000 people were required to sample for the 10 cyanotoxins and all PWS serving more than 10,000, including SW, GWUDI, and groundwater (GW) PWSs, were required to sample for the additional 20 chemicals. The 20 chemicals include 3 brominated haloacetic acids (DBPs), 9 pesticides, 3 alcohols, 3 semivolatile chemicals, and 2 metals. Additionally, 800 randomly selected SW or GWUDI PWS serving 10,000 people or less were required to sample for the 10 cyanotoxins and a different group of 800 randomly selected PWSs serving 10,000 people or less were required to sample for the 20 additional chemicals.

A comparison was made between the Phase 1 data set for UCMR4 data and the UCMR4 data set publicly available for download from EPA's website (https://www.epa.gov/monitoring-unregulated-drinking-water-contaminants/occurrence-data-unregulated-contaminant#4) to verify that the Phase 1 UCMR4 data set includes all detected results sampled before the end of 2019. Consistent with the Phase 1 UCMR3 data set, there are no data records for PWSs in states that begin with letters between A-L. For completeness, the summary provided in Table 9 is based on the UCMR4 data that was directly downloaded from the EPA website, for samples collected by PWSs in the 50 US states and DC through December 31, 2019 with detected results. The table shows that brominated HAAs, which are classes of DBPs, occur in virtually all PWSs, and manganese occurrence is detectable in drinking water in every state across the country. These contaminants with be prioritized in the predictive model, and all detect contaminants will be considered in the model development.

Table 9 Summary of UCMR4 detected contaminants in samples collected through December 31, 2019

Contaminant	Contaminant Type	No. of Detections	No. of States* w/ Detection	No. of PWS w/ Detection
HAA5	List 1 (Brominated HAA)	45,679	51	4,045
HAA6Br	List 1 (Brominated HAA)	45,675	51	4,045
HAA9	List 1 (Brominated HAA)	45,658	51	4,045
Manganese	List 1 (Metal)	19,491	51	3,671
Germanium	List 1 (Metal)	2,062	41	524
1-Butanol	List 1 (Alcohol)	235	34	160
Anatoxin-a	List 1 (Cyantoxin)	117	17	41

o-Toluidine	List 1 (Semivolatile Chemical)	104	25	73
Quinoline	List 1 (Semivolatile Chemical)	75	23	48
2-Methoxyethanol	List 1 (Alcohol)	57	19	46
2-Propen-1-ol	List 1 (Alcohol)	27	13	18
alpha-Hexachlorocyclohexane	List 1 (Pesticide)	22	14	22
Total permethrin	List 2 (Pesticide)	14	8	12
Cylindrospermopsin	List 1 (Cyanotoxin)	11	4	11
Butylated hydroxyanisole	List 1 (Semivolatile Chemical)	7	5	6
Oxyfluorfen	List 1 (Pesticide)	7	6	7
Dimethipin	List 1 (Pesticide)	5	4	5
Ethoprop	List 1 (Pesticide)	5	4	5
Total microcystin	List 1 (Cyanotoxin)	4	4	4
Profenofos	List 1 (Pesticide)	3	3	3
Tebuconazole	List 1 (Pesticide)	3	2	3
Tribufos	List 2 (Pesticide)	3	2	3
Chlorpyrifos	List 1 (Pesticide)	1	1	1

HAA = Haloacetic Acid
*States include the 50 states and the District of Columbia

2: Assess Water Quality Sampling Data

The *Task 2: Assess Water Quality Sampling Data* used the comprehensive water quality database developed as part of the WQRF Contaminant Occurrence Study. The Contaminant Occurrence Study database contains data records that were collected from 46 state regulatory agencies in 2019-2020. The data records are predominantly for samples collected between 2009 through mid-2019. Initially, the database of quality checked (QC'd) data included 57 analytes based on contaminants with an MCL greater than the maximum contaminant level goal (MCLG) and specific aesthetic analytes that can impact taste, odor, and color of drinking water. Later phases of the Contaminant Occurrence Study included QC of data records for additional drinking water analytes that were collected as part of the original study's data collection effort. The database now includes data for 169 drinking water quality analytes that are available for use in this Predictive Modeling Study.

The Contaminant Occurrence Study database was used for this task because it is currently the most comprehensive and current database of national drinking water quality data. Despite the advantages of using this database, there are still some limitations that are important to note. While water quality data were requested from all 50 states, data were received from 46 states. Besides data records that were incorporated into the database from EPA's UMCR4, the database does not have data available for Indiana, Kansas, South Dakota, or Tennessee. Additionally, the number of drinking water analytes for which data were available differed by state, so for a given analyte, there may be data available for less than 46 states. Microbial data were reported in different formats from various states, including some presence/absence data and some count quantity data. Some states reported microbial data in the same format as chemical data, while other states provided separate data tables for microbial data with different data fields to describe the data results. Due to the different inconsistencies with the microbial data, this analysis in this task excludes microbial data. Based on the high frequency of Total Coliform Rule (TCR) violations identified in Task 1 of this project, we would expect that this task would identify total coliform as a top contaminant based on the occurrence of total coliform positive data if the methodology was inclusive of microbial data.

Our methodology for this task focuses on whether the occurrence level of these analytes is approaching (i.e., 80% or greater) or exceeding a regulatory limit (i.e., federal or state MCL) or health-based goal (i.e., MCLG) and if the occurrence level is increasing over time. The first step to accomplish this objective was to create a comprehensive table of all federal and state MCLs and health goals. The table we developed as part of this task includes 714 up-to-date state MCLs, secondary MCLs, action levels, health advisory levels, and health goals, and 108 federal MCLs, secondary MCLs, action levels, and health goals. These levels are used as reference levels for identifying drinking water quality contaminants for the predictive model.

We have then developed an R script to review contaminant data by:

1. Identifying all contaminants that have occurrences at levels equal to 80% of the federal MCL or greater in the period from 2009 through 2019
2. For contaminants identified in (1) above, identifying contaminants with increasing trends based on the Mann -Kendall non-parametric statistical test for monotonic trends

The script also creates visual representations of the data for contaminants identified in (1) and (2) in the form of yearly boxplots. After this process was completed for federal MCLs, we utilized the same methodology for state specific MCLs using contaminant data for only systems in the corresponding states.

Federally regulated contaminants

Occurrence data for the period from 2009 through 2019 for federally regulated contaminants were evaluated to determine contaminants with occurrences at 80% of the MCL or greater in the period from 2009 through 2019. Based on available occurrence data, all federally regulated contaminants except dalapon, glyphosate, di(2-ethylhexyl) adipate, hexachlorocyclopentadiene, 2,4,5-TP (Silvex), and 1,2,4-trichlorobenzene had at least one reported occurrence at or above 80% of their respective MCLs. The remaining federally regulated contaminants, except for diquat, oxamyl (vydate), and xylenes (total), all had at least one reported occurrence above their MCLs.

Contaminants were then ranked based on the number of public water systems (PWSs) with occurrence above the MCL. The top ten contaminants based on the number of PWSs that had occurrences above the MCL are summarized in Table 10. In addition to the number of PWSs with occurrence greater than the MCL, the table also shows the sum of the population served by PWSs with occurrence greater than the MCL. All PWS types, including community water systems (CWSs), non-transient non-community water systems (NTNCWSs), and transient non-community water systems (TNCWSs), are included in this summary so the total population served could count individual people more than once.

Lead was found as the top contaminant in terms of the number of PWSs with occurrence greater than the action level of 15 µg/L. Over 13,000 PWSs reported occurrence greater than 15 µg/L based on available data. These systems serve a total population of 112 million. Total trihalomethanes (TTHM) resulted in the second most PWSs with occurrence greater than the MCL of 80 µg/L with over 8,000 PWSs reporting occurrence greater than 80 µg/L. These systems serve a total population of 133 million, which is more than the population served by systems with lead occurrence greater than the action level. In the case of disinfection byproducts, i.e., TTHM and the sum of five haloacetic acids (HAA5), the systems with occurrence greater than the MCL were predominantly systems using surface water as the primary source water type. For all other contaminants in Table 10, the percent of surface water systems and groundwater systems represented were relatively consistent. Since there are more groundwater systems in the US as compared with surface water systems, the number of groundwater PWSs with occurrence above the MCL was greater than the number of surface water PWSs with occurrence above the MCL.

An exceedance of the MCL does not necessarily cause a system to be in violation because in most cases, compliance is based on a running annual average or in the case of lead and copper, the 90th percentile result in a compliance period. As part of this project, contaminants resulting in the most health-based violations were summarized as part of Task 1. The results for the top ten federally regulated contaminants based on number of PWSs with occurrence above the MCL shown in Table 10 were also identified as top contaminants of concern in Task 1.

Table 10 Top ten federally regulated contaminants based on number of PWSs with occurrence greater than the MCL or Action Level

Contaminant	MCL or Action Level	Number of PWSs w/ occurrence > MCL	Percent of PWSs w/ data and w/ occurrence > MCL	Sum of population served by PWSs w/ occurrence > MCL*
Lead	15 µg/L (AL)	13,020	23%	112 M
TTHM	80 µg/L	8,169	17%	133 M
Copper	1.3 mg/L (AL)	5,510	10%	28.3 M
HAA5	60 µg/L	5,343	12%	97.7 M
Arsenic	10 µg/L	2,669	5.1%	16.3 M
Nitrate	10 mg/L as N	2,602	2.5%	8.03 M
Nitrate + Nitrite	10 mg/L as N	1,239	1.8%	3.74 M
Radium	5 pCi/L	1,008	4.6%	6.19 M
Fluoride	4 mg/L	437	0.8%	1.34 M
Uranium	30 µg/L	378	2.3%	2.21 M

For the top ten contaminants shown in Table 10, Table 11 provides a summary of the PWSs with data above the MCL or Action Level by system size category based on the population served. Specifically, the table shows the number of PWSs with occurrence above the MCL or Action Level and the percent of PWSs with data available that had occurrence above the MCL or Action Level by system size category. In general, there are a greater number of smaller PWSs than larger PWSs, so there are typically a greater number of smaller systems with occurrence above the MCL or Action Level, while the percentages provide a more normalized comparison across system sizes. For the DBPs (TTHM and HAA5), the percentages are higher for the larger systems likely due to a greater percent of surface water systems as compared with groundwater systems and larger distribution systems, where DBP formation continues after the application of a disinfectant. The percentages of PWSs with data over the Action Level for lead were also higher for larger systems as compared with smaller systems.

Table 11 Summary of PWSs with occurrence greater than the MCL or Action Level by system size category for top ten federally regulated contaminants

Contaminant	Number (and Percent) of PWSs by Size Category with Occurrence Above MCL/Action Level				
	Very Small (<500)	Small (500-3,300)	Medium (3,300-10,000)	Large (10,000-100,000)	Very Large (>100,000)
Lead	6,050 (17%)	3,483 (29%)	1,558 (40%)	1,443 (50%)	180 (51%)
TTHM	2,338 (8.4%)	2,660 (21%)	1,388 (32%)	1,368 (41%)	216 (53%)
Copper	2,966 (8.5%)	1,534 (13%)	450 (12%)	363 (13%)	43 (12%)
HAA5	1,374 (5.5%)	1,777 (15%)	1,003 (23%)	943 (26%)	144 (34%)
Arsenic	1,863 (5.4%)	412 (4.2%)	133 (4.1%)	126 (4.9%)	23 (6.6%)
Nitrate	2,062 (2.5%)	232 (2.1%)	27 (0.9%)	52 (2.2%)	21 (6.2%)
Nitrate + Nitrite	915 (1.8%)	124 (1.5%)	11 (0.4%)	13 (0.7%)	7 (2.8%)
Radium	551 (4.1%)	254 (5.1%)	100 (5.3%)	75 (5.6%)	6 (3.4%)
Fluoride	285 (0.8%)	82 (0.8%)	42 (1.3%)	22 (0.9%)	2 (0.7%)
Uranium	268 (2.6%)	61 (1.8%)	23 (1.6%)	15 (1.3%)	5 (2.5%)

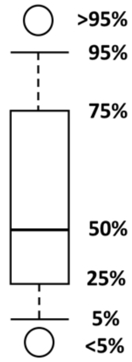
For the top ten contaminants shown in Table 10, Table 12 provides a summary of the PWSs with data above the MCL or Action Level by primary source water type. Specifically, the table shows the number of PWSs with occurrence above the MCL or Action Level and the percent of PWSs with data available that had occurrence above the MCL or Action Level by primary source water type. In general, there are a greater number of groundwater PWSs than surface water PWSs, so there are typically a greater number of groundwater systems with occurrence above the MCL or Action Level, while the percentages provide a more normalized comparison between groundwater and surface water PWSs. For the DBPs (TTHM and HAA5), the percentages are notably higher for the surface water systems as surface water tends to have higher concentrations of organic matter, which are DBP precursors. The percentages of PWSs with occurrences over the Action Level for lead were also higher for surface water systems as compared with groundwater systems, while the percent of PWSs with occurrences over the MCL for arsenic, radium, and uranium were higher for groundwater systems.

Table 12 Summary of PWSs with occurrence greater than the MCL or Action Level by primary source water type for top ten federally regulated contaminants

Contaminant	Number (and Percent) of PWSs by Primary Source Water Type with Occurrence Above MCL/Action Level	
	Groundwater	Surface Water
Lead	9,727 (21%)	2,985 (35%)
TTHM	2,383 (6.3%)	5,585 (51%)
Copper	4,468 (9.9%)	888 (10%)
HAA5	1,129 (3.3%)	4,109 (37%)
Arsenic	2,403 (5.3%)	154 (2.8%)
Nitrate	2,271 (2.5%)	123 (1.9%)
Nitrate + Nitrite	1,015 (1.7%)	55 (1.1%)
Radium	913 (4.9%)	72 (2.3%)
Fluoride	394 (0.8%)	39 (0.8%)
Uranium	327 (2.4%)	45 (1.7%)

The next step in this effort included an investigation of how the occurrence of these contaminants may be changing over time. Identifying trends over time may help to understand which contaminants are most likely to be of the greatest concern for the next 5-10 years. Trends over time were analyzed visually using yearly boxplots for the period from 2009 – 2018 and using the Mann-Kendall non-parametric statistical test for monotonic trends. Figure 1 shows a key for the boxplots. For all figures with yearly boxplots, the y-axis is limited to three times the MCL to show the distribution of results for the majority of the data. Data with results below the lower limit of the y-axis (i.e. pH) and above the upper limit of the y-axis are not included in these figures. The Mann-Kendall test assumes that data used for the test are consistently spaced over time. To address this requirement and to focus on the occurrences that represent a greater health concern, annual 95th percentiles from 2009 through 2018 were used for each contaminant. The outcome of the test includes an alpha value and a test statistic. Based on a 95% confidence level, an alpha value less than 0.05 was identified as a statistically significant trend, while an alpha value equal to or greater than 0.05 was identified as not statistically significant. A positive test statistic indicates an increasing trend, while a negative test statistic indicates a decreasing trend. Results for the top ten contaminants from Table 10 are presented below grouped by the trend test outcome.

Figure 1 Boxplot legend



Increasing trend

No contaminants were found to have an increasing annual 95^{th} percentile values over the period from 2009 through 2018.

No significant trend

Three of the top ten contaminants (Table 10) were found to have no significant trend over time. Those contaminants include nitrate, HAA5, and nitrate + nitrite.

Yearly boxplots for HAA5 occurrence data are shown in Figure 2. Annual 95^{th} percentile HAA5 values are close to the MCL of 60 µg/L. The only annual 95^{th} percentile that exceeded the MCL in the period of interest was in 2009. Although the Mann-Kendall test did not find a statistically significant monotonic decreasing trend over the period of 2009 through 2018, the comparison of the annual 95^{th} percentile value in 2009, which is greater than the MCL, with 2018, which is below the MCL, suggests some decrease over time. The numerous occurrence data that exceed the MCL in all years suggests that HAA5 will likely remain a contaminant of concern for the next 5-10 years.

Yearly boxplots for nitrate are shown in Figure 3. The figure shows national finished water nitrate levels were consistent over time from 2009 through 2018. The annual 95^{th} percentile values are close to 75% of the MCL over the analysis period, with occurrences up to three times the MCL. Nitrate is an acute contaminant, so any occurrence above 10 µg/L could pose a potential health risk. Based on occurrence data exceeding the MCL, we believe that nitrate will remain a contaminant of concern for the next 5-10 years.

Yearly boxplots for nitrate + nitrite occurrence data are shown in Figure 4. While there's not a statistically significant trend in annual 95^{th} percentile values for nitrate + nitrite, the annual 75^{th} percentile value in 2018 is higher than in 2009, suggesting some increase in concentrations over time is possible. As mentioned above, nitrate is regulated as an acute contaminant and any occurrence above the MCL of 10 mg/L for nitrate or nitrate + nitrite could pose a health risk. Therefore, it is likely that nitrate + nitrite will remain a contaminant of concern for the next 5-10 years.

Figure 2 Yearly boxplots of HAA5 occurrence data (2009-2018)

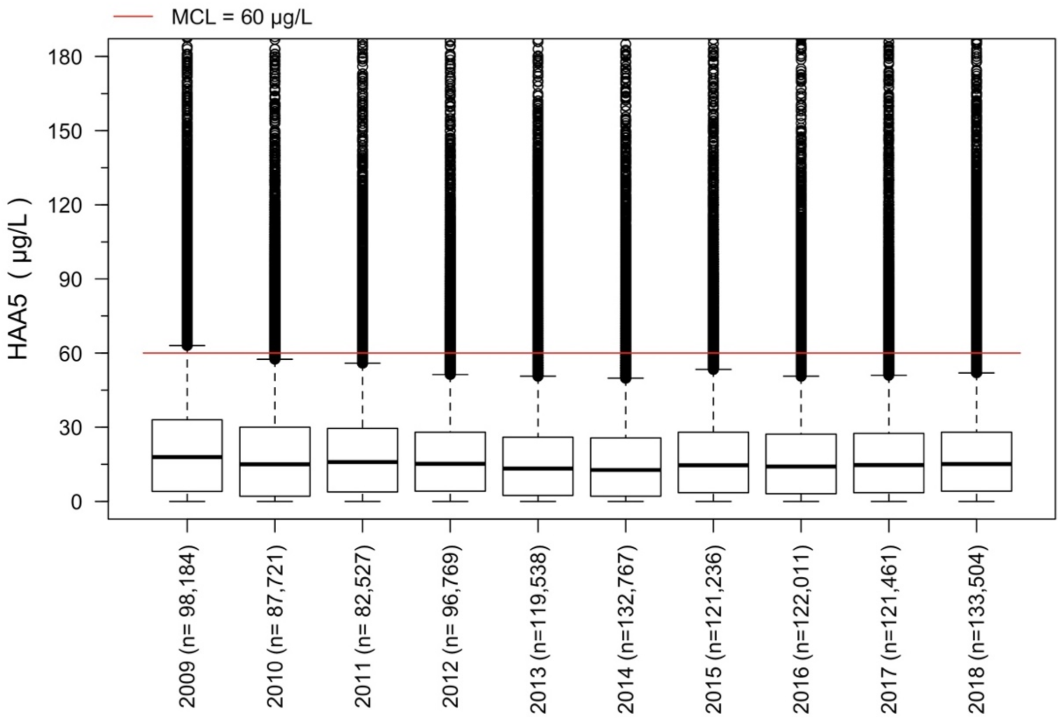


Figure 3 Yearly boxplots of nitrate occurrence data (2009-2018)

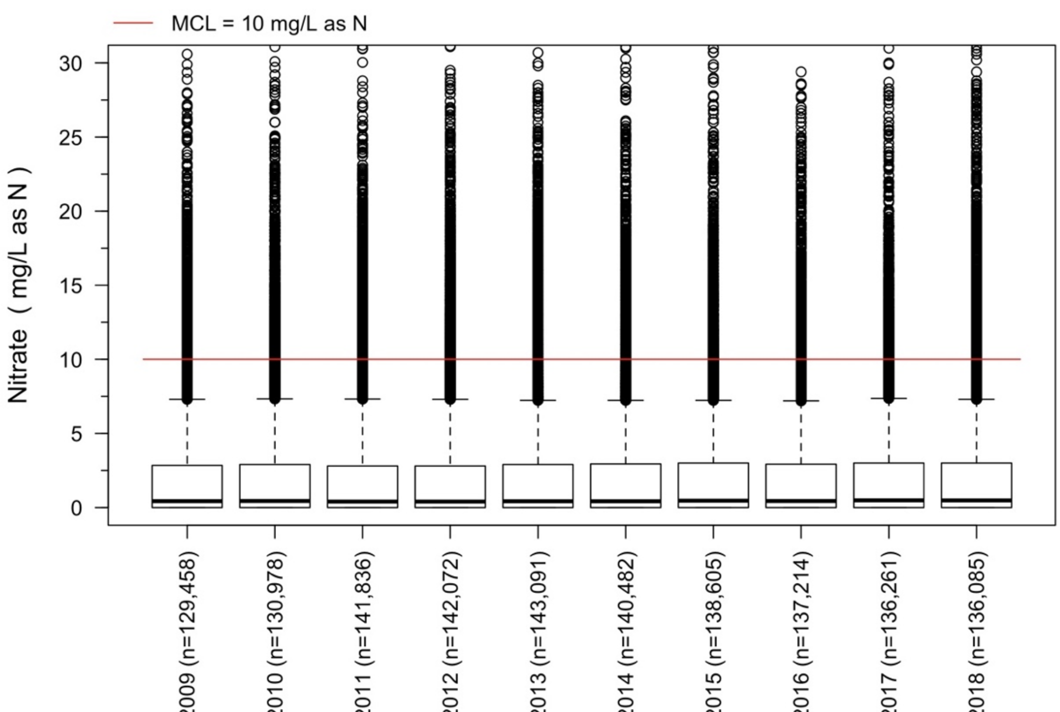
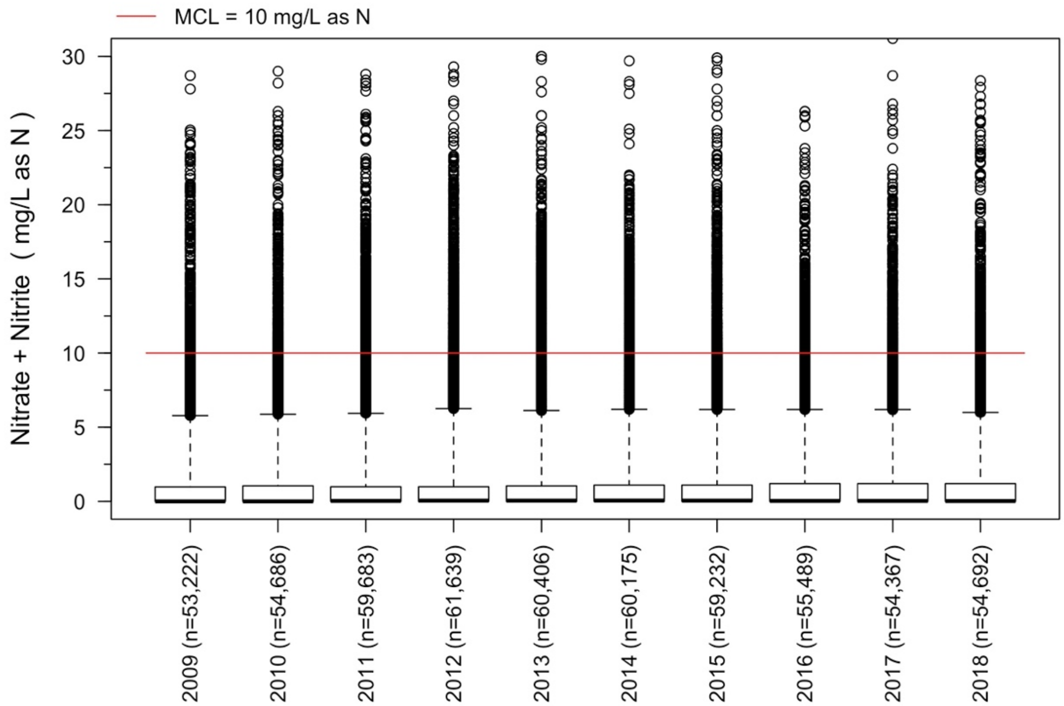


Figure 4 Yearly boxplots of nitrate + nitrite occurrence data (2009-2018)



Decreasing trend

The remaining contaminants in Table 10, including lead, TTHM, copper, arsenic, radium, fluoride, and uranium were found to have decreasing annual 95th percentile values over the period from 2009 through 2018.

