

Supporting Information for

**Arsenic Drinking Water Violations Decreased Across the United States Following Revision of the
Maximum Contaminant Level**

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DESCRIPTION OF SUPPORTING INFORMATION

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time period 2006-2017. States with “NA” values had no recorded health-based violations during this period but did have monitoring or reporting violations (not shown here). Alaska and Hawaii excluded from the analysis.

Figure S1. The percent of PWS (CWS and NTNCWS) in violation for arsenic (exceedance of MCL) by system type between 2006 and 2017.

Figure S2. Comparison of the percent of PWS in FAR violation between 2006 and 2017 for either monitoring/reporting or a health-based violation (exceeding the 10 µg/L MCL). Both violation types demonstrate significant downward trends over time. Monitoring/Reporting: $p < 0.05$, slope = -0.054; Health-Based: $p < 0.001$, slope = -0.070.

Figure S3. The mean number of discontinued facilities for PWS from 2014 to 2017, stratified by those in violation and those no longer in violation.

Table S1. Metrics for public water system (PWS) arsenic violations obtained from EPA’s Safe Drinking Water Information System (SDWIS). See footnotes^{a,b}.

Metric	Calculation Method
Temporal Metrics	
Number of Systems in Violation	Number of PWS with at least one violation in a particular calendar year. No PWS in violation is counted more than once per year, even if it has a violation in multiple quarters per year.
Percent of Systems in Violation	Number of systems in violation for a calendar year divided by the inventory of active systems for that fiscal year (beginning on July 1 and ending on June 30) and multiplied by 100. Inventory data is the number of systems active at least part of that fiscal year, and this data (for 1994-2017) came from a request to EPA’s Office of Ground Water and Drinking Water. Using the calendar year for the number of violations and the fiscal year for the inventory may lead to some errors since they only have a 6-month period in common, however, this likely does not affect long-term trends.
Number of People Served by Systems in Violation	Sum of population served by each PWS in violation for a year. Population served is provided for each PWS in SDWIS.
Percent of People Served by Systems in Violation	Number of people served by a CWS in violation for a year divided by the total sum of people served by all CWS and multiplied by 100. Only CWS data was utilized for this percent calculation to avoid double-counting people who may use both a CWS and a NTNCWS.

Maximum Violation Duration	The maximum number of consecutive quarters in violation was calculated for each PWS between 2006 and 2017; number divided by four to convert to annual basis. Calculated by using the compliance period begin date to determine which quarter the violation occurred. Duration is not the same as time between the compliance begin date and compliance end date, which would measure how long a single violation lasts.
Groundwater or Surface Water Violations	Number of PWS in violation having their source water listed as either ground water or surface water by SDWIS.
Percent Groundwater or Surface Water Violations	Number of groundwater or surface water systems in violation for a calendar year divided by the inventory of active systems with the respective source type for that fiscal year (beginning on July 1 and ending on June 30) and multiplied by 100. This inventory data was acquired from EPA's Office of Ground Water and Drinking Water. Using the calendar year for the number of violations and the fiscal year for the inventory may lead to some errors since they only have a 6-month period in common, however, this likely does not affect long-term trends.
Number of Violations by PWS Type	PWS were filtered by PWS type to calculate the number of systems in violations per year by PWS type. PWS types are: CWS, TNCWS, and NTNCWS. Since TNCWS are exempt from the Final Arsenic Rule, they were not included in this analysis.

Percent Violations by PWS Type
Number of CWS or NTNCWS in violation for a calendar year divided by the inventory of active systems with the respective PWS type for that fiscal year (beginning on July 1 and ending on June 30) and multiplied by 100. This inventory data was acquired from EPA's Office of Ground Water and Drinking Water. Using the calendar year for the number of violations and the fiscal year for the inventory may lead to some errors since they only have a 6-month period in common, however, this likely does not affect long-term trends.

Number of Violations by Owner Type
PWS were filtered by owner type to calculate the number of systems in violation per year by owner type. Owner types are: Federal Government, Local Government, Native American, Private, Public/Private, and State Government. For a PWS with multiple owner types, the most common owner type was chosen.