Yearly boxplots of lead occurrence data are shown in Figure 5. Annual 95th percentile values are close to half the action level of 15 µg/L, although there are numerous occurrences exceeding the action level. Due to the frequency of occurrences exceeding the action level and the well-known health risks due to lead contamination, lead is expected to be a contaminant of concern for the next 5-10 years.

Yearly boxplots of TTHM occurrence data are shown in

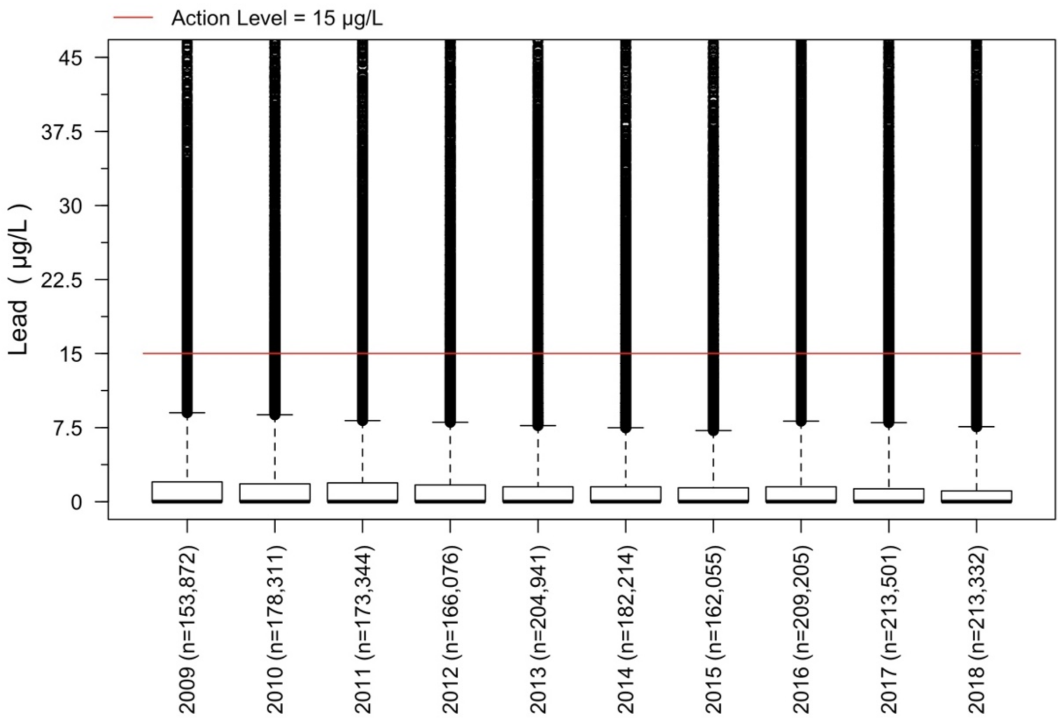


Figure 6. Annual 95th percentile values decreased over the period to approximately equal to the MCL of 80 µg/L. Despite the decrease in annual 95th percentile values, the frequency of occurrence above the MCL suggests that TTHM will likely remain a contaminant of concern over the next 5-10 years.

Yearly boxplots of copper occurrence data are shown in Figure 7. Decreasing annual 95th percentile values remain close to approximately half of the action level of 1.3 mg/L during the period of interest. Similar to lead and TTHM, the frequency of occurrence data exceeding the action level suggest that copper will likely remain a contaminant of concern over the next 5-10 years.

Yearly boxplots for arsenic occurrence data are shown in Figure 8. Annual 95th percentile values showed a decrease over the period, from approximately 14 µg/L to 10 µg/L, equal to the MCL. The figure shows the high frequency of occurrences above the MCL, which suggests that arsenic will likely remain a contaminant of concern for the next 5-10 years.

Yearly boxplots of radium occurrence data are shown in Figure 9. Despite the decreasing trend, annual 95th percentile values exceeded the MCL of 5 pCi/L in all years of interest. Variability in the distribution of yearly radium occurrence data shown by varying boxes in the boxplots may be a result of different monitoring schedules. Some systems may monitor yearly, while others may monitor every 3 years, for example. The frequency of occurrence data exceeding the MCL suggest that radium will likely remain a contaminant of concern over the next 5-10 years.

Yearly boxplots of fluoride occurrence data are shown in Figure 10. Annual 95th percentile concentrations are well below the MCL of 4 mg/L. Relative to other contaminants identified in Table 10 there are few occurrences exceeding the MCL, likely isolated to certain regions where naturally occurring fluoride may be problematic. Particularly in areas of high fluoride concentrations, it is likely that fluoride will remain a contaminant of concern for the next 5-10 years.

Yearly boxplots of uranium occurrence data are shown in Figure 11. Despite the decreasing trend, annual 95th percentile values exceeded that MCL of 30 µg/L in all years of interest. As mentioned above for radium, different monitoring frequencies for systems are likely the reason for the variability in the data distributions from year to year. The frequency of occurrence data exceeding the MCL suggest that uranium will likely remain a contaminant of concern over the next 5-10 years.

Figure 5 Yearly boxplots of lead occurrence data (2009-2018)

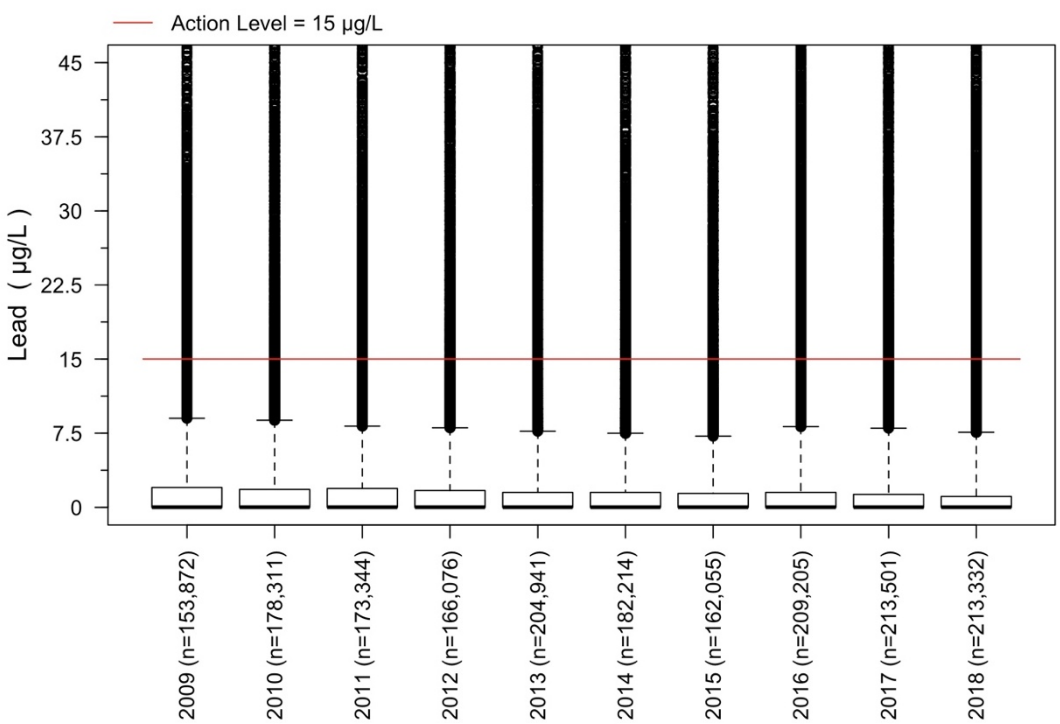


Figure 6 Yearly boxplots of TTHM occurrence data (2009-2018)

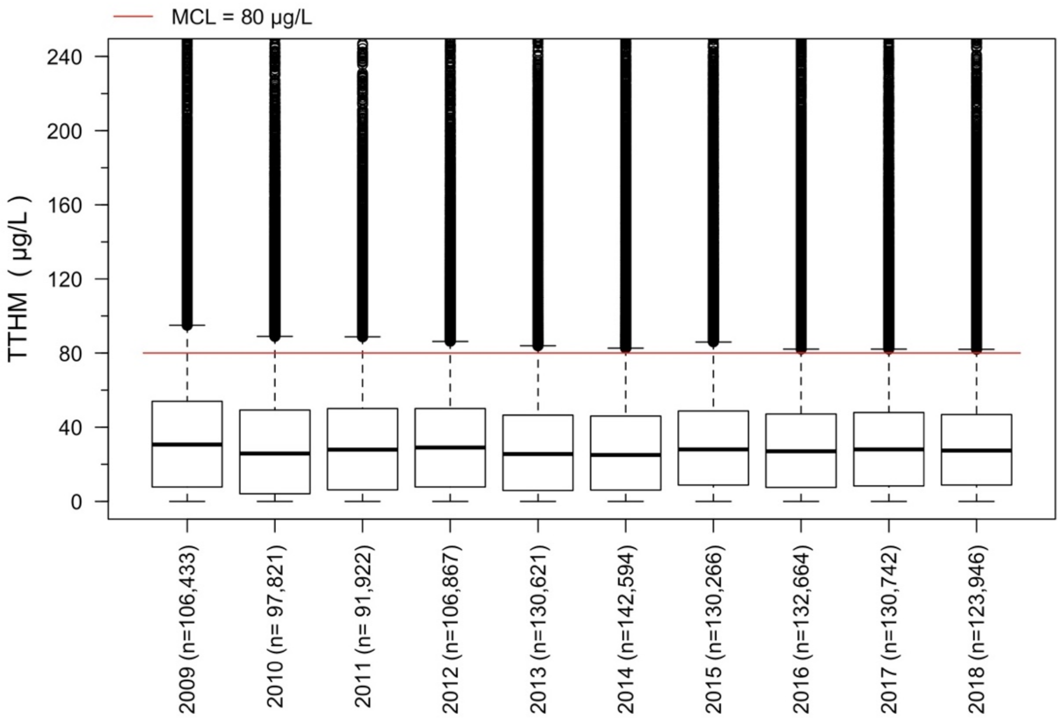


Figure 7 Yearly boxplots of copper occurrence data (2009-2018)

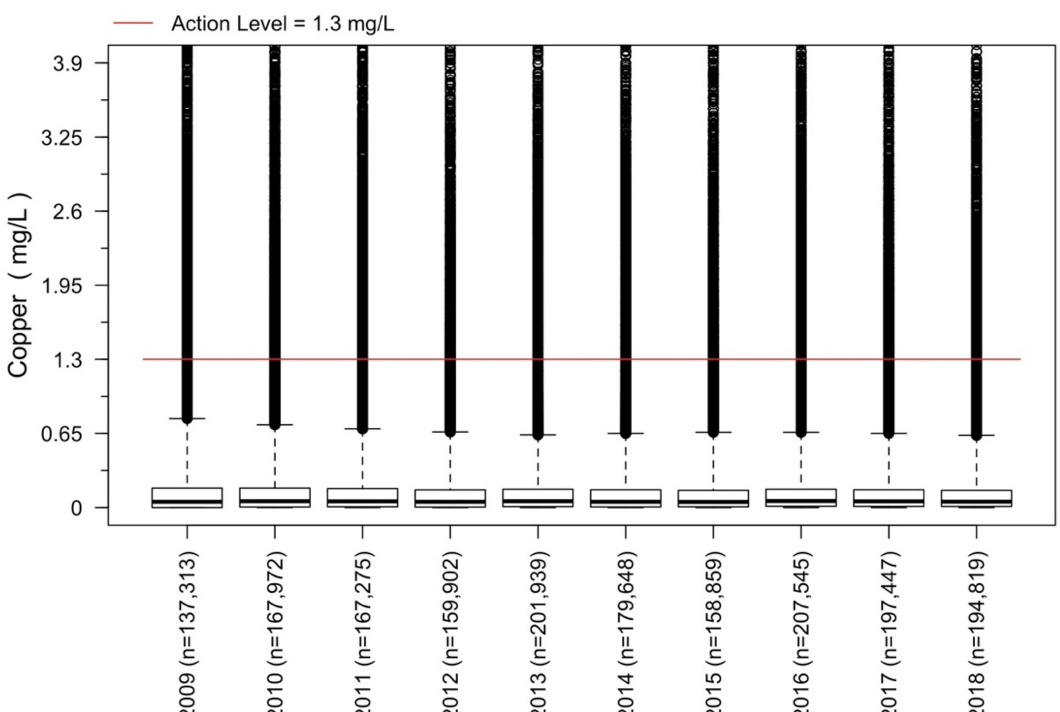


Figure 8 Yearly boxplots of arsenic occurrence data (2009-2018)

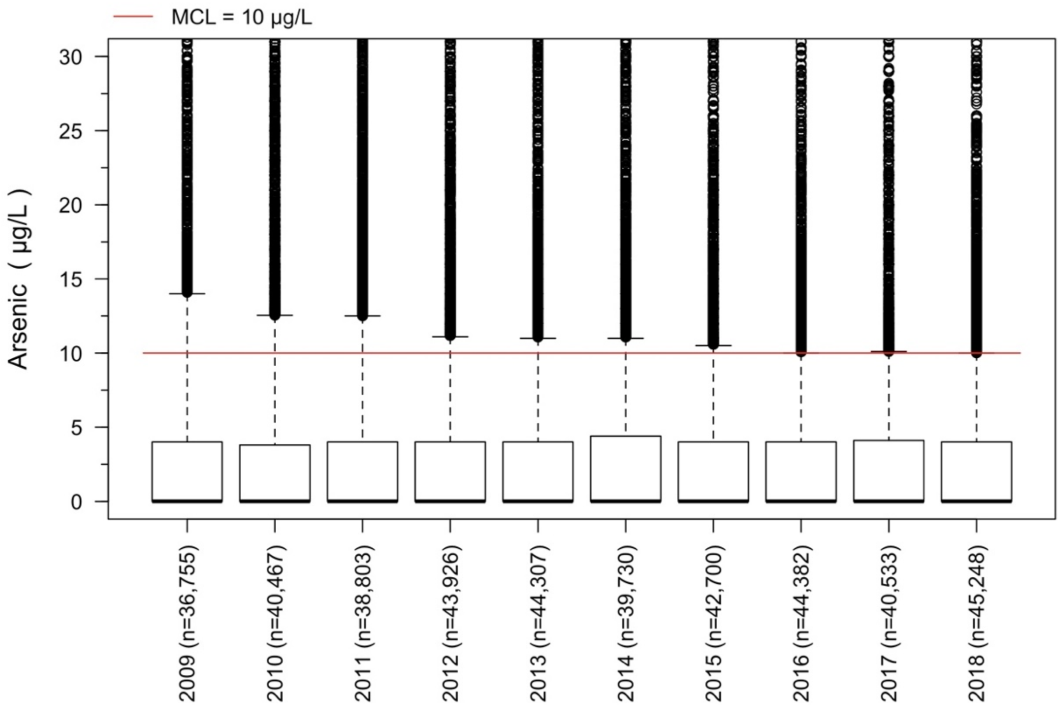


Figure 9 Yearly boxplots of radium occurrence data (2009-2018)

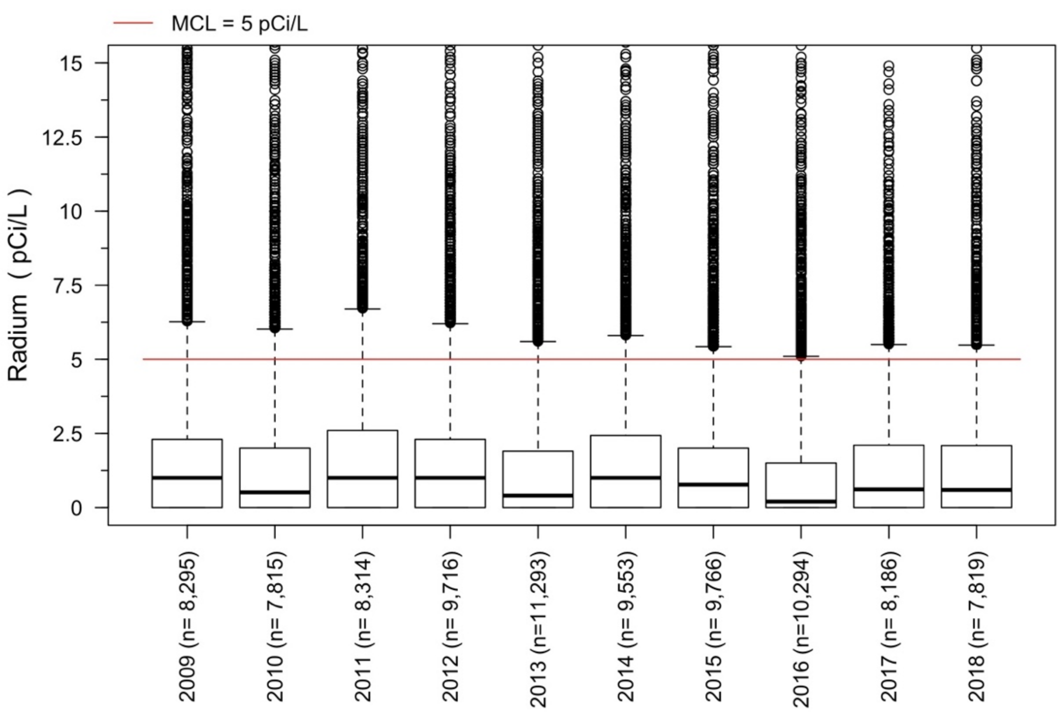


Figure 10 Yearly boxplots of fluoride occurrence data (2009-2018)

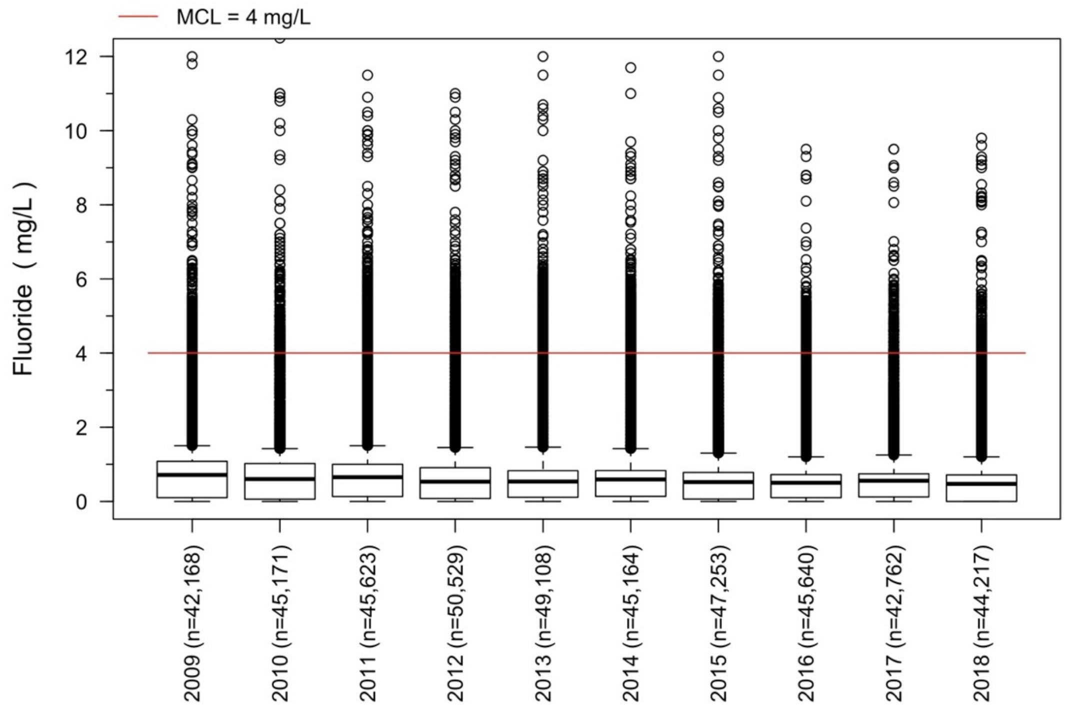
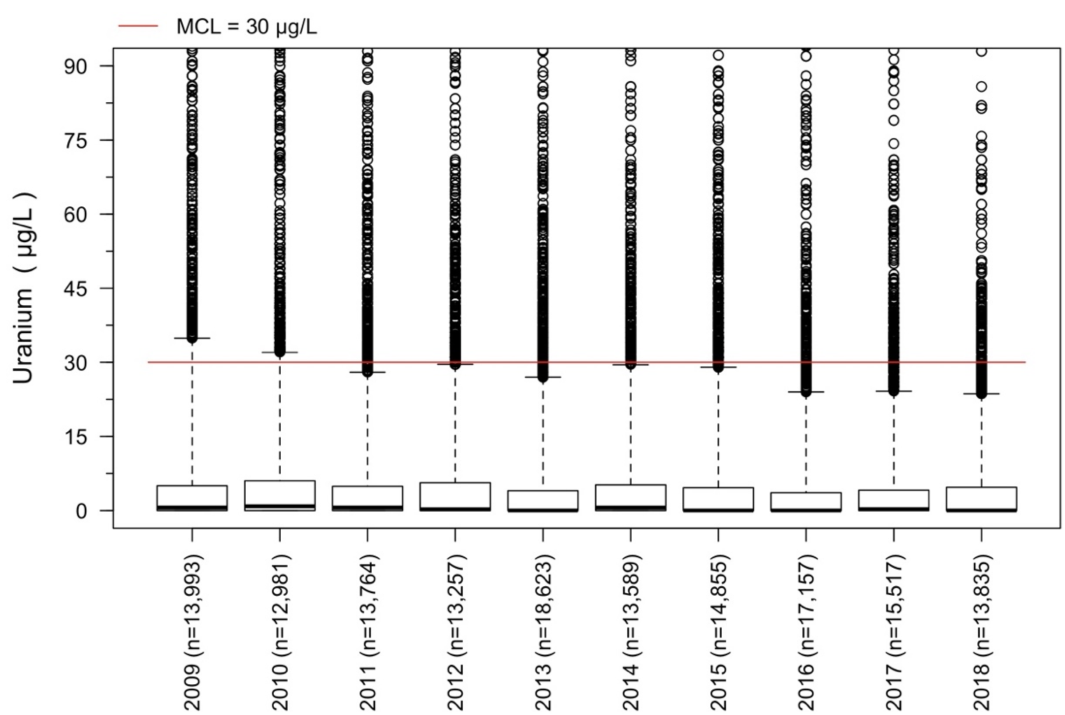


Figure 11 Yearly boxplots of uranium occurrence data (2009-2018)



State-specific regulated contaminants

Occurrence data for the period from 2009 through 2019 for state-specific regulated contaminants were evaluated to determine contaminants with occurrences at 80% of the MCL or greater in the period from 2009 through 2019. Based on available occurrence data, Table 13 summarizes the top ten state-specific regulated contaminants based on the number of PWSs with occurrence greater than the MCL or action level. Some of these contaminants are also federally regulated but certain states have imposed a more stringent regulation (i.e., arsenic and tetrachloroethylene in New Jersey), and some contaminants have non-enforced federal secondary standards based on aesthetic impacts on drinking water while states impose an enforced MCL (i.e., iron and manganese in North Carolina and New York).

A noteworthy group of contaminants that are regulated by several states that are missing from Table 13 is per- and poly-fluoroalkyl substances (PFAS). The reason for the exclusion of PFAS is largely due to data availability outside of UCMR3, which is summarized as part of Task 1. Due to recent and upcoming regulatory changes for PFAS, it is expected that PFAS analytes would likely be captured here if this process is repeated in the future when more data are available.

Table 13 Top ten state-specific regulated contaminants based on number of PWSs with occurrence greater than the MCL

Contaminant	State	MCL	No. of PWSs w/ occurrence > MCL	Percent of PWSs w/ data and occurrence > MCL	Sum of population served by PWSs w/ occurrence > MCL*
Iron	NC	300 µg/L	670	28%	1,166,394
Manganese	NC	50 µg/L	584	25%	1,750,973
Iron	NY	300 µg/L	453	23%	1,449,173
Chloride	NY	250 mg/L	384	20%	143,060
Manganese	NY	300 µg/L	258	13%	702,746
Arsenic	NJ	5 µg/L	71	5.3%	251,293
Chloride	CT	250 mg/L	65	5.7%	22,125
Fluoride	NY	2.2 mg/L	38	2.8%	43,522
Zinc	NY	5 mg/L	38	1.0%	86,381
Tetrachloroethylene (PCE)	NJ	1 µg/L	29	2.1%	436,190

For the top ten contaminants shown in Table 13, Table 14 provides a summary of the PWSs with occurrence above the MCL by system size category based on the population served. Specifically, the table shows the number of PWSs with data above the MCL by system size category and the percent of PWSs with data available that had occurrence above the MCL by system size category. As mentioned above in respect to Table 11, there are a greater number of smaller PWSs than larger PWSs, so there are typically a greater number of smaller systems with occurrence above the MCL, while the percentages provide a more normalized comparison across system sizes.

Table 14 Summary of PWSs with occurrence greater than the MCL by system size category for top ten state-specific regulated contaminants

Contaminant (State)	Number (and Percent) of PWSs by Size Category with Occurrence Above MCL				
	Very Small (<500)	Small (500-3,300)	Medium (3,300-10,000)	Large (10,000-100,000)	Very Large (>100,000)
Iron (NC)	492 (27%)	120 (40%)	18 (21%)	23 (22%)	3 (19%)
Manganese (NC)	453 (25%)	84 (28%)	9 (10%)	19 (18%)	2 (13%)
Iron (NY)	352 (23%)	58 (22%)	16 (22%)	14 (21%)	4 (33%)
Chloride (NY)	336 (23%)	29 (12%)	4 (5.6%)	2 (2.8%)	0
Manganese (NY)	201 (14%)	34 (13%)	8 (11%)	9 (9.4%)	1 (6.7%)
Arsenic (NJ)	46 (5.3%)	13 (5.2%)	3 (3.7%)	9 (7.4%)	0
Chloride (CT)	59 (6.0%)	5 (4.4%)	0	1 (3.1%)	0
Fluoride (NY)	18 (0.7%)	7 (1.3%)	2 (1.7%)	3 (3.3%)	0
Zinc (NY)	31 (3.2%)	4 (1.9%)	0	2 (3.2%)	0
Tetrachloroethylene (PCE) (NJ)	12 (1.3%)	0	5 (6.0%)	12 (9.8%)	0

Also, for the top ten contaminants shown in Table 13, Table 15 provides a summary of the PWSs with data above the MCL by primary source water type. Specifically, the table shows the number of PWSs with data above the MCL by primary source water type and the percent of PWSs with data available that have data above the MCL by primary source water type. As mentioned above in respect to Table 12, there are a greater number of groundwater PWSs than surface water PWSs, so there are typically a greater number of groundwater systems with data above the MCL, while the percentages provide a more normalized comparison between groundwater and surface water systems. The percent of PWSs with occurrences above the MCL for iron, manganese, and chloride were greater for groundwater systems, while the percent of PWSs with occurrences above the MCL for fluoride and tetrachloroethylene (PCE) were greater for surface water systems.

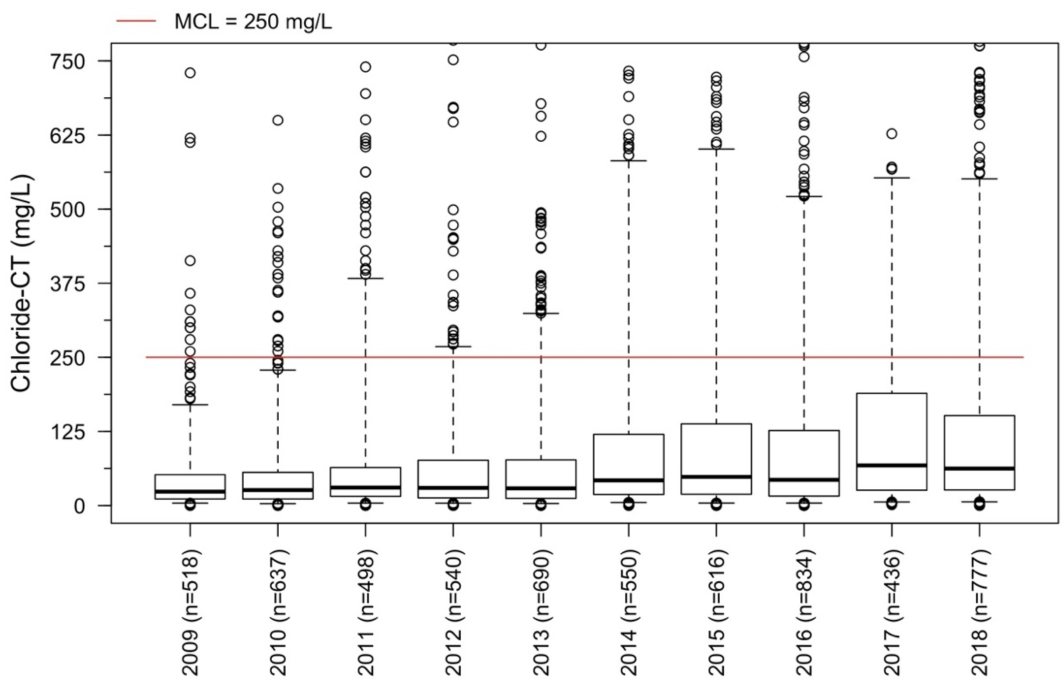
Table 15 Summary of PWSs with occurrence greater than the MCL by primary source water type for top ten state-specific regulated contaminants

Contaminant (State)	Number (and Percent) of PWSs by Primary Source Water Type with Occurrence Above MCL	
	Groundwater	Surface Water
Iron (NC)	617 (29%)	38 (19%)
Manganese (NC)	528 (25%)	37 (18%)
Iron (NY)	405 (24%)	38 (15%)
Chloride (NY)	347 (21%)	22 (9.4%)
Manganese (NY)	223 (14%)	29 (11%)
Arsenic (NJ)	65 (5.3%)	6 (5.4%)
Chloride (CT)	64 (5.9%)	1 (2.0%)
Fluoride (NY)	22 (0.8%)	8 (1.8%)
Zinc (NY)	30 (2.7%)	7 (3.2%)
Tetrachloroethylene (PCE) (NJ)	21 (1.6%)	8 (7.0%)

Increasing trend

The only contaminant in the top ten state-specific regulated contaminants shown in Table 13 that was found to have an increasing trend over time using the Mann-Kendall statistical test was chloride in Connecticut. Yearly boxplots of chloride occurrence data in Connecticut are shown in Figure 12. The USEPA has a non-enforceable secondary standard of 250 mg/L for chloride. Chloride is regulated in the state of Connecticut with an MCL of 250 mg/L, equivalent to the federal secondary standard. From 2009 through 2018, there was a steady increase in annual 95th percentile chloride concentrations from below the MCL of 250 mg/L to more than double the MCL.

Figure 12 Yearly boxplots of chloride occurrence data in Connecticut (2009-2018)



No statistically significant trend

Several contaminants with state-specific regulations included in Table 13 did not have a statistically significant trend over time based on annual 95th percentile values. These contaminants include iron in North Carolina (Figure 13), manganese in New York (Figure 14), arsenic in New Jersey (Figure 15), chloride in New York (Figure 16), and tetrachloroethylene (PCE) in New Jersey (Figure 17). Iron and manganese have federal secondary standards of 0.3 mg/L and 50 µg/L, respectively. In the case of iron in North Carolina and chloride in New York, the states regulate these contaminants at the level of their secondary standard. In the cases of manganese, New York has a health-based regulation of 300 µg/L, well above the non-health-based secondary standard of 50 µg/L. Both arsenic and PCE are federally regulated with MCLs of 10 µg/L and 5 µg/L, respectively. New Jersey regulated these contaminants with lower MCLs of 5 µg/L and 1 µg/L.

Although there was no statistically significant trend, annual 95th percentile values for iron in North Carolina, manganese in New York, and chloride in New York were consistently above their MCLs. This suggests these contaminants may remain contaminants of concern within these states. The annual 95th percentile values for arsenic and PCE were generally below their MCLs, but occurrence above the MCLs suggests they may still be a concern for public health in New Jersey.

Figure 13 Yearly boxplots of iron concentration data in North Carolina (2009-2018)

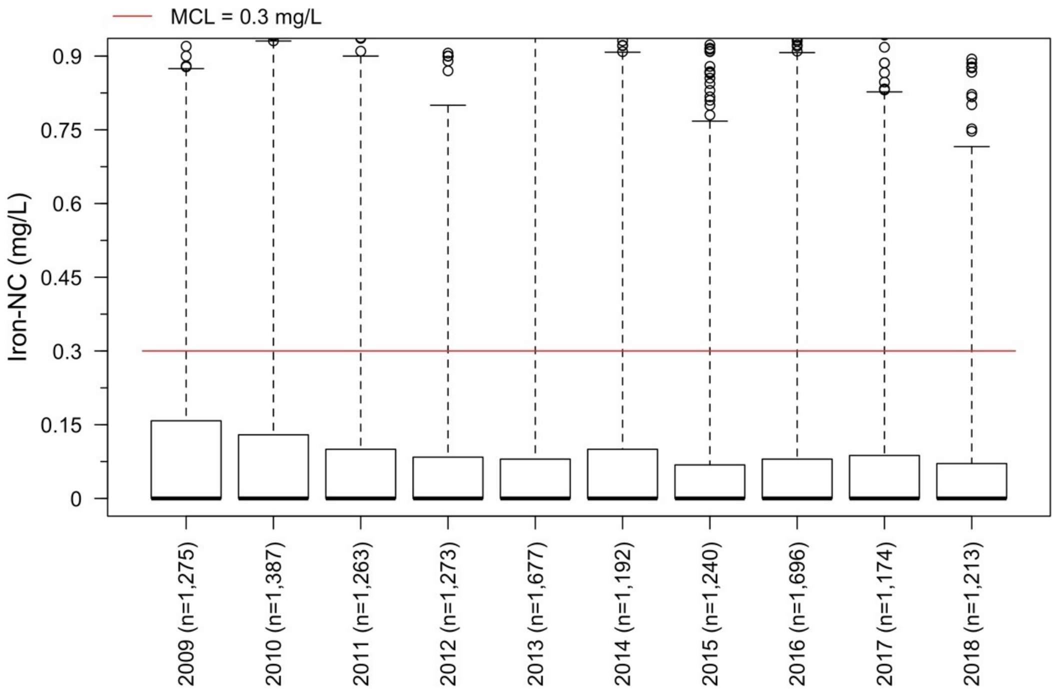


Figure 14 Yearly boxplots of manganese occurrence data in New York (2009-2018)

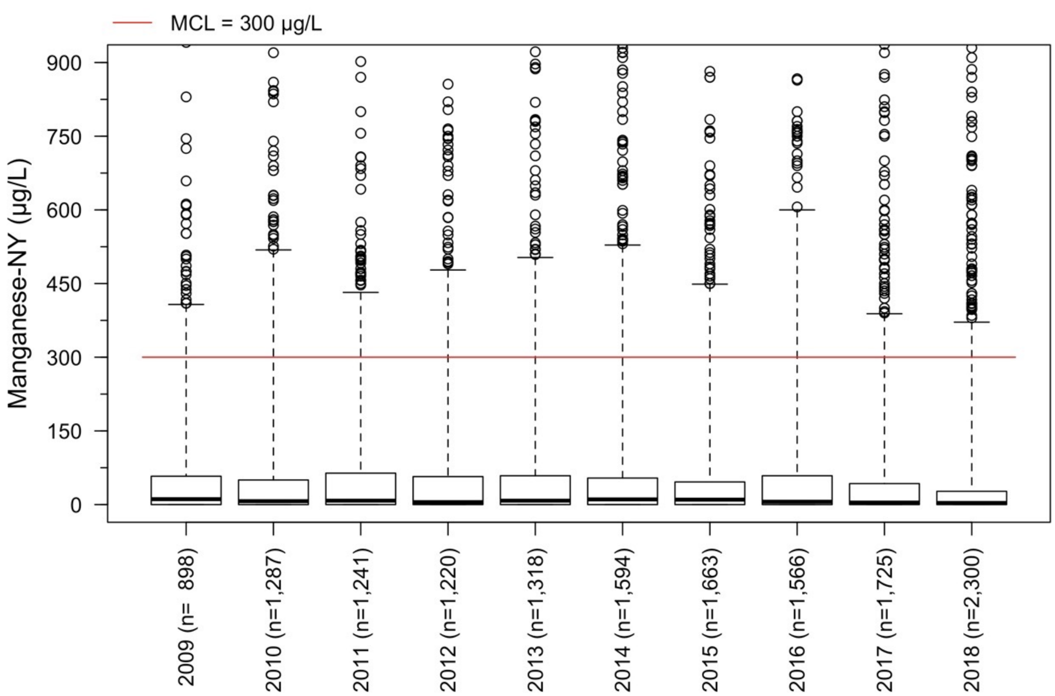


Figure 15 Yearly boxplots of arsenic occurrence data in New Jersey (2009-2018)

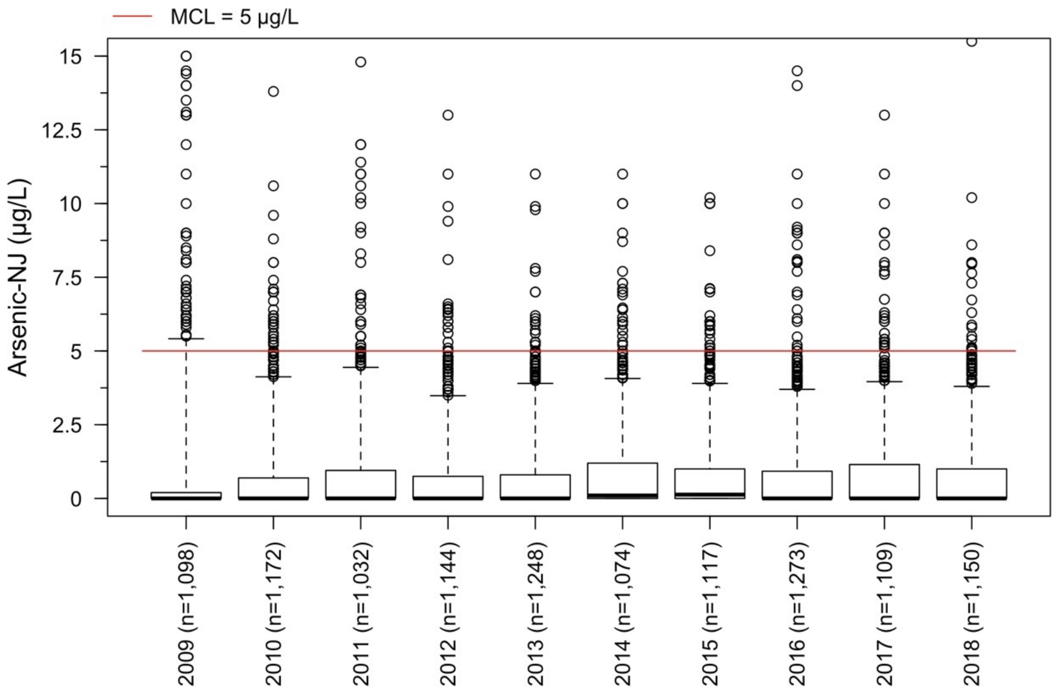


Figure 16 Yearly boxplots of chloride occurrence data in New York (2009-2018)

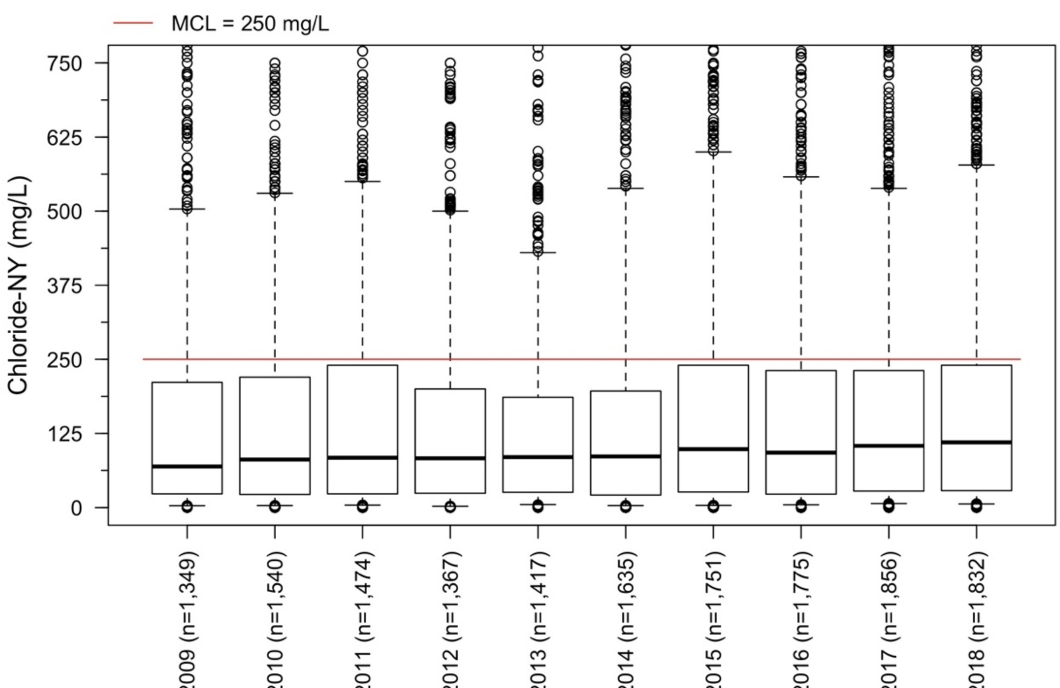
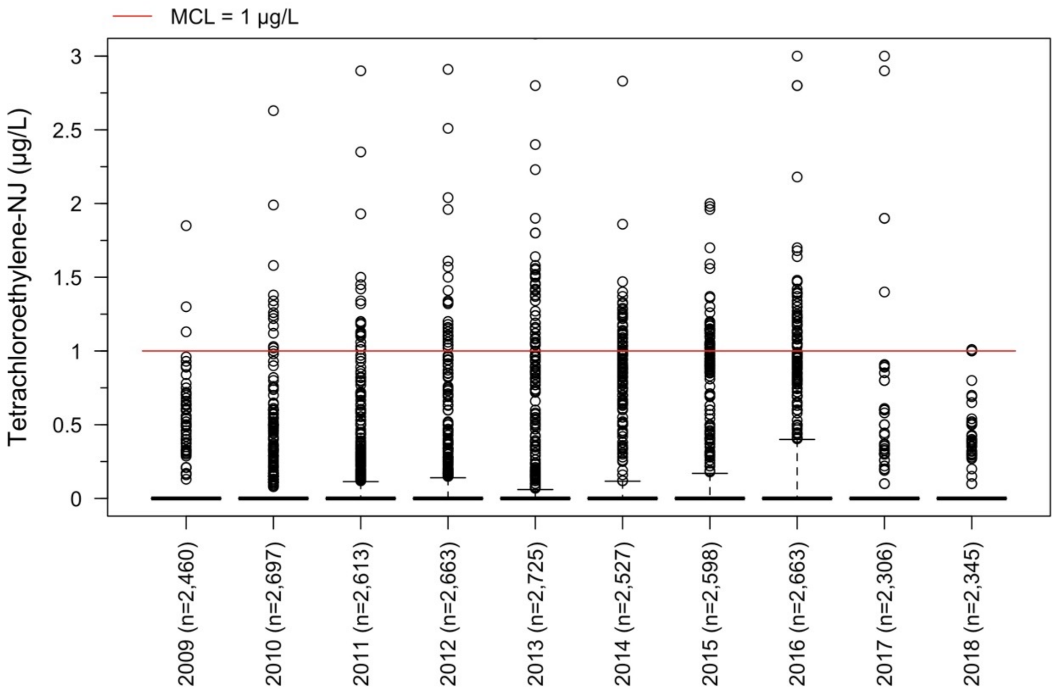


Figure 17 Yearly boxplots of tetrachloroethylene (PCE) occurrence data in New Jersey (2009-2018)



Decreasing trend

The remaining contaminants shown in Table 13 were found to have a decreasing trend from 2009 to 2018 based on their annual 95th percentile values. These contaminants include iron (Figure 18), fluoride (Figure 19), and zinc (Figure 20) in New York. As mentioned above, there is a federal secondary standard for iron of 0.3 mg/L. New York regulated iron at the same level as the secondary standard. Fluoride is federally regulated with an MCL of 4 mg/L. New York regulates fluoride with a lower MCL of 2.2 mg/L. Similar to iron, New York regulates zinc at a level equivalent to its federal secondary standard of 5 mg/L. Annual 95th percentile iron concentrations were well above the MCL of 0.3 mg/L, despite a decrease over time. This suggests iron may remain a contaminant of concern in New York in the next 5-10 years. Annual 95th percentile values for fluoride and zinc were well below their respective MCLs and there were limited occurrences over the MCL suggesting these contaminants may be of less concern.