Geographic Metrics

Mean Annual Number of Violations per State or County
Average annual sum of number of systems in violation by state or county, from 2006 to 2017. Each violation is associated with a state/primacy agency. The county served by each PWS was obtained from the Geographic Area record in SDWIS, which is separate from the violations data. The county served was merged into the violations data by the PWS identifier, ensuring that each PWS was associated with only one county.

Mean Annual Population Served per State or County	Average annual number of people served by each PWS in violation per state or county from 2006 to 2017.
Mean Annual Number of GW or SW Violations per State	Average annual sum of number of systems in violation by state and by groundwater (GW) or surface water (SW) from 2006 to 2017.
Mean Annual Percent of Systems in Violation by State	The sum of violations per state and year was divided by the inventory of active systems for that state and year and multiplied by 100. This percent in violation per state and year was then averaged over all years, 2006 to 2017.
Mean Annual Percent of People Served per State	The sum of people served per state and year was divided by the inventory of all people served by active systems for that state and year and multiplied by 100. This percent of people served per state and year was then averaged over all years, 2006 to 2017.
Mean Annual Monitoring and Reporting Violations per State	Average number of systems per state and per year with a monitoring or reporting violation between 2006 and 2017. Listed in SDWIS as “(3) Monitoring, Regular” and “(4) Monitoring, Check/Repeat/Confirmation.”

^aA violation represents a PWS that exceeded the 10 µg/L MCL at least once during a given year.

^bCWS = community water system, NTNCWS = non-transient non-community water system, TNCWS = transient non-community water system, MCL = maximum contaminant level

Table S2. Arsenic removal treatment methods incorporated into treatment analysis of violating systems and the average annual number of systems with arsenic violations reporting each treatment between 2013-2017. See footnotes^{a,b}.

Treatments Effective for Removing Arsenic	Average Number of Systems Reporting Treatment
Ultraviolet Radiation	5
Reverse Osmosis	19.4
pH Adjustment, Pre	6
pH Adjustment	3.4
Permanganate	5.6
Ozonation, Pre	1
Microscreening	0
Lime-Soda Ash Addition	1.25
Ion Exchange	40.8
Filtration, Ultrafiltration	0
Filtration, Greensand	11.4
Filtered	4.5
Electrodialysis	0
Coagulation	7.4
Activated Alumina	17.4

Source: Environmental Protection Agency. Treatment technologies for arsenic removal [Internet]. 2005

[cited 2018 Mar 30]. Available from: <https://nepis.epa.gov/Exe/ZyPDF.cgi/20017IDW.PDF?Dockey=20017IDW.PDF>

^aSome newer technologies considered effective for arsenic removal are not included within the current treatment reporting system in SDIWS and so do not appear below.

^bTreatment information only available between 2013-2017.

Table S3. Number and percent of violations and mean population served for all PWS by water source, PWS type, and owner type during period of 2006 to 2017. See footnotes^{a-d}.

Category	Type	Number of		Mean Population
		Violations	% of Violations	Served per Year
All PWS	–	7,671	100	965,215
Water source	Ground water	7,387	96.30	700,579
	Surface water	284	3.70	264,636
PWS type	CWS	5,632	73.42	914,700
	NTNCWS	2,039	26.58	50,515
Owner type	Federal government	109	1.42	24,445
	Local government	2464	32.12	769,166
	Native American	248	3.23	29,173
	Private	4545	59.25	122,537
	Public/Private	247	3.22	8,612
	State government	58	0.76	11,282

^aThe number of violations represents the total number of violations over the time period for each specified category.

^bThe percent of violations was calculated by dividing the number of violations in that category by the total number of violations over the time period and multiplying by 100.

^cMean population served per year indicates the average number of people served per year by systems in violation within each specified category. Populations served by both CWS and NTNCWS are included in these calculations, which likely leads to overestimates as many people are served by both CWS and

NTNCWS (i.e. CWS serving the home and NTNCWS serving the workplace). Mean population values were rounded up to the nearest integer if greater than 0.5 in the decimal place.

^dCWS = Community water system, NTNCWS = Non-transient non-community system.

Table S4. Mean annual number of systems in FAR violation and annual percent of systems in FAR violation by state within the conterminous US. See footnotes^{a,b}.