Figure 18 Yearly boxplots of iron concentration data in New York (2009-2018)

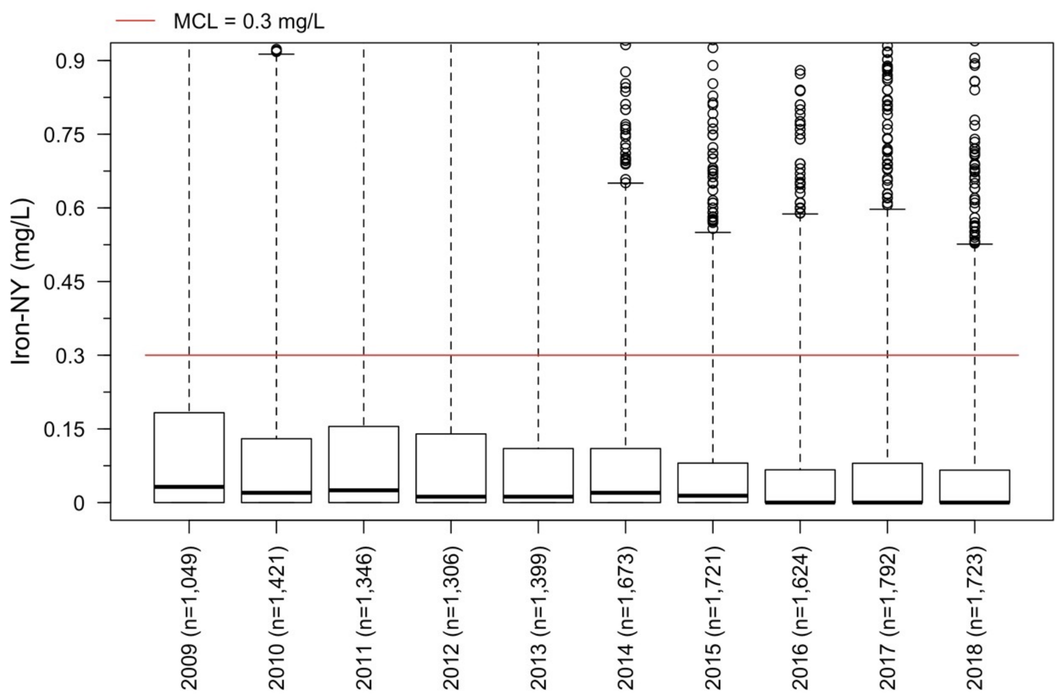


Figure 19 Yearly boxplots of fluoride occurrence data in New York (2009-2018)

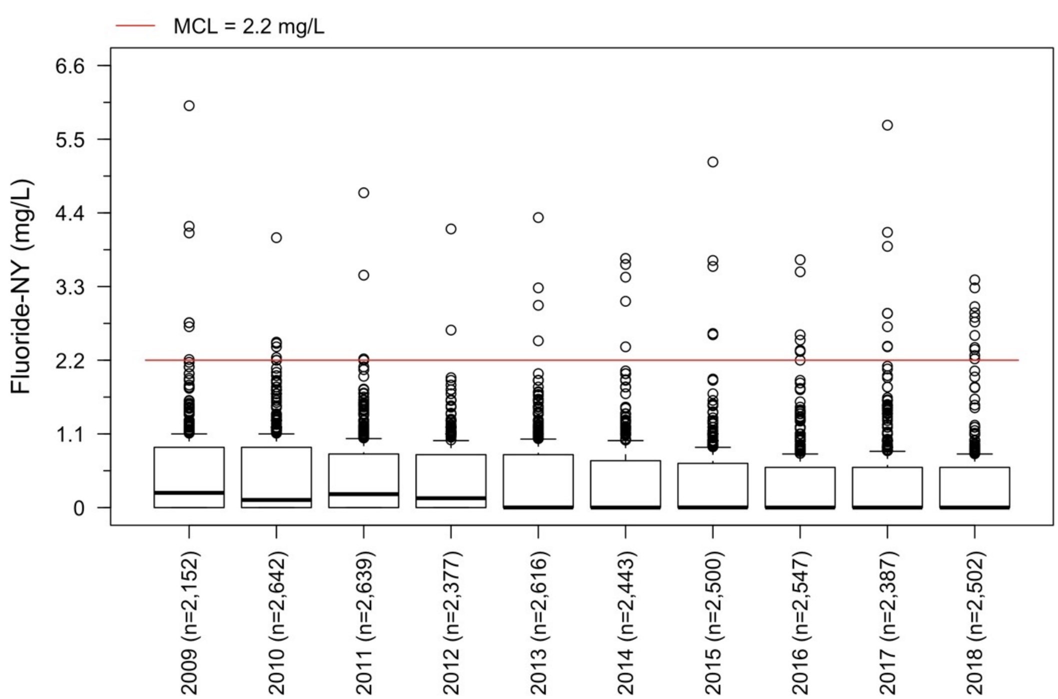
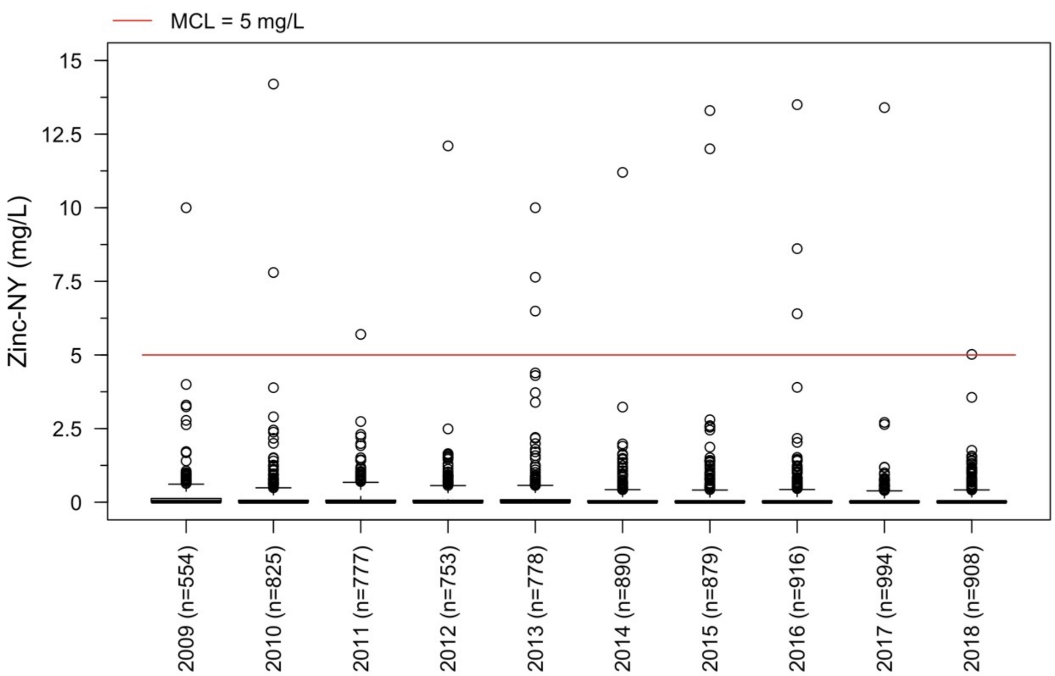


Figure 20 Yearly boxplots of zinc occurrence data in New York (2009-2018)



3: Evaluate Data Gaps

The objective of Task 3 is to explore other resources outside of violation data and UCMR data sets that were used in Task 1 and occurrence data that were used in Task 2 to identify contaminants likely to be a concern for the next 5-10 years. Concern for contaminants can be generated from regulatory changes, which identify the health risks of contaminants as well as the potential for an increase in violations, at least temporarily, while systems respond to changes in standards. Concern can also be generated through academic research, publications, and news articles, which can inform the public about drinking water contaminants and potential health risks. This task explores the upcoming regulatory horizon through a review of EPA's draft Fifth Contaminant Candidate List (CCL5), revisions to the lead & copper rule (LCR), future federal PFAS regulations, and potential Microbial and Disinfectant & Disinfection Byproduct (M/DBP) Rule revisions, among other state-specific potential regulatory changes and emerging contaminants of regulatory interest. Additionally, recent publications and news articles were reviewed to identify top contaminants for research interest and causing public consumer concerns.

EPA's Draft Fifth Contaminant Candidate List (CCL5)

The USEPA's Contaminant Candidate Lists (CCLs) are lists of contaminants that are:

- Not currently subject to any proposed or promulgated national primary drinking water regulations (NPDWRs)
- Known or anticipated to occur in public water systems
- May require future regulations under the Safe Drinking Water Act

The current Draft CCL was released on July 19, 2021 (USEPA 2021a). The draft list includes 66 chemicals, three chemical groups (PFAS, cyanotoxins, and DBPs), and 12 microbes. The contaminants were selected from known chemicals used in commerce, pesticides, biological toxins, disinfection byproducts, and waterborne pathogens. The full draft CCL5 chemical list is shown in Table 16. The full DBP list and microbial list are shown in Table 17 and Table 18, respectively.

Table 16 EPA's Draft CCL5 Chemical List

1,2,3-Trichloropropane	Desisopropyl atrazine	Oxyfluorfen
1,4-Dioxane	Desvenlafaxine	Per- and polyfluoroalkyl substances (PFAS)
17-alpha ethynyl estradiol	Diazinon	Permethrin
2,4-Dinitrophenol	Dicrotophos	Phorate
2-Aminotoluene	Dieldrin	Phosmet
2-Hydroxyatrazine	Dimethoate	Phostebupirim
4-Nonylphenol (all isomers)	Disinfection Byproducts (DBPs) (see Table 17)	Profenofos
6-Chloro-1,3,5-triazine-2,4-diamine	Diuron	Propachlor
Acephate	Ethalfluralin	Propanil
Acrolein	Ethoprop	Propargite
alpha-Hexachlorocyclohexane (alpha-HCH)	Fipronil	Propazine
Anthraquinone	Fluconazole	Propoxur
Bensulide	Flufenacet	Quinoline
Bisphenol A	Fluometuron	Tebuconazole
Boron	Iprodione	Terbufos
Bromoxynil	Lithium	Thiamethoxam
Carbaryl	Malathion	Tri-allate
Carbendazim (MBC)	Manganese	Tribufos
Chlordecone (Kepone)	Methomyl	Tributyl phosphate
Chlorpyrifos	Methyl tert-butyl ether (MTBE)	Trimethylbenzene (1,2,4-)
Cobalt	Methylmercury	Tris(2-chloroethyl) phosphate (TCEP)
Cyanotoxins	Molybdenum	Tungsten
Deethylatrazine	Norflurazon	Vanadium

Table 17 EPA's CCL5 DBP List

Group	Chemical
Haloacetic Acids	Bromochloroacetic acid (BCAA), Bromodichloroacetic acid (BDCAA), Dibromochloroacetic acid (DBCAA), Tribromoacetic acid (TBAA)
Haloacetonitriles	Dichloroacetonitrile (DCAN), Dibromoacetonitrile (DBAN)
Halonitromethanes	Bromodichloronitromethane (BDCNM), Chloropicrin (trichloronitromethane, TCNM), Dibromochloronitromethane (DBCNM)
Iodinated Trihalomethanes	Bromochloroiodomethane (BCIM), Bromodiiodomethane (BDIM), Chlorodiiodomethane (CDIM), Dibromoiodomethane (DBIM), Dichloroiodomethane (DCIM), Iodoform (triiodomethane, TIM)
Nitrosamines	Nitrosodibutylamine (NDBA), N-Nitrosodiethylamine (NDEA) N-Nitrosodimethylamine (NDMA), N-Nitrosodi-n-propylamine (NDPA), N-Nitrosodiphenylamine (NDPhA), Nitrosopyrrolidine (NPYR)
Other	Chlorate, Formaldehyde

Table 18 EPA's CCL5 Microbial List

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

The most notable contaminants in the draft CCL5 based on potential future federal or state regulatory actions or current state regulations, as well as public and research interest, include 1,2,3-trichloropropane, 1,4-dioxane, cyanotoxins, DBPs especially unregulated haloacetic acids, *Legionella pneumophila,* manganese, and PFAS. Currently, 1,2,3-trichloropropane is regulated in California, Hawaii, and New Jersey, 1,4-dioxane is regulated in California and New York, and manganese is regulated in California New York, and North Carolina. Cyanotoxins, manganese, and unregulated haloacetic acids were recently included in EPA's UCMR4. EPA is currently obligated to propose revisions to microbial, disinfectant and disinfection byproduct (M/DBP) rules, which is described further in the section on M/DBP rule revisions below. Potential M/DBP rule revisions may include unregulated haloacetic acids and *Legionella pneumophila*.

Lead & Copper Rule Revisions

The EPA's Lead and Copper Rule Revisions (USEPA 2021b) (LCRR), published on January 15, 2021, became effective as of December 16, 2021 with a scheduled compliance date of October 16, 2024. The LCRR keeps the action level of 15 µg/L for lead, and it establishes a 10 µg/L "trigger level". At this trigger level, systems that currently treat for corrosion are required to re-optimize their existing treatment and systems that do not currently treat for corrosion will be required to conduct a corrosion control study. Systems above the trigger level may also be required to increase their lead service line (LSL) replacement rate. The revised rule also requires community water systems to conduct testing for lead in drinking water and public education in schools and childcare facilities. The most relevant update to the Lead and Copper Rule for the POU/POE industry is that the revised rule now allows community water systems serving populations equal to or less than 10,000 and all non-transient non-community water systems to achieve compliance through the provision and maintenance of POU devices that are certified to reduce lead concentrations (USEPA 2019, WQA 2022).

EPA also published their Review of the National Primary Drinking Water Regulation: Lead and Copper Rule Revisions (USEPA 2021c) on December 17, 2021. In their review, EPA describes their intention to propose a new rule to revise the LCRR to meet goals of replacing 100% of lead service lines (LSLs), equitably improve public health protection for those who cannot afford to replace the customer-owned portions of their LSLs, improve the methods to identify and trigger action in communities that are most at risk of elevated drinking water lead levels, and explore ways to reduce the complexity of the regulations.

The regulatory developments around the lead and copper rule (LCR) and its revisions demonstrate the level of importance and urgency around the topic of lead in drinking water. The removal of 100% of LSLs could dramatically reduce lead concentrations in drinking water, but even in the best possible scenario it will take many years to complete. Lead, as well as copper, will therefore remain major contaminants of concern for the next 5-10 years.

Federal and State PFAS Regulations

The US EPA is currently working towards setting drinking water regulations for PFAS, with developments planned for the next several years. Table 19 summarizes past, current, and planned future federal actions on PFAS, starting with UCMR3 monitoring during 2013 through 2015. Plans for 2022 and 2023 include the release of health advisories for GenX and PFBS, proposed and final regulations for PFOA and PFOS, and the start of UCMR5, which will require PWSs to monitor for 29 PFAS analytes.

Beyond federal regulations, states including California, Connecticut, Illinois, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, North Carolina, Vermont, and Washington have set their own regulations or health advisories levels. State regulations include different PFAS analytes and different MCLs.

Based on the current and future regulatory framework for PFAS, as well as the upcoming UCMR5 monitoring, it is anticipated that PFAS will remain a major contaminant group of concern for the next 5-10 years. UMCR5 is expected to provide the most comprehensive PFAS occurrence data to date, which will provide a better understanding of the extent of contamination as well as treatment needed to meet future regulatory levels and health-based goals.

Table 19 Timeline of past, current, and planned future federal actions on PFAS

Date	Action
2013 – 2015	EPA required PWSs to monitor for 6 PFAS analytes as part of UCMR3
May 25, 2016	EPA released lifetime health advisory levels for two PFAS analytes, PFOA and PFOS
June 20, 2018	US Department of Health and Human Services' Agency for Toxic Substance & Disease Registry (ATSDR) released their Toxicological Profile for Perfluoroalkyls draft for public comment
March 3, 2021	EPA published the Fourth Regulatory Determinations (USEPA 2021d), with a final determination to regulate PFOA & PFOS in drinking water
May, 2021	The ATSDR released their final Toxicological Profile for Perfluoroalkyls
October 18, 2021	EPA announced a PFAS Strategic Roadmap
Fall 2021 and ongoing	EPA to publish final toxicity assessment for GenX and five additional PFAS – PFBA, PFHxA, PFHxS, PFNA, and PFDA
2022 and ongoing	EPA plans to restrict PFAS discharges from industrial sources through a multi-faceted Effluent Limitations Guidelines program
June 15 2022	EPA released interim health advisories for PFOA (0.004 ppt) and PFOS (0.02 ppt) and final health advisories for GenX (10 ppt) and PFBS (2,000 ppt)
Fall 2022	EPA expects to issue a proposed regulation for PFOA & PFOS
2023 – 2025	EPA will require PWSs to monitor for 29 PFAS analytes as part of UCMR5
Fall 2023	EPA expects to issue a final rule for PFOA & PFOS

Potential Microbial and Disinfectant & Disinfection Byproduct (MDBP) Rule Revisions

In 2020, EPA reached a settlement agreement with the Waterkeepers Alliance, Inc. that commits EPA to propose revisions to the current primary standards for chlorite, *Cryptosporidium*, *Giardia lamblia*, haloacetic acids, heterotrophic bacteria, *Legionella*, TTHM, and viruses, by Nov. 31, 2024 unless action is delayed by EPA seeking data through an information collection rule or input from a federal advisory committee. EPA hosted an initial two-day workshop in October 2020 followed by a series of MDBP Stakeholder Meetings throughout 2021 to solicit input on improving public health protection from M/DBPs in drinking water. DBPs, including unregulated haloacetic acids, and *Legionella*, in particular *Legionella pneumophila*, as well as minimum disinfectant residual requirements, distribution system and storage tank management, and building water system quality were all topics of interest throughout these meetings.

In November 2021, EPA requested that the National Drinking Water Advisory Council (NDWAC), a Federal Advisory Committee (FAC) established under the Safe Drinking Water Act (SDWA), provide the agency with advice and recommendations on key issues related to potential revisions to MDBP rules. The inclusion of the NDWAC is expected to delay any proposed revisions until 2025. As a result, MDBPs, especially *Legionella*, TTHM, and haloacetic acids are anticipated to be contaminants of concern for the next 5-10 years.

Other Evidence for Identifying Contaminants of Concern

General research was conducted by reviewing recent publications, conference presentations, news articles, and shared information among the drinking water community to identify contaminants of the greatest concern. The sources of information and summary of results are presented in Table 20. Top contaminants of concern identified include PFAS, lead, arsenic, DBPs, nitrate, *Legionella*, pesticides/insecticides, harmful algal blooms, fluoride, microplastics, perchlorate, 1,2,3-trichloropropane, 1,4-dioxane, chromium-6, and vanadium.

Table 20 Summary of general research to identify drinking water contaminants of concern

Sources of Information	Summary of Results
Web search utilizing key words: "drinking water", "drinking water contaminants"	• PFAS regulations (federal and various state-specific) • Lead contamination (various locations) • Responses to the Environmental Working Group's (EWG) tap water database (multiple contaminants, including PFAS, arsenic, lead, DBPs, nitrate, etc.) • Nitrate and impact of climate change • Boil water orders and infrastructure issues • Taste & odor related issues, i.e., chemical smell, brown water, etc. • Nanomaterials • Other contaminants, including radium and fluoride
Review of recent peer-reviewed publications and conference presentations	• PFAS (treatment, regulations, risk communication, sources, analysis) • Lead (solubility, pipe scales, lead service line detection, reduction, sampling) • Pesticides/insecticides (occurrence, exposure, health risks, removal) • Plastics/microplastics (occurrence, removal) • Harmful algal blooms • DBPs (nitrosamines, regulated, nitrogenous DBPs, formation and control) • Other topics: Affordability, *Legionella pneumophila*, nitrate, arsenic, fluoride, and vanadium
Other potential state-specific regulatory changes	• California's Department of Drinking Water (DDW) released a new revised draft regulation for chromium-6 on March 21, 2022 (California Water Boards 2022)
Drinking water community shared information	• The American Water Works Association (AWWA) held a virtual roundtable *Legal and Regulatory Issues in the Water Space: An Update As 2021 Comes to a Close* on December 10, 2021 that discussed developments with emerging contaminants including PFAS, perchlorate, 1,2,3-trichloropropane, NDMA and other nitrosamines, and 1,4-dioxane • The Association of State Drinking Water Administrators (ASDWA) highlights three contaminants in their special topics pages of their website: lead, PFAS, and *Legionella* • A list of emerging contaminants that consumers are aware from WQRF's Emerging Contaminants Consumer Study by Dr. Marcia Silva at UWM identified the following top ten contaminants: pesticides/herbicides, pharmaceuticals, microplastics, personal care products, PFAS, antimicrobial resistant bacteria, algal blooms, mycobacteria, 1,4-dioxane, and flame retardants

4: Review Chemical Production and Release Databases

The objective of Task 4 was to review EPA's Toxic Substances Control Act (TSCA) Chemical Data Reporting (CDR) and Toxics Release Inventory (TRI) datasets for chemical production, use and release quantities and trends.

The TSCA CDR database includes basic production and exposure-related information for substances produced domestically and imported into the United States. The EPA requests this information every four years from manufacturers, most recently in 2016 (the 2020 data are not yet released). Small manufacturers and certain chemicals are exempt from reporting, and the identity or other information may be withheld from the publicly available dataset if it is claimed as Confidential Business Information and approved by EPA.

The TSCA CDR dataset was used in this analysis to answer the following questions to inform the predictive model:

1) Which chemicals are most commonly produced or imported to the US?
2) Which chemicals are newly produced or imported to the US?
3) Which chemicals have increasing or decreasing trends in production volumes?
4) Which of the most commonly produced chemicals are regulated in drinking water?

The TRI dataset includes information reported by certain specified industries (e.g., manufacturing, chemical manufacturing, hazardous waste treatment) relating to the quantity of toxic chemicals released to the environment or for disposal, reuse or further waste processing. Many of these releases are regularly occurring planned releases related to the management of waste products, but unintended spills or releases are also recorded if the reporting threshold is tripped. The program is intended to provide the public with information about releases of toxic chemicals in their communities and support emergency planning. TRI data are submitted by industries annually and include information about the identity and quantity of material released as well as the release pathway (e.g., air, land, water). Most petroleum mixtures (i.e., gas and diesel) are not directly reportable to the TRI program, although certain common components of petroleum mixtures are on the TRI chemical list (e.g., toluene, benzene). From other data sources, such as the EPA's National Response Center, petroleum mixtures are reported to be among the most commonly released substances. These substances may be under-represented releases in the TRI dataset.

The TRI dataset was used in this analysis to answer the following questions to inform the predictive model:

1) Which toxic chemicals are most commonly released to the environment?
2) Which toxic chemicals are released in the greatest volumes?
3) Which toxic chemicals have increasing or decreasing trends in release volumes?
4) Which of the most commonly released toxic chemicals are regulated?

Methods

TRI and TSCA CDR datasets were downloaded to cover multiple years in the last decade. TRI is released yearly, with the most recent data from 2020. A total of nine years, from 2012 to 2020, were downloaded and processed. The latest dataset for TSCA CDR is 2016 with updates from 2020, but each iteration of the TSCA dataset includes production volume values from past years. The 2016 TSCA CDR dataset includes production volumes from 2016, 2014, 2013 and 2012.

TSCA CDR Data Processing

The TSCA CDR dataset contains four separate files related to different aspects of chemical production. Production information is separated into Consumer and Commercial Use, Industrial Processing and Use, and Manufacturing Information, and the EPA also provides a dataset of nationally aggregated production volumes. The first three files were combined and reduced to a single record per chemical at a facility. The physical forms of each reported chemical were provided, and facilities that only reported chemicals in a solid or gaseous form were excluded from the analysis.

The National Aggregate file provides a range or single value for the national production volume for each chemical. This value is presumed to include production volumes redacted in the public facility dataset as CBI. Chemical ranges in this dataset were not standardized (e.g., some facilities reported a range of 1-10,000 while others reported 1-5,000 or 5,000-10,000). A set of standardized ranges was produced that covered the range of reported volumes. The file was then processed to sort all entries into the applicable range. The low end of each reported range value was used as a single value to sort each chemical into the new standardized ranges to evaluate national production from the National Aggregate file.

Annual production statistics were also evaluated in more detail for each chemical by compiling facility level data. Reported production volumes from individual facilities were aggregated into national and statewide totals to facilitate ranking production volumes within the standardized bins. Facilities reporting a range for production volumes were removed from calculation, as well as entries redacted for confidentiality. Results for the most commonly produced chemicals, chemical categories (see below) and chemicals in the available drinking water quality database (Task 2) are presented below along with statistics for the greatest production volumes.

TRI Data Processing

The TRI dataset consists of one file with many fields covering the breakdown of release pathways. Each yearly file was filtered to applicable columns and output into a single file covering 9 years. The data were then aggregated to national and state release totals by chemical and chemical category (see below). Results for the most commonly released chemicals and chemical categories were calculated along with statistics for the greatest release volumes.

To understand the distribution of both manufactured and released chemicals, chemical names for both the TRI and TSCA CDR datasets were placed into categories using a database developed by Corona for an EPA assessment of acute contamination threats to public water supplies in the United States. These categories were broadly developed to reflect general chemical characteristics most relevant to drinking water systems, such as human health toxicity and treatability. The TRI dataset is limited to toxic chemicals, which are generally those causing cancer or other chronic human health effects, significant adverse acute human health effects or significant adverse environmental effects. The TRI list currently contains 770 chemicals and 33 chemical categories, many of which were encountered during development of the EPA chemical category matching dataset. This overlap lead to the majority of chemicals in the merged TRI dataset being successfully matched to a chemical category by chemical abstract service number (CAS) or chemical name. After a review of the unmatched chemicals, only one chemical name out of 595 was left unmatched. In contrast, the TSCA CDR dataset contains any substance produced or imported into the United States above the reporting threshold regardless of toxicity. Only 48% of the total chemicals in the TSCA CDR dataset were successfully matched using the previously developed EPA database. However, it is expected that most of the contaminants of greatest interest to the drinking water community would be among the list of contaminants that were matched to a category.

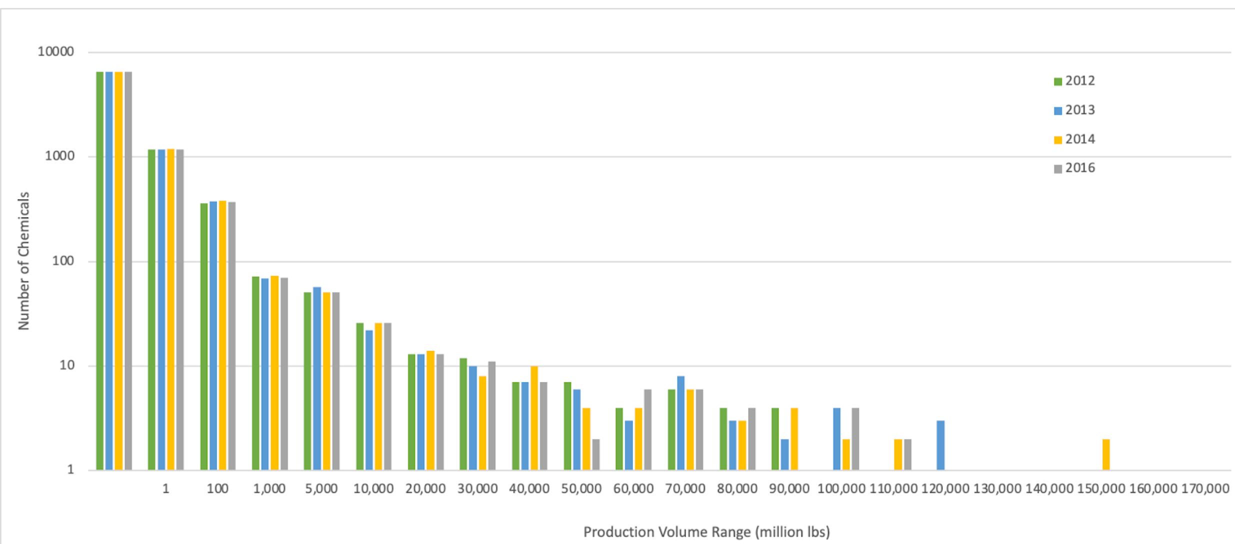
The TRI dataset includes data for releases to multiple air, water and ground pathways. Releases to air may be expected to have a different magnitude of impact on drinking water quality than releases to water or ground due to the additional fate and transport mechanisms involved in air transport and deposition. To investigate whether any of the top contaminants released by volume and occurrence were dominated by releases to air, the top 10 list was reviewed for the set of facilities with no releases to air. Releases to air were defined as the sum of the 'Fugitive Air' and 'Stack Air' data fields from the TRI dataset. (Products sent to incinerators are considered 'off-site treatment' and are not included the release totals in the TRI dataset.)

Results

TSCA CDR Results

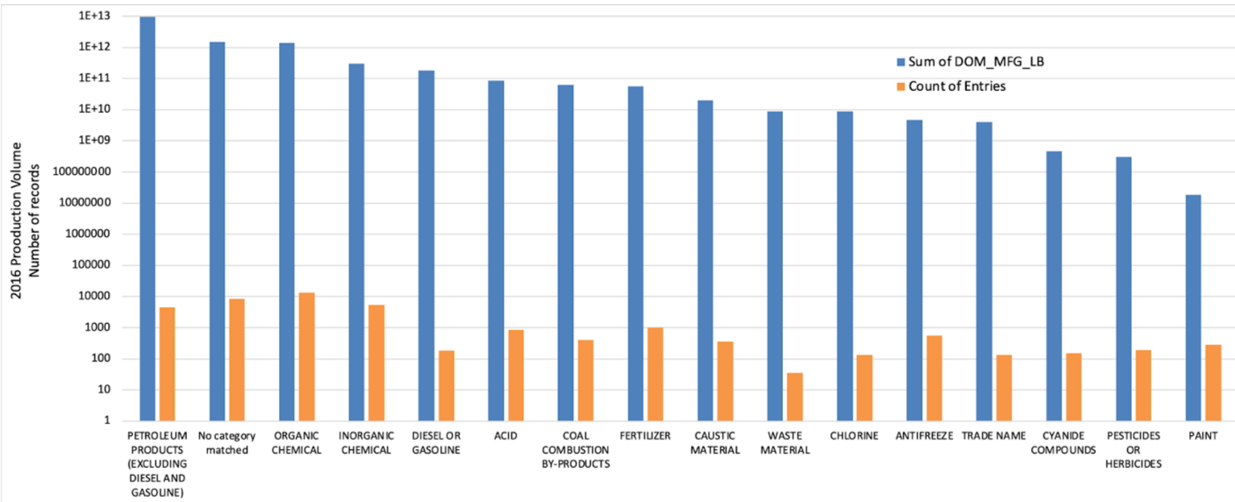
The TSCA CDR dataset included 8,316 unique chemicals, covering over 35,000 entries at specific facilities. Overall chemical production was relatively similar across the four years included in the dataset (Figure 21). Seventy-eight percent of chemicals were produced at quantities under 1 billion pounds.

Figure 21 Annual number of TSCA CDR chemicals for each binned national aggregate production volume



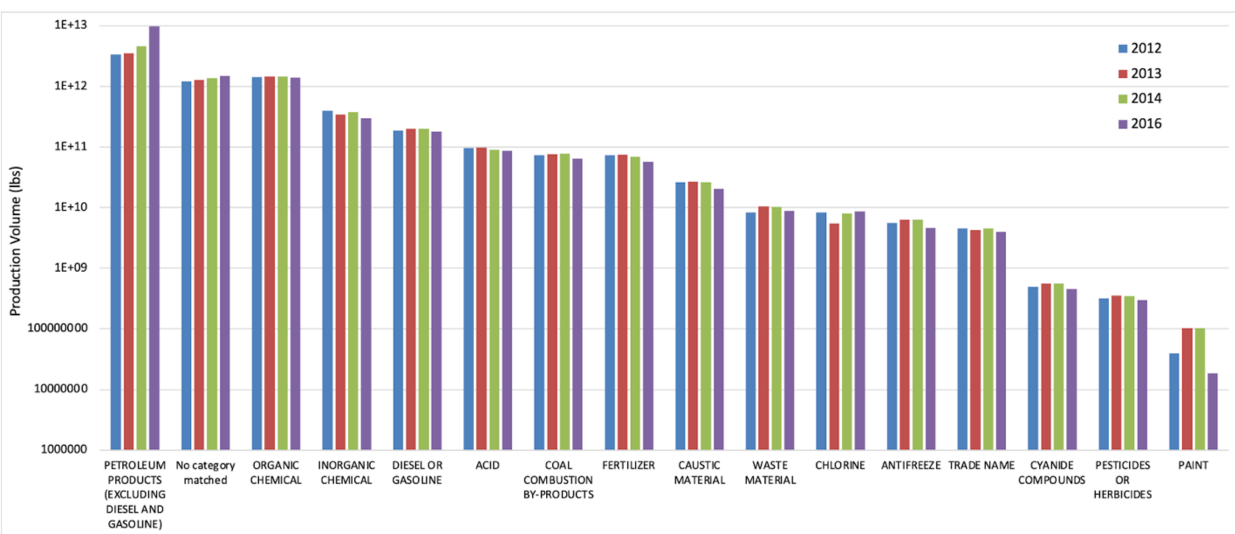
When aggregated by chemical category, the greatest production volumes in 2016 were for petroleum products (excluding diesel and gasoline), organic chemicals and inorganic chemicals (Figure 22). However, the total production volume of chemicals that were not matched to any category was second only to petroleum products in total production volume. A quick skim of the list of uncategorized contaminants revealed a wide variety of chemicals and mixtures. Additional research would be required to confidently place these substances into one of the established chemical categories. Several of the chemical categories with the largest production volumes are likely to contain substances with state or federal drinking water regulations, such as Cyanide Compounds, Pesticides or Herbicides, Organic Chemicals, etc.

Figure 22 TSCA CDR total production volume and frequency of production for 2016 aggregated by chemical category



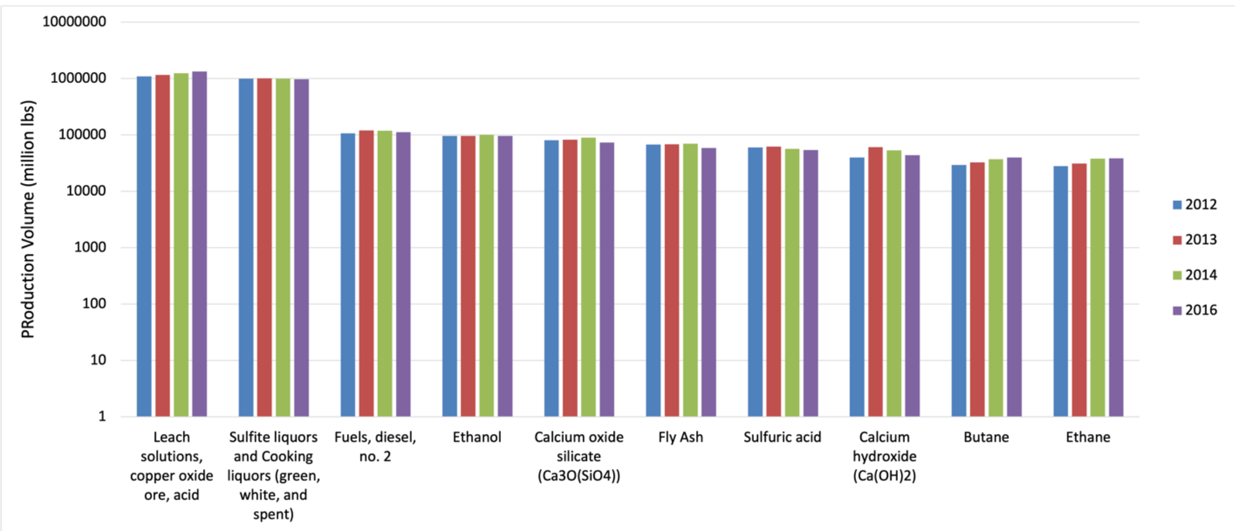
Chemical production volumes by category remained relatively stable over the 4-year study period, except for paint, which had variable production volume from year to year and petroleum products, which showed an increasing trend in production volume over time (Figure 23).

Figure 23 The TSCA CDR production volume aggregated by chemical category over 4 years



Annual production data for the top ten chemicals produced in the greatest volumes in the United States are displayed in Figure 24. Production volumes for each of the top 10 chemicals remained relatively constant over the study period, with the exception of a slight increase in butane and ethane. Leach solutions, a byproduct of mining/metallurgy operations, and sulfite liquors, a byproduct of paper pulp manufacturing, exceeded production in the other categories by approximately an order of magnitude. None of the top 10 chemicals by production volume have federal MCLs, although leach solutions, sulfite liquors and fly ash (a chemically diverse byproduct of coal combustion) are mixtures that may contain federally regulated substances. Butane and ethane are generally gaseous at under atmospheric pressure and temperature and thus are not anticipated to pose a significant threat to drinking water quality.

Figure 24 Annual production volumes for the top ten chemicals produced in the greatest volumes in 2016



The 60 chemicals produced or imported in 2016 that were not previously reported in 2012, 2013 or 2014 are listed below. Further review of the fate, transport, potential health impacts and treatability of these substances may identify a set of contaminants that could become priorities farther in the future, as the drinking water quality and public health impacts of many of these substances are likely not well understood.

- 1-Butanol, 3-methyl-
- 1-Hexadecanol, 1-(dihydrogen phosphate), potassium salt (1:1)
- 1-Propene, 1-chloro-3,3,3-trifluoro-, (1E)-, manufacturing of, residues
- 1,2-Benzenedicarboxylic acid, 1,2-dihexyl ester
- 1,2-Benzenedicarboxylic acid, di-C11-14-branched alkyl esters, C13-rich
- 2-Butenedioic acid (2Z)-, 1-dodecyl ester
- 2-Naphthalenesulfonic acid, 6-hydroxy-5-[2-(2-methoxy-5-methyl-4-s ulfophenyl)diazenyl]-, sodium salt (1:2)
- 2-Propen-1-amine
- 2-Propen-1-amine, N-2-propen-1-yl-
- 2-Propen-1-amine, N-ethyl-2-methyl-
- 3,8-Dioxa-4,7-disiladecane, 4,4,7,7-tetraethoxy-

- 4-Undecanol, 7-ethyl-2-methyl-
- 7-Octen-2-ol, 2-methyl-6-methylene-, 2-acetate
- 9-Octadecenoic acid (9Z)-, 2,3-dihydroxypropyl ester
- Acetic acid, ammonium zinc salt (1:?:?)
- Aliphatic glycol (PROVISIONAL)
- Alkanes, C10-13-branched and linear
- Alkanes, C12-15-branched and linear
- Alkanes, C14-16-branched and linear
- Alkanes, C15-19-branched and linear
- Alkanes, C18-24-branched and linear
- Alkanes, C8-11-branched and linear
- Alkanes, C9-12-branched and linear
- Alkanes, C9-13-branched and linear
- Benzene, octyl-
- Benzenepropanal, .alpha.,.alpha.-dimethyl-
- Benzenesulfonic acid, C16-24-alkyl derivs.
- Benzothiazole, 2-[(chloromethyl)thio]-
- Betaines, C10-16-alkyl(2-hydroxy-3-s ulfopropyl)dimethyl
- Carbon fluoride
- Chromium, 4-hydroxy-3-[2-(2-hydroxy-1-n aphthalenyl)diazenyl]benzenesulfonamide N-[7-hydroxy-8-[2-(2-hydroxy-5-n itrophenyl)diazenyl]-1-n aphthalenyl]acetamide lithium sodium complexes
- D-Fructose
- Distillates (petroleum), naphtha-raffinate pyrolyzate-derived, gasoline-blending
- Fatty acids, C18-unsatd., dimers, reaction products with diethylenetriamine
- Fatty acids, tall-oil, compds. with oleylamine
- Fatty acids, tall-oil, reaction products with 2-[(2-aminoethyl)amino]ethanol
- Fatty acids, unsaturated, reaction products with unsaturated heterocycle (PROVISIONAL)
- Fatty acids, vegetable-oil, reaction products with diethylenetriamine, acetates
- Glycine, N,N'-1,2-ethanediylbis[N-(carboxymethyl)-, potassium salt (1:4)
- Hexanoic acid, 3,5,5-trimethyl-, 1,1'-[2-ethyl-2-[[(3,5,5-trimethyl-1-o xohexyl)oxy]methyl]-1,3-propanediyl] ester
- Isononanoic acid, 2-ethylhexyl ester
- Isononanoic acid, C16-18-alkyl esters
- Isononanoic acid, triester with 2,2'-[oxybis(methylene)]bis[2-(hydroxymethyl)-1,3-propanediol] tris(2-ethylhexanoate)
- Magnesium, chloromethyl-
- Maleate mixed esters with straight and branched alkyl alcohols (PROVISIONAL)
- Morpholine, 4-ethyl-
- Morpholinium, 4-dodecyl-4-ethyl-, ethyl sulfate (1:1)
- Morpholinium, 4-ethyl-4-hexadecyl-, ethyl sulfate (1:1)
- Phosphinic acid, calcium salt (2:1)
- Phosphorous acid, tris(methylphenyl) ester
- Polyaromatic organophosphorus compound (PROVISIONAL)

- Propanoic acid, 2,3,3,3-tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)-
- Propanoic acid, 2,3,3,3-tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)-, ammonium salt (1:1)
- Pyridine, alkyl derivs., acetates
- Quaternary ammonium compounds, (oxydi-2,1-ethanediyl)bis[coco alkyldimethyl, dichlorides
- Reaction product of alkylthioalcohol and substituted phosphorus compound (PROVISIONAL)
- Sulfonic acids, C15-20-alkane hydroxy and C15-20-alkene, sodium salts
- Sulfurized hydrocarbon
- Tetradecane, naphthalenediylbis-
- Tetradecane, naphthalenetriyltris-

The EPA allows companies to redact certain Confidential Business Information (CBI) from the publicly available TSCA CDR dataset. The identity of the chemical may not be withheld but other production and facility information may be claimed as CBI and withheld (Table 21). Information about the parent company is withheld at a rate nearly twice that of the site company. More than one third of production volumes for 2016 are redacted as CBI. Over the four-year record, the percentage of redacted production volumes decreased by 8%.

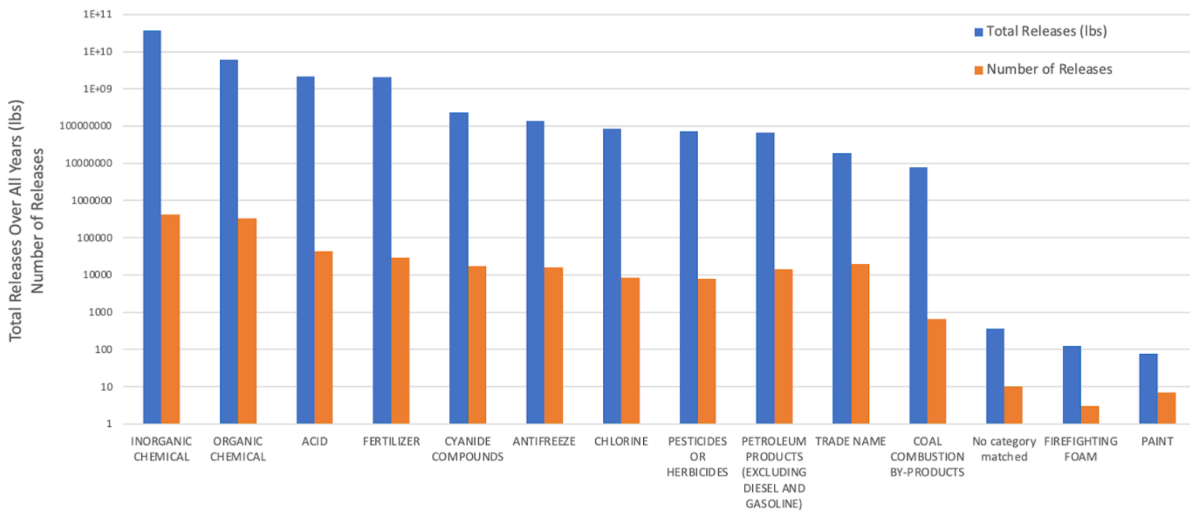
Table 21 Number and Percent of Confidential Business Information (CBI) entries in the TSCA CDR dataset for 2016

Data Field	**Number of CBI Records**	**Percent of CBI Records**
CASRN	0	0
Chemical Name	0	0
2016 Domestic Production	12991	37
2014 Domestic Production	14961	42
2013 Domestic Production	12899	42
2012 Domestic Production	15587	44
Parent Name	4131	12
Parent Address	4131	12
Parent State[1]	4131	12
Site Name	2223	6.3
Site Address	2223	6.3
Site State	2223	6.3

TRI Results

The total mass of releases over the 9-year study period from 2012-2020 generally follows the same distribution as the number of releases (Figure 25). Inorganic and organic chemicals have both the greatest total number of releases and release amounts. Acids and fertilizers are the next two categories released most frequently and in the greatest masses. Petroleum products included in the TRI dataset are naphthalene, polychlorinated biphenyls, and polychlorinated alkanes; diesel and gasoline products are excluded from reporting. Several of the chemical categories are likely to contain regulated substances, such as Cyanide Compounds, Pesticides or Herbicides, Organic Chemicals, etc. In the next phase of work, we will investigate whether these releases are primarily to air, which may have a more diffuse impact on drinking water sources, or other pathways that might affect drinking water sources more directly (e.g., land or water).

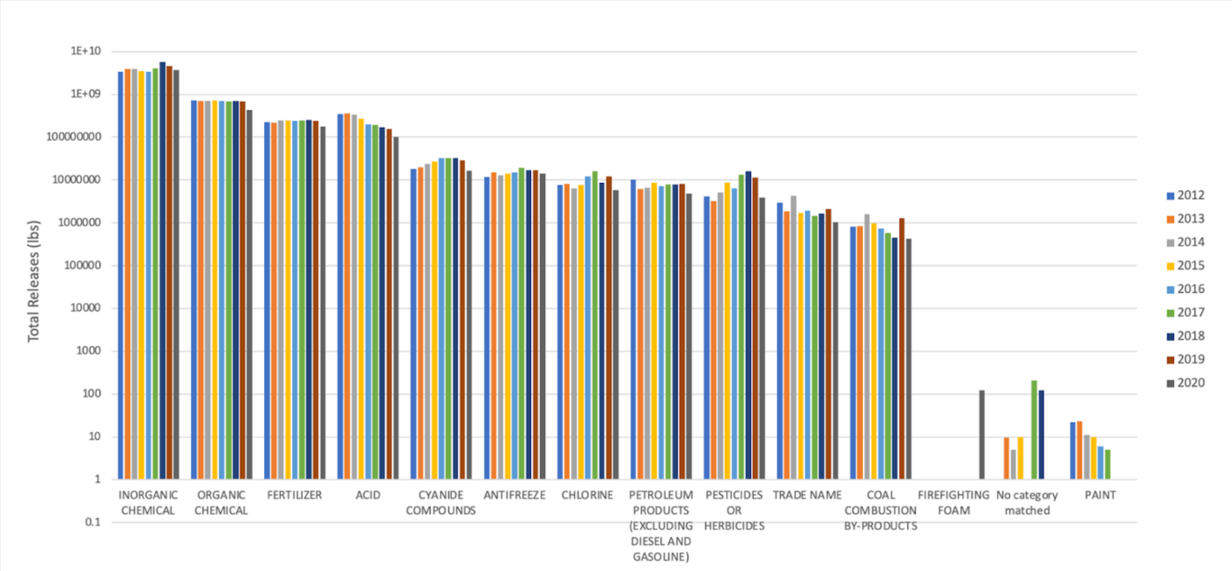
Figure 25 Number and cumulative quantity of releases by chemical category in the TRI dataset (2012-2020)



The trend in releases of toxic substances over the study period is variable by category (Figure 26). Organic, inorganic, fertilizer, non-diesel or gasoline petroleum products and antifreeze chemical releases have not significantly changed since 2012. However, acids, coal combustion by-products, and trade name chemical releases appear to be decreasing in total released mass since 2012. Other categories, such as chlorine, cyanide compounds, and pesticides/herbicides do not have obvious trends. Firefighting foam was introduced as a reportable chemical category in 2020 with the introduction of certain per- and polyfluoroalkyl substances (PFAS) to the list of reportable substances under the TRI program. Some of the firefighting foams contain PFAS that are likely to be regulated at the federal level soon and are already regulated in some states. Paint was last reported as released in 2017 when a single paint product with a unique chemical fingerprint was reported.

A small but noticeable decrease in releases was observed for reporting year 2020 across all of the chemical categories. Fertilizer and organic chemicals demonstrate this trend most obviously. Our hypothesis is that this consistent decrease in 2020 is likely due to supply chain challenges during the Coronavirus-19 pandemic. It would be interesting to compare this trend against 2020 TSCA CDR chemical production and import data when it becomes available.

Figure 26 Annual release totals for all chemical categories 2012-2020

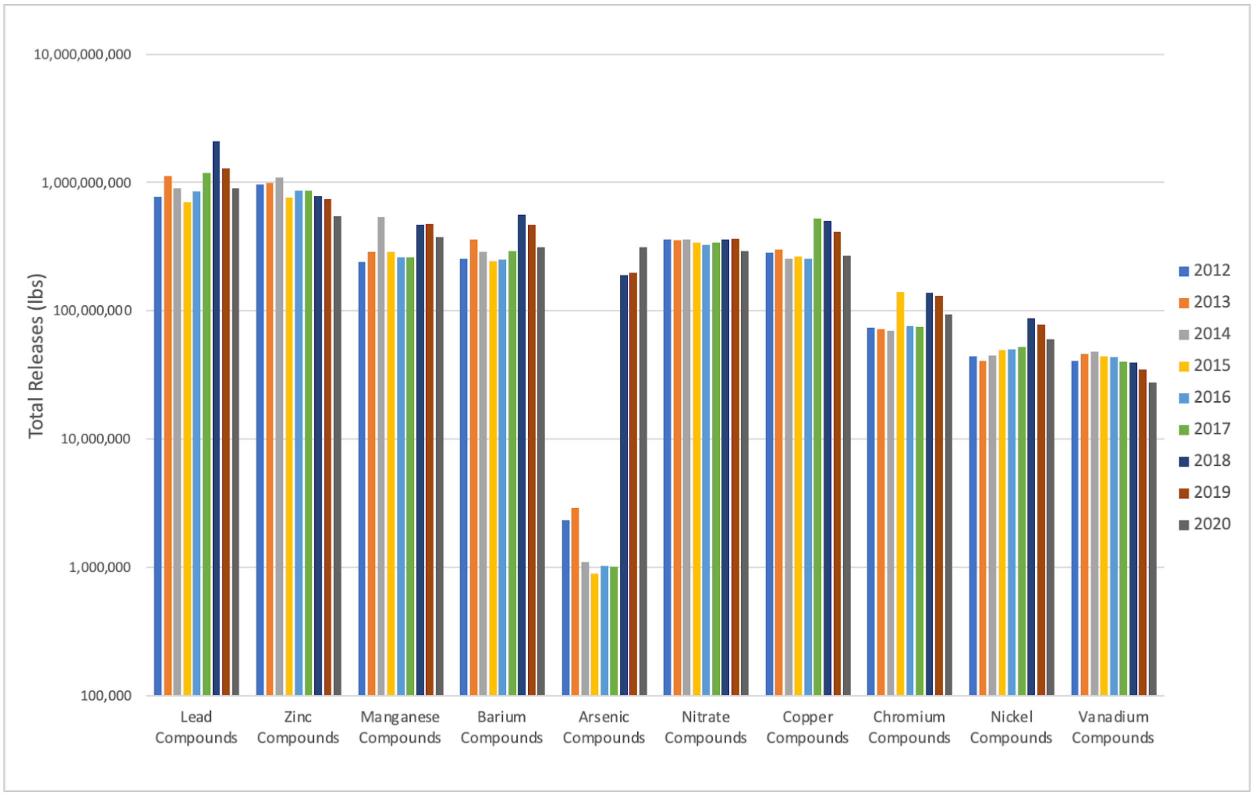


In the category with the greatest released mass, inorganic chemicals, six have federal MCLs chemicals (arsenic, barium, chromium, copper, nickel, and nitrate compounds) (Figure 27). Except for arsenic compounds, each of the top ten inorganic chemicals displayed the same decrease in releases in 2020 that was seen in the category as a whole.

Despite the 2020 decrease and overall variable releases, seven of the most commonly released substances had increasing releases overall from 2012 to 2020. Barium, lead, copper, manganese, nickel, and chromium had modest increases in 2017/2018 and are still above former levels despite the 2020 drop. Arsenic compound releases increased significantly in 2018, and this is the only category for which releases increased in 2020. Vanadium and zinc releases were the only two among the top 10 inorganic chemicals to decrease. Nitrate releases were stable over the study period, except for the 2020 drop. Certain chemicals on the list of top 10 released inorganics have federal drinking water standards: arsenic, barium, chromium, copper, nickel, and nitrate all have federal MCLs, and manganese has an SMCL.

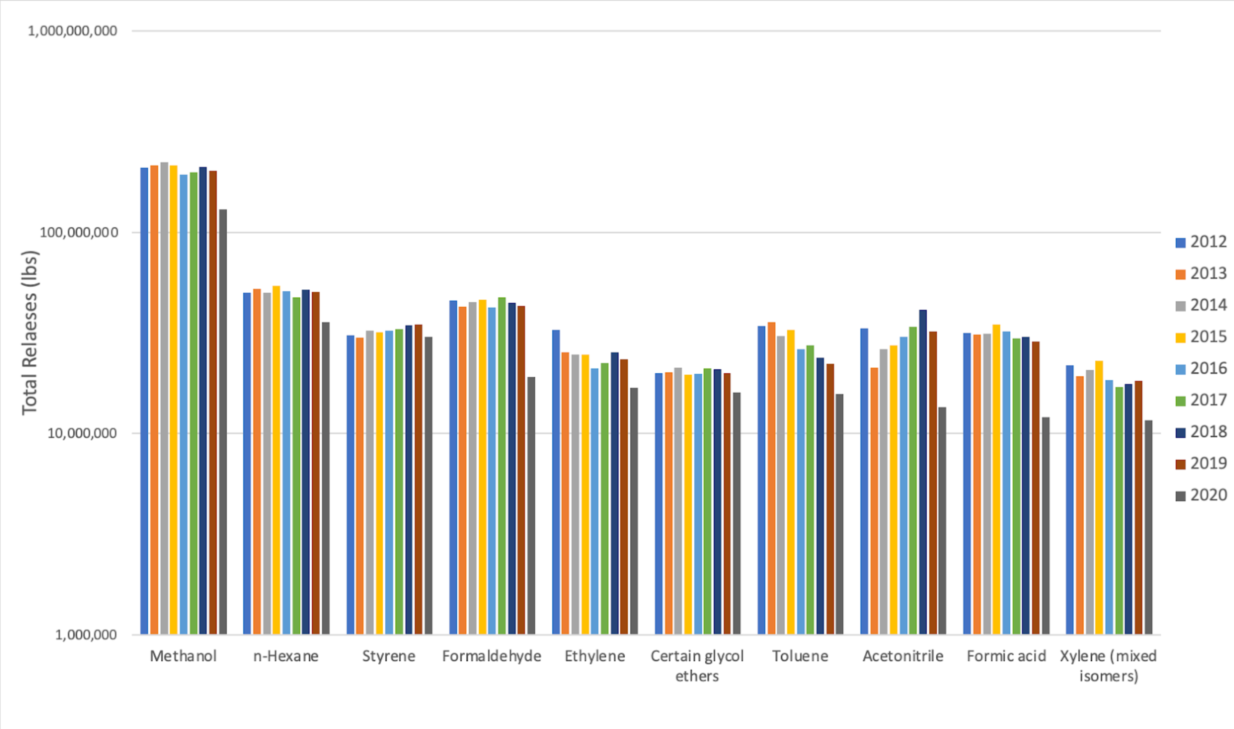
The inorganic chemicals with the top 10 greatest released masses were also the top 10 releases overall, with the exception of methanol and sulfuric acid which replaced nickel and vanadium compounds.

Figure 27 Total releases for the top chemicals in the inorganic category



The category with the second highest total releases was organic chemicals. Figure 28 displays release totals for the top ten chemicals in the organic chemical category. Three of these organic chemicals have federal MCLs (styrene, toluene, and xylene). Unlike the inorganic chemicals, releases of organic chemicals remained relatively stable for six of the ten chemicals (certain glycol ethers, formaldehyde, methanol, formic acid, n-Hexane, and styrene), with the exception of the 2020 drop. Toluene, xylene, and ethylene are generally decreasing, while acetonitrile has increased. A decrease in 2020 is again evident across all chemicals. Two of the three inorganic chemicals with federal MCLs have noticeably decreasing releases across the time period (toluene and xylene), while styrene has remained stable.

Figure 28 Release totals for the top ten chemicals in the organic chemicals category



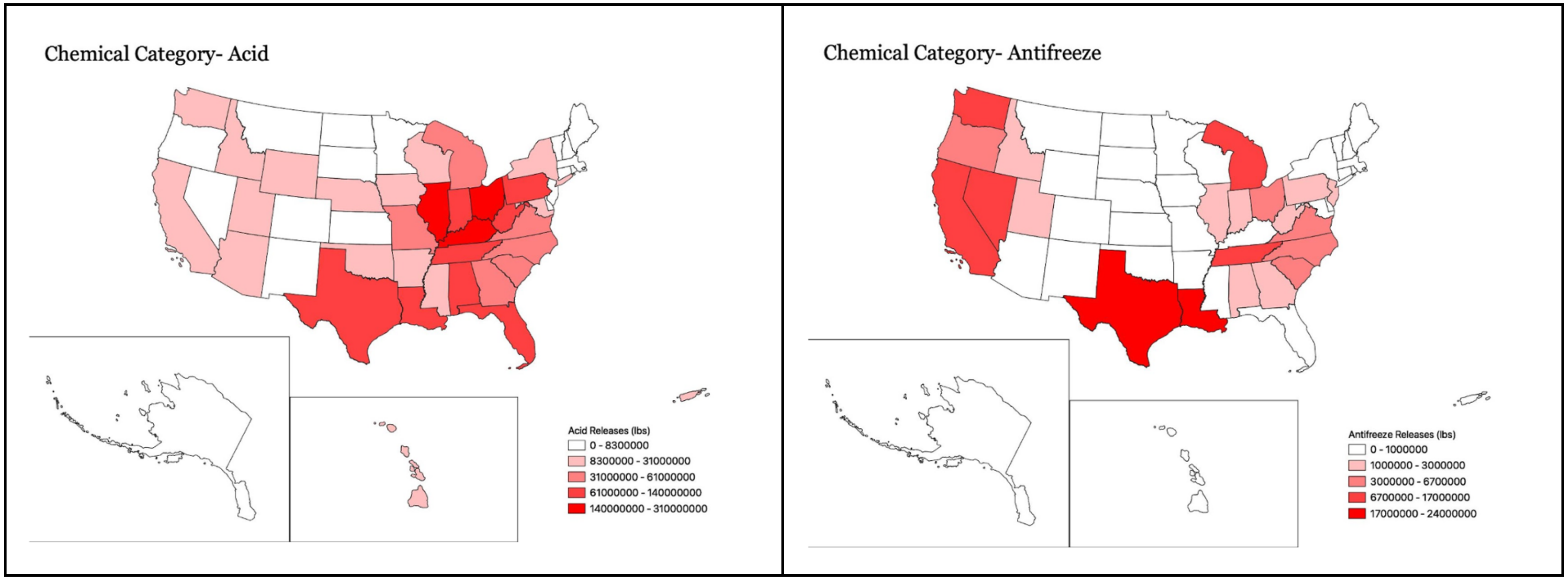
Releases to Air

Releases to air in 2020, as defined previously, constituted 14% of the total volume of reported releases. Among facilities with no releases to air, asbestos, sodium nitrite and nitric acid moved up into the list of top 10 chemicals released by volume, pushing lead, arsenic and methanol farther down the list but still within the top 30 releases by volume. Only sulfuric acid was pushed significantly farther down the list, since this chemical was further defined as 'acid aerosols including mists, vapors, gas, fog, and other airborne forms of any particle size' in the TRI dataset. The rest of the list of top 10 released chemicals by volume was unchanged by the inclusion of releases to air.

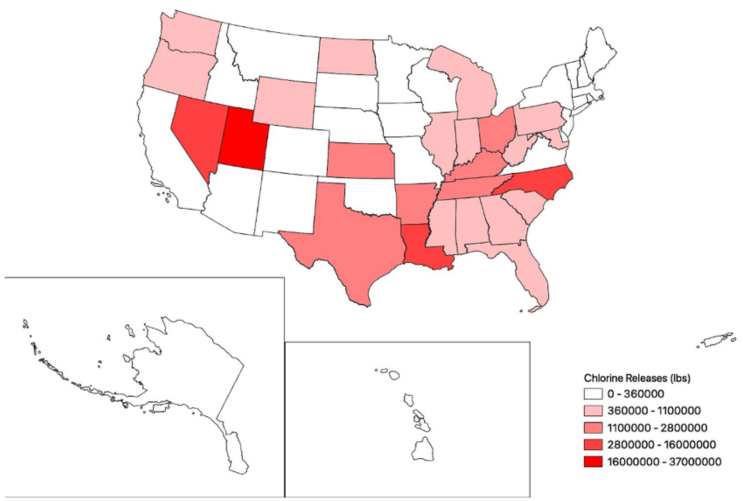
Regional Release Maps

The release of chemicals varies by state due to different levels of production and usage [Fig. 30]. Overall, releases are greatest in the southeastern and southwestern states. Many southern states have large total reported releases in multiple categories due to high levels of production and industry. Texas in particular has significant releases in nearly all chemical categories. By contrast, the northeast has very few and/or small releases across all categories. Releases are typically widespread across the country and are very rarely concentrated in a few states. The two exceptions are firefighting foam and paint, which are only reported in two states. This possibly reflects a niche industry where production of products with reportable substances is concentrated among few companies or factories or confusion over reporting requirements for categories where requirements have changed, as for PFAS in firefighting foams. Interestingly, Alaska had the highest total releases despite only having releases in two categories, inorganic chemicals and cyanide compounds. This result may be due to extensive mining activities, as evidenced by similar patterns for Texas and Nevada, two other states with significant mining activities.

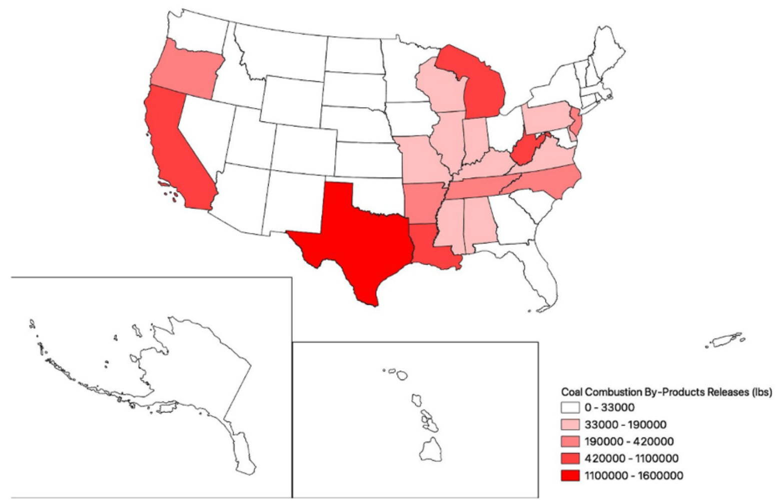
Figure 29 Cumulative releases by category for all states for the study period (2012-2020)



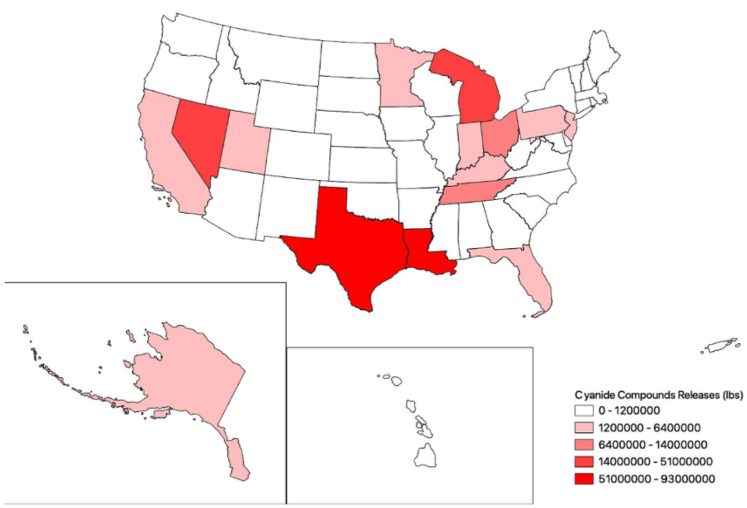
Chemical Category- Chlorine



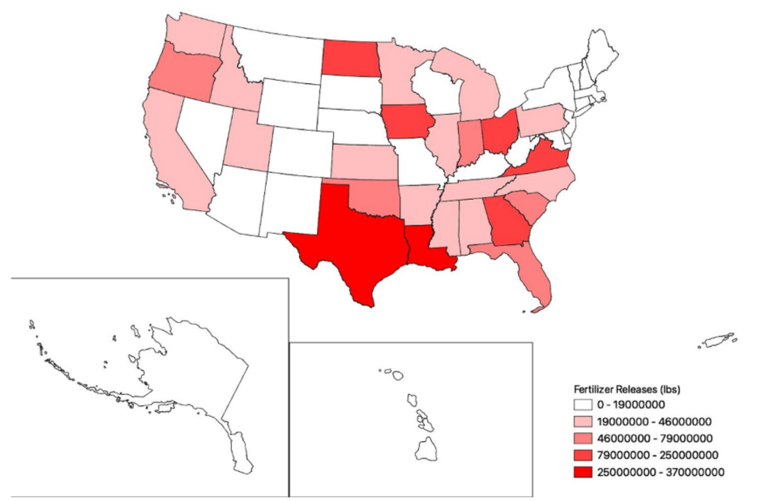
Chemical Category- Coal Combustion By-Products



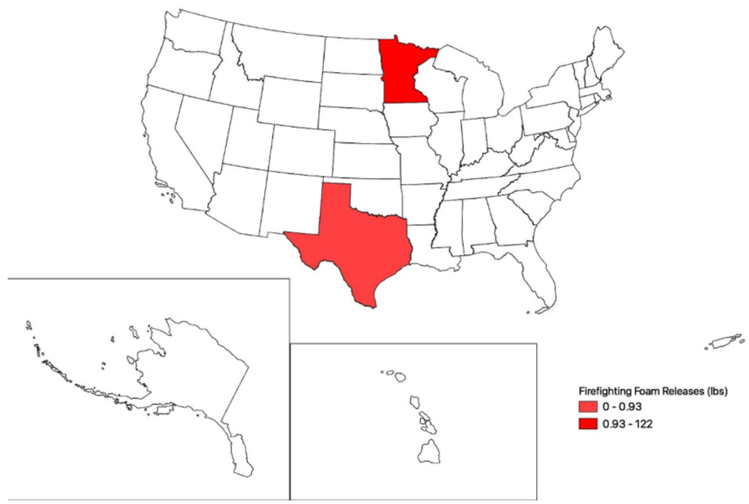
Chemical Category- Cyanide Compounds



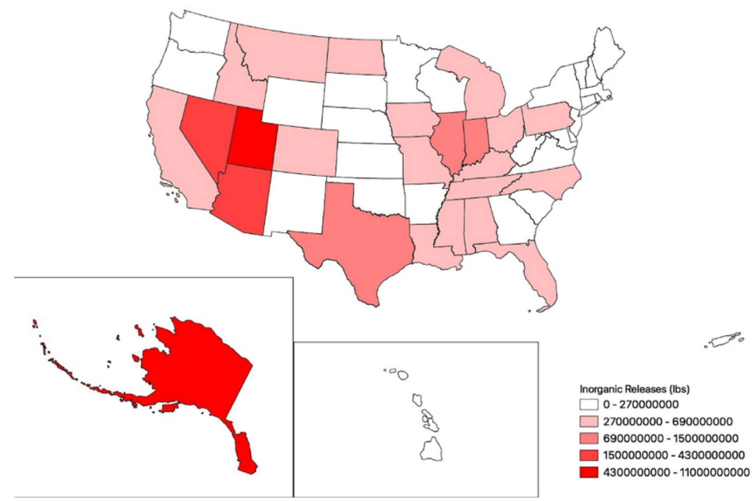
Chemical Category- Fertilizer



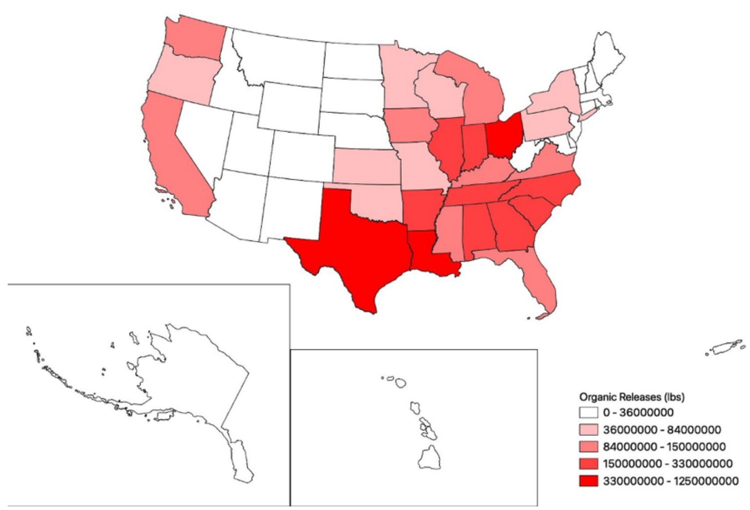
Chemical Category- Firefighting Foam



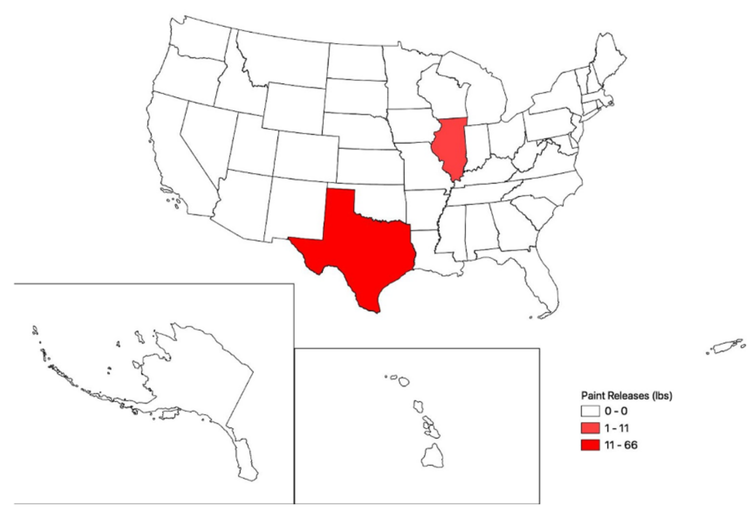
Chemical Category- Inorganic

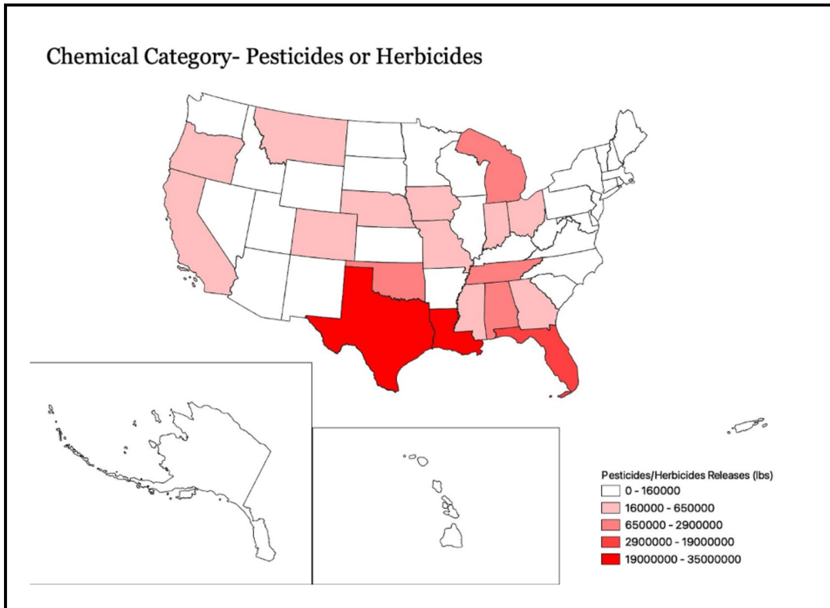


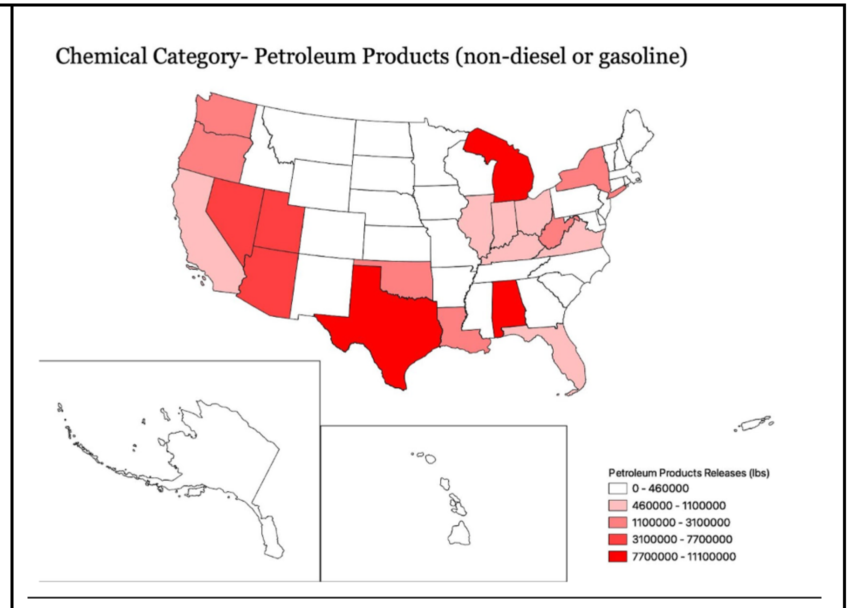
Chemical Category- Organic

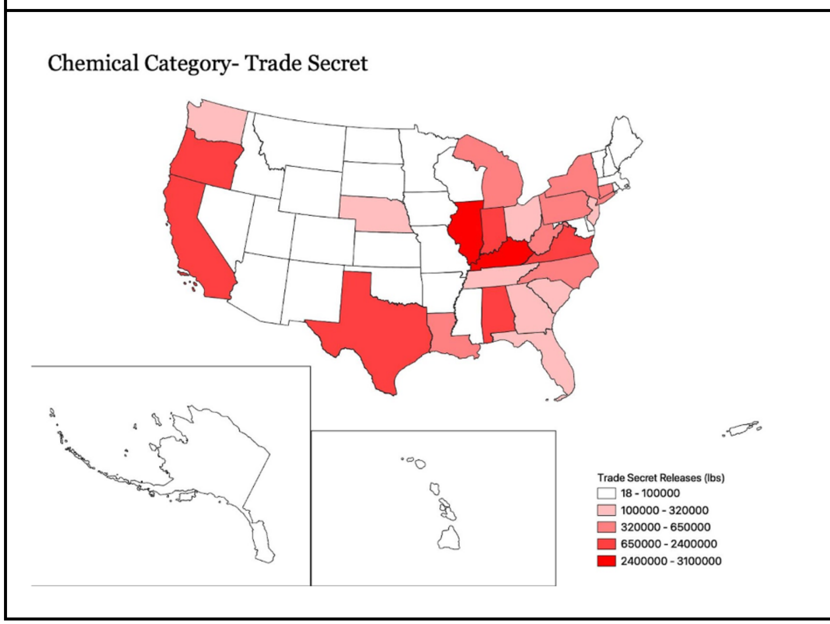


Chemical Category- Paint




Chemical Category- Pesticides or Herbicides
Pesticides/Herbicides Releases (lbs)
0 - 160000
160000 - 650000
650000 - 2900000
2900000 - 19000000
19000000 - 35000000


Chemical Category- Petroleum Products (non-diesel or gasoline)
Petroleum Products Releases (lbs)
0 - 460000
460000 - 1100000
1100000 - 3100000
3100000 - 7700000
7700000 - 11100000


Chemical Category- Trade Secret
Trade Secret Releases (lbs)
18 - 100000
100000 - 320000
320000 - 650000
650000 - 2400000
2400000 - 3100000

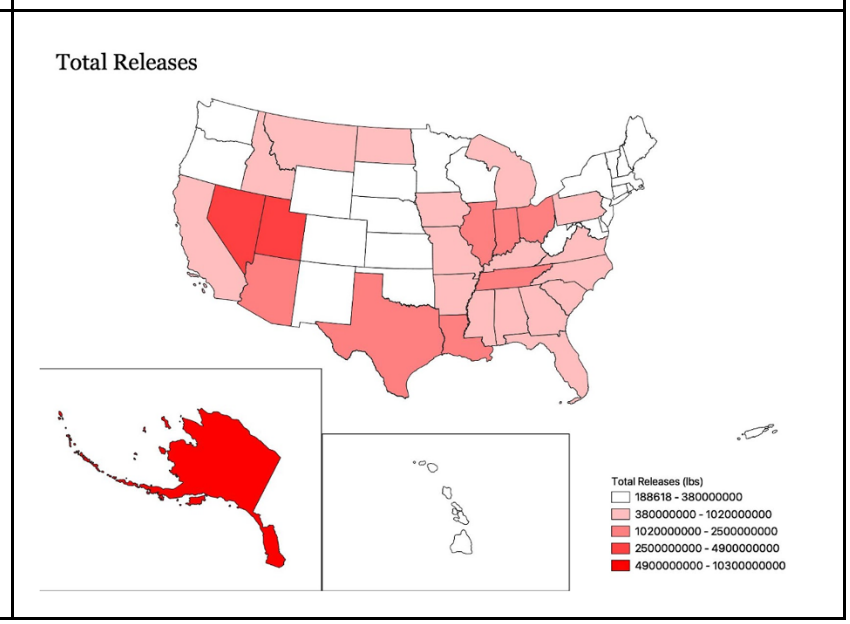

Total Releases
Total Releases (lbs)
188618 - 380000000
380000000 - 1020000000
1020000000 - 2500000000
2500000000 - 4900000000
4900000000 - 10300000000

Table 22 presents a summary of the chemicals with the largest production volumes and largest total release masses from the analysis. Sulfuric acid was the only chemical common to both lists, although Leach Solutions, with the second largest production volume, may include some of the top 10 chemicals by release mass (e.g., copper, lead or zinc compounds).

Table 22 Chemicals with the top 10 production volumes and release masses

Release Data (2020)	**Production Data (2016)**
Lead Compounds	Leach solutions
Zinc Compounds	Sulfite/Cooking liquors
Manganese Compounds	Fuels, diesel No. 2
Barium Compounds	Ethanol
Arsenic Compounds	Calcium oxide silicate
Nitrate Compounds	Fly ash
Copper Compounds	Sulfuric acid
Chromium Compounds	Calcium hydroxide
Methanol	Butane
Sulfuric Acid	Ethane

5 Evaluate POU/POE Treatment Options

In Task 5, the outcomes of Tasks 1-4 were reviewed to develop a list of the contaminants of highest concern identified by each analysis. The development of the list of contaminants of the highest concern considered the analyses conducted in each task and the corresponding outcomes, as well as the authors' best professional judgment on those contaminants that were appropriate for consideration. The chemicals identified from Task 4 were reported as the top produced and/or released chemicals by the EPA. These chemicals were included on the list of contaminants of highest concern, even in cases of little to no data available for drinking water occurrence, as they could represent potential future challenges.

Once the list of the contaminants of the highest concern was compiled, the contaminants were evaluated based on the reasons they were selected, their priority as a drinking water contaminant of concern, and the POU and/or POE treatment options currently available for each contaminant. The evaluations were made through conducting research of available publications as well as the authors' best professional judgment gained from knowledge and experience working in the drinking water community.

Table 23 provides an abbreviated version of the Task 5 deliverable spreadsheet, submitted with this final report. The abbreviated table includes the full list of contaminants, the priority ranking as a drinking water contaminant, the reason for inclusion on the list, the POU/POE treatment category, and the POE and POU treatment options currently available. Contaminants for which POU/POE treatment is not applicable or dependent on the chemical composition of the contaminant that is not specified are listed and described separately in Table 24. The full Task 5 deliverable spreadsheet also includes references and additional information for the contaminants on the list. There are two types of rankings provided in the table: priority for drinking water and POU/POE treatment category. *These are qualitative and subjective rankings assigned by the authors based on the best information available and expert knowledge*. Below is an explanation for the rankings shown in the table:

- Priority for drinking water:
    1. High – contaminants have understood health risks, relatively high occurrence in drinking water at levels of concern based on their health risks in all or most states across the US, and are high priority for the drinking water community (i.e., utilities, treatment providers, researchers, consumers, etc.)
    2. Medium – contaminants that have understood health risks, aesthetic effects, or are emerging contaminants of interest for the drinking water community, occurrence in drinking water at levels of concern may be nationwide or limited to certain regions with contaminated source water
    3. Low – contaminants that have aesthetic effects and are not high priority for the drinking water community at large
- POU/POE treatment category:
    1. Established – Established POU/POE treatment evidenced by NSF/ANSI certified products based on removal claims for contaminant of interest (NSF 2022); available technologies are relatively efficient at removing the contaminant of interest
    2. Available – POU/POE treatment available, needs further research, testing, and/or validation; there may be NSF/ANSI certified products available but there is no verified removal claim for the contaminant of interest, only one technology type is certified while other technologies exist but are not certified for removing the contaminant, or available treatment technologies are not relatively effective or efficient at removing the contaminant of interest
    3. Not Available – POU/POE treatment not well established, not available, or not applicable; no NSF/ANSI certified products with verified removal claims for the contaminant of interest

The results shown in Table 23 provide a summary of the POU/POE treatment options currently available for top priority contaminants, as well as the gaps that may exist in treatment options. *The results provided in the table do not consider aspects such as the initial cost, operational and/or maintenance costs (i.e., filter replacements, energy costs), operational challenges, site-specific considerations, or any unintended consequences associated with the POU/POE treatment options.* It is recommended that these aspects be explored deeper to truly assess the opportunities available for improving POU/POE treatment options for top priority contaminants.

Table 23 POE and POU treatment options for highest priority contaminants

Contaminant	Priority for Drinking Water	Reason for Inclusion	POU/POE Treatment Category	Point of Entry (POE) Treatment Options	Point of Use (POU) Treatment Options
Arsenic	1	*Top 10 list based on number of health based SDWA violations *Top 10 list based on PWSs w/ occurrence over federal MCL *Top 10 list for 2020 chemical release data ("arsenic compounds")	Established	Iron oxide/hydroxides Activated alumina Anion exchange resin in a fixed bed (requires regeneration) Manganese greensand (requires regeneration) Titanium oxy/hydroxide Iron-doped anion resin and activated alumina	Iron oxide/hydroxides Activated alumina with or without iron oxide coating Anion exchange Titanium oxy/hydroxide Reverse osmosis (RO) Carbon block filters
Copper	1	*Top 10 list based on number of health based SDWA violations *Top 10 list based on PWSs w/ occurrence over federal MCL *Top 10 list for 2020 chemical release data ("copper compounds")	Established	Reverse osmosis Cation exchange resin pH neutralizing filter (if copper source is in-home corrosion)	Reverse osmosis (RO) Cation exchange resin
Lead	1	*Top 10 list based on number of health based SDWA violations *Top 10 list based on PWSs w/ occurrence over federal MCL *Top 10 list for 2020 chemical release data ("lead compounds") *Recent revisions to Lead & Copper Rule *Identified in web search for recent new articles and publications	Established	Fine filtration + adsorption	Reverse osmosis Fine filtration + adsorption

Contaminant	Priority for Drinking Water	Reason for Inclusion	POU/POE Treatment Category	Point of Entry (POE) Treatment Options	Point of Use (POU) Treatment Options
Nitrate	1	*Top 10 list based on number of health based SDWA violations *Top 10 list based on PWSs w/ occurrence over federal MCL *Top 10 list for 2020 chemical release data ("nitrate compounds") *Identified in web search for recent new articles and publications	Established	Reverse osmosis (RO) Anion exchange resin (subject to sulfates competitive ion exchange) Nitrate "selective" anion exchange resins	Reverse osmosis (RO) Anion exchange resin (subject to sulfates competitive ion exchange) Nitrate "selective" anion exchange resins
DBPs (TTHM)	1	*Top 10 list based on number of health based SDWA violations *Top 10 list based on PWSs w/ occurrence over federal MCL *Identified in web search for recent new articles and publications *Potential future changes to M/DBP Rules in next 5-10 years	Established	Reverse osmosis (RO) Granular activated carbon (GAC)	Reverse osmosis (RO) Granular activated carbon (GAC), powdered activated carbon (PAC), and carbon block filters
Total Coliform	1	*Top 10 list based on number of health based SDWA violations	Available[1]	Ultraviolet (UV) Reverse osmosis (RO) Ozonation	Ultraviolet (UV) Reverse osmosis (RO) Ozonation P231 rated filters

[1] The NSF site (NSF 2022) indicates that there are NSF/ANSI certified POU and POE treatment options for ultraviolet (UV) microbiological water treatment systems with claims for Class A and Class B disinfection performance. The are no certified products utilizing the other technologies listed for microbiological treatment (i.e., reverse osmosis, ozonation, P231 filters)

Contaminant	Priority for Drinking Water	Reason for Inclusion	POU/POE Treatment Category	Point of Entry (POE) Treatment Options	Point of Use (POU) Treatment Options
Legionella	1	*Potential future regulatory changes to M/DBP Rule *Identified in web search for recent news articles and publications *Included in EPA's CCL5 list	Available [2]	Ultraviolet (UV) Reverse osmosis (RO) Ozonation	Ultraviolet (UV) Ozonation 0.2 micron biological filter P231 rated filters
DBPs (HAA5/HAA9)	1	*Top 10 list based on number of health based SDWA violations *Top 10 list based on PWSs w/ occurrence over federal MCL *Identified in web search for recent new articles and publications *Regulated (HAA5) and unregulated (HAA6Br, HAA9) included in EPA's UCMR4 *Potential future changes to M/DBP Rules in next 5-10 years	Available	Reverse osmosis (RO) Granular activated carbon (GAC)	Reverse osmosis (RO) Granular activated carbon (GAC), powdered activated carbon (PAC), and carbon block filters
PFAS (PFOA + PFOS)	1	*Included in EPA's UCMR3 and upcoming UCMR5 *Top finding in web search for recent news articles and publications *Upcoming regulations planned by EPA	Established	Granular activated carbon (GAC) Anion exchange resin	Reverse osmosis (RO) Granular activated carbon (GAC), powdered activated carbon (PAC), and carbon block filters Anion exchange resin

[2] The NSF site (NSF 2022) indicates that there are NSF/ANSI certified POU and POE treatment options for ultraviolet (UV) microbiological water treatment systems with claims for Class A and Class B disinfection performance. The are no certified products utilizing the other technologies listed for microbiological treatment (i.e., reverse osmosis, ozonation, P231 filters)

Contaminant	Priority for Drinking Water	Reason for Inclusion	POU/POE Treatment Category	Point of Entry (POE) Treatment Options	Point of Use (POU) Treatment Options
PFAS (other PFAS)	1	*Included in EPA's CCL5 *Included in EPA's UCMR3 and upcoming UCMR5 *Top finding in web search for recent news articles and publications *Upcoming regulations planned by EPA	Available	Granular activated carbon (GAC) Anion exchange resin	Reverse osmosis (RO) Granular activated carbon (GAC), powdered activated carbon (PAC), and carbon block filters Anion exchange resin
DBPs (unregulated, i.e., haloacetonitriles, halonitromethanes, iodinated THMs, nitrosamines, chlorate)	1	*Identified in web search for recent new articles and publications *Unregulated DBPs included in EPA's CCL5 *Potential future changes to M/DBP Rules in next 5-10 years	Available	Reverse osmosis (RO) Granular activated carbon (GAC) *Above treatment options are not effective for removal of nitrosamines	Reverse osmosis (RO) Granular activated carbon (GAC) *Above treatment options are not effective for removal of nitrosamines
Manganese	2	*Top 10 list based on PWSs w/ occurrence over state MCL *Included on EPA's CCL5 list *Included in EPA's UCMR4, most detected UCMR4 contaminant after DBPs (HAAs)	Established	Ion exchange Greensand filter/ manganese dioxide	Ion exchange resin Greensand filter/ manganese dioxide Reverse osmosis
Barium	2	*Top 10 list for 2020 chemical release data ("barium compounds")	Established	Cation exchange resin Reverse osmosis (RO)	Cation exchange resin Reverse osmosis (RO)
Fluoride	2	*Top 10 list based on number of health based SDWA violations *Top 10 list based on PWSs w/ occurrence over federal MCL *Identified in web search for recent news articles and publications	Established	Activated alumina (requires regeneration or tank exchange) Anion exchange (requires regeneration or tank exchange) Reverse osmosis (RO)	Activated alumina Anion exchange Reverse osmosis (RO)
Iron	2	*Top 10 list based on PWSs w/ occurrence over state MCL	Established	Ion exchange resin Greensand filter Oxidation / filtration	Ion exchange resin Greensand filter Reverse osmosis (RO)

Contaminant	Priority for Drinking Water	Reason for Inclusion	POU/POE Treatment Category	Point of Entry (POE) Treatment Options	Point of Use (POU) Treatment Options
Radium	2	*Top 10 list based on number of health based SDWA violations *Top 10 list based on PWSs w/ occurrence over federal MCL *Identified in web search for recent new articles and publications	Established	Cation exchange softening Reverse osmosis (RO)	Cation exchange softening Reverse osmosis
Uranium/ Gross Alpha	2	*Top 10 list based on number of health based SDWA violations *Top 10 list based on PWSs w/ occurrence over federal MCL	Established	Strong base anion exchange resins (chloride form) Reverse osmosis (RO)	Strong base anion exchange resins (chloride form) Reverse osmosis (RO)
Chromium Compounds/ Chromium-6, Total chromium	2	*Top 10 list for 2020 chemical release data ("chromium compounds") *CA's draft hexavalent chromium regulations released in March 2022	Established	Reverse osmosis (RO) Ion exchange resin	Reverse osmosis (RO) Ion exchange resin
Perchlorate	2	*Emerging contaminant of concern	Available	Anion exchange resin (regenerable and non-regenerable) Reverse osmosis (RO)	Anion exchange resin (regenerable and non-regenerable) Reverse osmosis
1,2,3-trichloropropane (TCP)	2	*Included in EPA's CCL5 *Included in EPA's UCMR3	Available	Granular activated carbon (GAC)	Granular activated carbon (GAC), powdered activated carbon (PAC), and carbon block filters
Cyanotoxins	2	*Included in EPA's CCL5 *Included in EPA's UCMR4 *Identified in web search for recent new articles and publications	Available [3]	Reverse osmosis (RO) Granular activated carbon (GAC)	Reverse osmosis (RO) Granular activated carbon (GAC), powdered activated carbon (PAC), and carbon block filters

[3] While there are POU/POE treatment options with NSF/ANSI certified microcystin removal claims, there are no certified removal claims for other cyanotoxins

Contaminant	Priority for Drinking Water	Reason for Inclusion	POU/POE Treatment Category	Point of Entry (POE) Treatment Options	Point of Use (POU) Treatment Options
Microplastics	2	*Identified in web search for recent news articles and publications *Emerging contaminant of concern	Available	Reverse osmosis (RO)	Carbon block filter Reverse osmosis (RO)
1,4-dioxane	2	*Included on EPA's CCL5 *Identified as emerging contaminant of concern	Not Available	Granular activated carbon (GAC) Reverse osmosis (RO)	Reverse osmosis (RO) Granular activated carbon (GAC)
Calcium hydroxide	3	*Top 10 list for 2016 chemical production data	Established	Cation exchange water softener (treatment for calcium/hardness)	Cation exchange water softener (treatment for calcium/hardness) Reverse osmosis (RO)
Calcium oxide silicate	3	*Top 10 list for 2016 chemical production data	Established	Cation exchange water softener (treatment for calcium/hardness)	Cation exchange water softener (treatment for calcium/hardness) Reverse osmosis (RO)
Chloride	3	*Top 10 list based on PWSs w/ occurrence over state MCL, increasing concentrations over time in CT	Available	Reverse osmosis (RO) Ion exchange resin	Reverse osmosis (RO) Ion exchange resin
Sulfuric Acid (Sulfate considered for POU/POE treatment options)	3	*Top 10 list for 2016 chemical production data	Available	pH neutralizing filter	Reverse osmosis (RO) Anion exchange resin Adsorptive media filtration pH neutralizing filter
Zinc	3	*Top 10 list for 2020 chemical release data ("zinc compounds")	Established	Ion exchange resin Reverse osmosis (RO)	Ion exchange resin Reverse osmosis (RO)

Table 24 Identified contaminants for which POU/POE treatment options cannot be determined or may not be applicable

Contaminant	Priority for Drinking Water	Reason for Inclusion	POU/POE Treatment Category	Reasons for Why POU/POE Treatment Options Cannot Be Determined or May Not Be Applicable
Butane	3	*Top 10 list for 2016 chemical production data	Not Available	Under atmospheric temperature and pressure, butane occurs as a gas, not a liquid
Ethane	3	*Top 10 list for 2016 chemical production data	Not Available	Under atmospheric temperature and pressure, ethane occurs as a gas, not a liquid
Ethanol	3	*Top 10 list for 2016 chemical production data	Not Available	Volatile and biodegradable organic, likely not amenable to POE/POU treatment
Methanol	3	*Top 10 list for 2016 chemical production data	Not Available	Volatile and biodegradable organic, likely not amenable to POE/POU treatment
Sulfite/ Cooking liquors	3	*Top 10 list for 2016 chemical production data	Not Available	May not be a concern for drinking water
Fly Ash	Dependent on chemical composition	*Top 10 list for 2016 chemical production data	Not Available	Treatment depends on chemical composition
Fuels, diesel #2	Dependent on chemical composition	*Top 10 list for 2016 chemical production data	Not Available	Treatment depends on chemical composition
Leach solutions	Dependent on chemical composition	*Top 10 list for 2016 chemical production data	Not Available	Treatment depends on chemical composition

6 Develop Future Expectations for the POU/POE Industry

The objective of Task 6 is to synthesize the information collected through Tasks 1-5 to develop future expectations for the POU/POE industry for the next 5- to 10-year horizon. The top priority contaminants that were identified in Tasks 1-5 are grouped by federally regulated contaminants, state regulated contaminants, and unregulated/emerging contaminants. The future expectations for these contaminants and for the POU/POE industry with respect to each contaminant are described below.

Task 5 results for POU/POE treatment options are included in the summaries below for each contaminant or group of contaminants. *The Task 5 effort did not consider aspects such as the initial cost, operational and/or maintenance costs (i.e., filter replacements, energy costs), operational challenges, site-specific considerations, or any unintended consequences associated with the POU/POE treatment options.* There is a wide array of potential unintended consequences for POU/POE treatment that should be considered by the POU/POE treatment industry and by consumers before treatment options are implemented. These unintended consequences may be related to water quality and co-occurring contaminants (i.e., some NSF/ANSI certifications specify a reference concentration and valency of arsenic in the water), the impact of the treatment on water quality (i.e., removing the disinfectant residual and risk for microbiological growth), or site-specific conditions. Any future research and development related to POU/POE treatment options for the contaminants identified in this study or any other drinking water concerns should always consider and attempt to mitigate all potential unintended consequences.

Federally Regulated Contaminants

There are several federally regulated contaminants on the list of top priority contaminants, including lead, copper, fluoride, regulated DBPs (TTHMs and HAA5), arsenic, nitrate, total coliform (inclusive of *E.coli*), radium, uranium, and barium. While not currently federally regulated, PFAS was included in this group because EPA has announced plans to propose a PFAS drinking water regulation in the fall of 2022. The future expectations for the POU/POE industry regarding these contaminants are described below.

Lead and Copper

Lead and copper are high priority contaminants of concern and present a major opportunity for the POU/POE industry over the next 5-10 years in terms of health risk reduction. Lead has been a hot topic among the EPA, the broader drinking water community, and the public, due to the health risks associated with lead and the prevalence of lead in distribution system service lines and in home plumbing fixtures. December 16, 2021 was the effective date for EPA's Revised Lead and Copper Rule, and the initial compliance date is set to October 16, 2024. Also on December 16, 2021, EPA also announced their developments of a new regulation, Lead and Copper Rule Improvements.

Over the next 5-10 years, we anticipate many drinking water systems will be working on meeting compliance with the lead and copper rule (LCR) through replacing lead service lines and implementing optimal corrosion control treatment. The outcomes of Task 5 (see Table 23) indicate that there are established POU and POE options for lead, including reverse osmosis (RO) and fine filtration and adsorption, and for copper, including RO, cation exchange, and pH neutralizing filters. In some cases, drinking water utilities may implement the use of POU treatment as a compliance strategy. Denver Water in Denver, Colorado is an example of a drinking water utility that is currently implement POU treatment as one aspect of its Lead Reduction Program (https://www.denverwater.org/your-water/water-quality/lead/filter-program). The City of Newark in Newark, New Jersey and the Newark

Department of Water & Sewer Utilities have also implemented the use of POU filters for reducing consumers' lead exposure (https://www.newarkleadserviceline.com/filters). Beyond drinking water utilities, consumers that may have concerns about lead levels in their own drinking water may also look toward POU or POE treatment to reduce their exposure. Lead exposure at any level is understood to present a health risk, and therefore, even consumers served by a drinking water system that is in compliance with the LCR may look for additional treatment for lead.

We anticipate lead and copper to remain primary contaminants of concern in the next 5-10 years and for the POU/POE industry to be an important aspect of meaningful health risk reduction through the removal of lead and copper in drinking water.

Total Coliform and E.coli

One fundamental goal of drinking water treatment is to prevent pathogen growth and the risks associated with a pathogen outbreak in drinking water through appropriate disinfection practices. Total Coliform Rule (TCR) violations related to total coliform positive data were found to be the greatest number of violations of MCL violations of the period of data analyzed in Task 1. Boil water alerts that may be issued with these violations can be very disruptive and alarming to consumers. While the data available for analysis were all from public water systems, it is expected that private well owners experience similar or even greater exposure to drinking water contamination. The POU/POE industry provides consumers with the opportunity for an additional and final barrier against microbial contamination. The outcomes of Task 5 indicate established POU and POE options, including ultraviolet (UV) light, RO, ozonation, and P231 rated filters. Based on currently available data, total coliform and *E.coli* are expected to remain major contaminants of concern for the next 5-10 years. It is possible that EPA could propose revisions to the microbial, disinfectant, and disinfection byproduct (M/DBP) by 2024 that may strengthen disinfection requirements and subsequently reduce the occurrence of total coliform and *E.coli*, but the time period for such revisions to be implemented and affect meaningful change would be beyond the five year horizon.

DBPs

Regulated DBPs, including TTHM and HAA5, have been leading contaminants in terms of the number of health based MCL violations in drinking water. Unlike most other contaminants, DBPs are formed in the treatment process when disinfectants are added to the water. To properly protect consumers against risks associated with pathogens, a disinfectant residual should be maintained through the distribution system. This also leads to continued formation of DBPs as long as DBP precursor materials (i.e., total organic carbon (TOC), bromide, etc.) are present. DBPs issues tend to be a bigger challenge for drinking water utilities using surface water sources, which are often the larger utilities, as surface water tends to have higher levels of organic matter, but some groundwater systems have also had DBP challenges. Many drinking water utilities with surface water treatment plants have optimized their enhanced coagulation, sedimentation, and filtration processes, and some utilities have implemented advanced strategies, i.e., GAC filters, aeration in clearwells or storage tanks, switching from free chlorine to chloramines for their distribution system disinfectant residual. Despite these efforts, DBP reduction strategies will always be part of a balancing act between meeting the necessary disinfection to protect against acute risks associated with pathogens while reducing DBP levels to protect against health risks associated with long term exposure to DBPs. Due to this balancing act, it is not expected that a drinking water utility that applies disinfection would ever completely remove DBPs from the drinking water provide to its consumers. It is also important to note that EPA is currently working to revise the microbial, disinfectant, and disinfection byproduct (M/DBP) Rules. Any potential change to the disinfectant residual requirements could temporarily cause further DBP challenges for drinking water systems that are currently struggling to meet compliance.

Due to the nature of DBPs, the POU/POE industry will always have an opportunity to further protect the public against potential health risks from DBP exposure. The outcomes of Task 5 indicate POU and POE options for removing DBPs, including RO, granular activated carbon (GAC), powdered activated carbon (PAC), and carbon block filters. Depending on the application of the POU/POE treatment, e.g., for compliance, further testing and validation may be necessary. For example, the treatment technologies available are generally far more effective at removing TTHM as opposed to HAAs. The analysis conducted as part of this study suggests that DBPs will continue to be major contaminants of concern for the next 5-10 years, and POU/POE treatment options provide the public with a means to reduce their DBP exposure.

PFAS

Over the last 5 years, PFAS have been a major topic in drinking water communities, conferences, publications, and news articles. In 2013-2015, six PFAS analytes were included in the UCMR3 sampling effort, but due to relatively high reporting limits, there were few detections nationally as compared with other contaminants included in UCMR3. Since that time, analytical methods have improved, and reporting and detection limits have lowered. Many drinking water systems that did not detect PFAS in UCMR3 have since detected PFAS, and various states have set their own regulations for several PFAS analytes. Currently the EPA plans to propose the first federal PFAS drinking water regulation in fall of 2022, following by a final regulation in fall of 2023, starting with two PFAS analytes, PFOA and PFAS. Additionally, UCMR5 sampling will including 29 PFAS analytes, and it is expected that many more drinking water systems across the country will discover detectable PFAS. PFAS currently represents an important opportunity for the POU/POE industry to support consumers and potentially drinking water utilities, depending on the state and state approvals for compliance by POU/POE treatment, in effectively removing PFAS to protect public health. The Task 5 outcomes indicate that POU/POE treatment options include RO, GAC, PAC, carbon block filters, and anion exchange resin, although further testing and validation will be important based on the application of the POU/POE treatment and based on the specific PFAS contaminants. For example, there are NSF/ANSI certified POU/POE treatment options for the PFOS and PFOA removal claims, but not for other types of PFAS which may not be removed as effectively due their chemical composition.

Arsenic

The current arsenic MCL was set by the Arsenic Rule in 2001, which public drinking water systems were required to meet by 2006. Today, sixteen years later, the Arsenic Rule is still responsible for significant number of health based MCL violations, particularly for smaller drinking water systems. Arsenic was also found to be one of the top contaminants based on occurrence over the MCL. The outcomes of Task 5 indicate several established POU/POE treatment options, including iron oxide/hydroxides, activated alumina, anion exchange resin, manganese greensand, titanium oxy/hydroxide, and iron-doped anion resin and activated alumina. There is a meaningful opportunity for the POU/POE industry to help protect consumers against exposure to arsenic in the next 5-10 years, and in some states, there may be opportunities to work with drinking water utilities and state regulators to employ or enable POU/POE options for compliance purposes.

Nitrate

Similar to arsenic, nitrate has been regulated for many years. It is not an emerging contaminant or a new concern, but it is one of the top priority contaminants in terms of the number of health based MCL violations and occurrence over the MCL. Nitrate has an acute MCL due to the dangers of methemoglobinemia, also known as blue baby syndrome, from a single exposure over 10 mg/L for vulnerable populations, particularly infants. Nitrate is expected to remain a top concern over the next 5-10 years based on the analysis conducted in this study. While nitrate levels in drinking water served to consumers has remained relatively consistent, the analysis showed that levels in raw water samples have shown an increasing trend over time. This suggests that nitrate may become a bigger problem in the future for drinking water systems. The Task 5 outcomes indicate there are established POU/POE treatment options, including RO, anion exchange resin, and nitrate selective anion exchange resins. As with arsenic, there is an opportunity for the POU/POE industry to help protect consumers against exposure to nitrate above the MCL. Additionally, in some states, there could be an opportunity to work with drinking water utilities and state regulators to employ or enable POU/POE options for compliance purposes.

Radionuclides (Radium, Uranium)

Two radionuclides, radium and uranium, were found to be at the top of the list of contaminants based on number of violations and drinking water occurrences over the respective MCLs. These fall into a similar category as arsenic and uranium such that the Radionuclide Rule has been in place for years, no upcoming changes to the rule are anticipated, but the contaminants remain a concern for many public drinking water utilities. The Task 5 outcomes indicate that for radium, established cation exchange softening and RO POU and POE treatment options are available, and for uranium, established strong base anion exchange resins and RO POU and POE treatment options are available. Based on the analysis conducted, these contaminants are expected to still be a concern in the next 5-10 years, and they present an opportunity for the POU/POE industry through helping consumers protect themselves and potentially, for some states, could provide an opportunity to work with drinking water utilities and state regulators for compliance purposes.

Fluoride

Fluoride is often used in drinking water treatment for dental purposes, but also regulated due to health issues at higher concentrations. Fluoride was found to be one of the top ten contaminants based on the number of health based MCL violations and based on the occurrence above the MCL. In Task 2 analyses showing trends over time, fluoride was found to be decreasing over time. In the next 5-10 years, thought, it is expected that fluoride will continue to be a concern in areas with high naturally occurring levels. Based on state MCLs and available data, this study found the greatest number of PWSs with fluoride occurrence over the state MCL in New York, although further analysis would be warranted to determine areas of concern. The Task 5 outcomes indicate that established POU/POE treatment options for fluoride include activated alumina, anion exchange, and RO. The POU/POE industry has the opportunity to provide these treatment options to consumers, especially in areas with high naturally occurring fluoride.

Barium

Barium has not been a contaminant of concern based on violations and occurrence over the MCL, but barium compounds were found to be in the top 10 of chemicals released based on EPA's TRI dataset. While it is not clear whether these releases will result in any increased barium levels in source waters for drinking water systems, it is important to be aware that this is a possibility. While there's no clear indication that barium represents a significant opportunity for the POU/POE industry to protect public health, it important to identify this contaminant as a potential future contaminant of concern. Established POU/POE treatment options for barium include cation exchange resin and RO.

State Regulated Contaminants

There are also a group of contaminants on the list of top priority contaminants that are regulated by one or more states, chromium-6, manganese, iron, chloride, perchlorate, 1,4-dioxide, and 1,2,3-trichloropropane. Chromium-6 is particularly noteworthy at the time of this report because the California Department of Drinking Water released a new draft MCL for chromium-6. The reinstatement of a chromium-6 MCL could have implications for hundreds of drinking water systems in California. The new regulation could result in more consumers looking for additional home treatment options, such as POU or POE devices, or it is possible that systems could investigate POU/POE treatment options for compliance.

Contaminants such as manganese, 1,4-dioxane, and 1,2,3-trichloropropane are currently on EPA's CCL5, and while they are not currently federally regulated, there is the potential that they could be in the future. Perchlorate is another contaminant that has been considered for federal regulation by the EPA. In a decision published in 2020, the EPA chose not to regulate perchlorate, stating that it did not meet the requirements as a drinking water contaminant under the SDWA. EPA did release a plan to address perchlorate contamination on March 31, 2022 (USEPA 2022). In the case of manganese, 1,4-dioxane, 1,2,3-trichloropropane, and perchlorate, there are understood health risks from exposure, and the reduction or removal of their occurrence could be beneficial to consumer health. Therefore, the POU/POE industry has an opportunity to provide consumers with a treatment option for these contaminants. Task 5 evaluated current POU/POE treatment for manganese, including ion exchange, greensand filters, and RO, and for perchlorate, including anion exchange resin and RO, as established treatment options, while POU/POE treatment options for 1,2,3-trichloropropane, including GAC, need further validation and testing, and for 1,4-dioxane, including GAC and RO, are not well established.

Iron, chloride, zinc, and sulfate are three contaminants that are regulated in some states and have a secondary standard set by the EPA based on aesthetic impacts. Concerns with iron, chloride, zinc, and sulfate are expected to be focused on aesthetic issues, as opposed to health risks. While sulfate was not directly identified in Tasks 1-4, Task 4 found sulfuric acid to be one of the most produced chemicals in the most recent TSCA dataset. In terms of potential impacts on drinking water quality, sulfate was evaluated as a potential drinking water contaminant of concern. The established POU/POE treatment options for iron include ion exchange resin, greensand filter, oxidation/filtration, and RO, for chloride and zinc, include RO and ion exchange resin, and for sulfate, include pH neutralizing filters, RO, anion exchange resin, and adsorptive media filtration. Based on occurrence above state MCLs, iron, chloride, zinc, and sulfate are a challenge for some drinking water systems and provide an opportunity for the POU/POE industry, particularly in those states and systems where they are a concern.

Unregulated/ Emerging Contaminants

There are several unregulated or emerging contaminants that are expected to be primary contaminants of concern for at least the next 5-10 years.

Cyanotoxins

Harmful algal blooms (HABs) and cyanotoxins are a health risk in natural water bodies, including source waters for drinking water, and cyanotoxins are a concern for public drinking water. Currently, the EPA has health advisories for two cyanotoxins, cylindrospermopsin and microcystins, set in 2015. More recently, nine cyanotoxins and one cyanotoxin group (total microcystins) were included in the UCMR4 sampling that occurred in 2018-2020, although there were a relatively low number of detections. Cyanotoxins were included in the CCL5 draft and have been a major topic in recent drinking water focused conferences and publications. Conventional drinking water treatment processes can generally remove cyanobacteria and low levels of cyanotoxins, there is an opportunity for the POU/POE industry particularly for communities where source waters have been experiencing seasonal blooms and high levels of cyanotoxins. In these communities, consumers may have interest in further protection against these toxins. POU/POE treatment options include RO, GAC, PAC, and carbon block filters, although depending on the application of the treatment, further testing and validation may be needed. While there are POU/POE treatment options with NSF/ANSI certification for microcystin removal claims, there are no certified options for the removal of other cyanotoxins.

Unregulated DBPs

Several unregulated DBPs were identified in Tasks 1-4 and are expected to remain primary contaminants of interest over the next 5-10 years. The EPA's draft CCL 5 includes brominated HAAs, which were also included in the UCMR4 sampling, haloacetonitriles (HANs), iodinated trihalomethanes, nitrosamines (including NDMA), chlorate, and formaldehyde. Currently, EPA is tasked with proposing revisions to the M/DBP rules, and recent stakeholder meetings have suggested that the brominated HAAs, in the form of HAA9, are the most likely group of unregulated DBPs that may be regulated in the near future. Several unregulated DBPs were also included in UCMR2, and it is noteworthy that NDMA had the highest number of detections of the UCMR2 contaminants. Unregulated DBPs also remain a major topic for drinking water related research and publications. For consumers that may want to ensure further removal of DBPs, the POU/POE industry provides important treatment options, such as RO and GAC although these treatment options may not be well established depending on the intended application. For example, while there are POU/POE treatment options with NSF/ANSI certification based on haloacetonitriles removal claims, the available treatment options are ineffective at removing nitrosamines, i.e., NDMA. Further testing and validation, as well as gaining further understand of the public's concern with unregulated DBPs presents an important opportunity for the POU/POE industry.

Legionella

Legionella, especially *Legionella pneumophila*, was found to be the unregulated microbial contaminant of the greatest concern based on the efforts in Tasks 1-4. Currently, *Legionella* has been a major topic in stakeholder meetings related to EPA's efforts to propose revisions to the M/DBP rules. Controlling *Legionella* presents challenges for drinking water utilities because these efforts also rely on the management of building water systems and premise plumbing, which are not under the control of drinking water utilities. Due to the nature of *Legionella* and the reliance on building water system management, the POU/POE industry has an opportunity to provide options for building water managers and consumers to treat drinking water for *Legionella* at locations where it can be problematic. POU/POE treatment options for *Legionella* include UV light, RO, ozonation, and P231 rated filters.

Microplastics

Microplastics have been become a contaminant of concern over the last several years, and they have been at the center of drinking water related news articles, publications, and conference talks. Due to consumer concerns, the POU/POE industry has an opportunity to provide treatment options for microplastics. The Task 5 outcomes found that POU/POE treatment options for microplastics include RO and carbon block filters, and there are certified POU/POE treatment options for microplastics removal. Microplastics remain an emerging contaminant with far more research required to fully understand the impact on drinking water quality and human health, and similarly, further research is recommended to provide the best POU/POE treatment options.

Calcium/hardness

The Task 4 analysis found that calcium hydroxide and calcium oxide silicate were two of the most produced chemicals based on the EPA's most recent TSCA dataset. In drinking water, calcium increases the hardness of water. While hardness is not regulated or found to be a health concern, hard water can be a concern for various reasons. Hardness can interfere with the action of soaps and detergents, leave solid deposits that can clog pipes, lead to galvanic corrosion of metal pipes, etc. Any increase in hardness as a result of increased production of calcium hydroxide and calcium oxide silicate could present more need for POU/POE treatment options. The Task 5 outcomes identified established POU/POE options such as cation exchange water softeners and RO for treatment of calcium in drinking water.

Summary

The Predictive Modeling Study presented a methodology to evaluate all relevant data available to identify the top priority drinking water contaminants that will remain a concern for the next 5-10 years. The methodology evaluated violation data available from EPA's SDWIS, the occurrence of unregulated contaminants from EPA's UCMRs, the occurrence of regulated contaminants above their MCLs and trends in occurrence over time, upcoming or recent regulatory changes, contaminants that may be considered for future regulations based on inclusion on the CCL, recent drinking water related news articles, publications, and conferences, and EPA's TSCA and TRI data sets of the most produced and released chemicals. The methodology then evaluated the identified top contaminants of concern based on their priority as a drinking water contaminant, which took into account the authors' expert judgment based on understood health risks, occurrence, and priority from the drinking water community. Next the methodology included a review of available POU and POE treatment options and an evaluation of how well established the treatment options are currently for the removal of the contaminant.

The methodology resulted in a list of 28 top priority drinking water contaminants for the next 5-10 years. The future expectations for each of the contaminants are discussed in Task 6 of the methodology, which synthesizes the information gathered through Tasks 1-5. The methodology developed in the Predictive Modeling Study can be repeated at any time to evaluate future years of interest.

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* Additional references included in the Task 3 and Task 5 datasets submitted with the final report as spreadsheets