State	Mean Annual Number of Systems in Violation	Mean Annual Percent of Systems in Violation	Standard Deviation of Annual Percent of Systems in Violation	Range for Annual Percent of Systems in Violation
Alabama	NA	NA	NA	NA
Arizona	39.75	3.98	2.57	0.1-8.53
Arkansas	0.33	0.04	0.07	0-0.13
California	153.58	3.40	0.87	1.24-4.16
Colorado	2.00	0.19	0.15	0-0.4
Connecticut	4.67	0.41	0.25	0.09-0.85
Delaware	0.25	0.08	0.20	0-0.64
Florida	3.42	0.13	0.11	0-0.26
Georgia	1.75	0.09	0.12	0-0.4
Idaho	19.33	1.98	1.60	0.21-4.6
Illinois	18.83	0.87	0.49	0.32-1.67
Indiana	14.00	0.96	0.76	0.15-2.54
Iowa	3.92	0.31	0.18	0.08-0.63
Kansas	4.83	0.52	0.32	0-0.85
Kentucky	NA	NA	NA	NA
Louisiana	5.75	0.48	0.33	0-1.07

Maine	10.33	1.35	1.01	0.39-3.29
Maryland	4.25	0.40	0.41	0-1.58
Massachusetts	3.58	0.45	0.48	0-1.54
Michigan	29.42	1.02	1.47	0.18-5.33
Minnesota	7.25	0.49	0.38	0-1.33
Mississippi	0.08	0.01	0.03	0-0.09
Missouri	0.08	0.01	0.02	0-0.06
Montana	8.17	0.84	0.41	0-1.38
Nebraska	5.75	1.13	0.43	0.13-1.74
Nevada	8.50	4.02	2.18	0.29-7.81
New Hampshire	13.33	2.27	0.98	0.95-4.97
New Jersey	26.25	0.39	0.41	0-1.26
New Mexico	5.58	2.65	1.55	0.12-4.98
New York	20.25	0.34	0.14	0.16-0.56
North Carolina	11.42	0.02	0.03	0-0.08
North Dakota	0.50	0.53	0.78	0-2.25
Ohio	1.92	1.04	0.96	0.2-2.95
Oklahoma	21.83	0.67	0.15	0.43-0.98
Oregon	8.08	1.20	0.63	0.25-2.4
Pennsylvania	14.58	0.51	0.51	0.09-1.41
Rhode Island	NA	NA	NA	NA
South Carolina	0.25	0.03	0.06	0-0.13
South Dakota	5.08	1.05	0.69	0.21-2.28

Tennessee	NA	NA	NA	NA
Texas	97.75	1.76	0.25	1.39-2.16
Utah	1.67	0.31	0.85	0-2.95
Vermont	1.58	0.23	0.19	0-0.73
Virginia	2.50	0.14	0.09	0-0.3
Washington	7.83	0.30	0.50	0-1.7
West Virginia	0.58	0.10	0.11	0-0.34
Wisconsin	8.33	0.42	0.23	0.15-0.81
Wyoming	0.42	0.10	0.13	0-0.27

^aStates with “NA” values had no recorded health-based violations during this period but did have monitoring or reporting violations (not shown here).

^bAlaska and Hawaii excluded from the analysis.

Table S5. The range of systems in FAR violation, the most recent number of systems in violation, and the percent reduction of the number of systems in violation per state within the conterminous US over the time period 2006-2017. See footnotes^{a,b}.

State	Minimum Number of Systems in Violation	Maximum Number of Systems in Violation	Number of Systems in Violation in 2017	Percent Reduction from Peak Year to Most Recent Year
Alabama	NA	NA	NA	NA
Arizona	1	87	15	82.76
Arkansas	0	1	0	100.00
California	55	194	121	37.63
Colorado	0	4	1	75.00
Connecticut	1	10	1	90.00
Delaware	0	2	0	100.00
Florida	0	7	1	85.71
Georgia	0	8	0	100.00
Idaho	2	45	2	95.56
Illinois	7	36	7	80.56
Indiana	2	38	2	94.74
Iowa	1	8	1	87.50
Kansas	0	8	2	75.00
Kentucky	NA	NA	NA	NA
Louisiana	0	13	5	61.54
Maine	3	25	3	88.00

Maryland	0	17	0	100.00
Massachusetts	0	12	0	100.00
Michigan	5	159	11	93.08
Minnesota	0	20	6	70.00
Mississippi	0	1	0	100.00
Missouri	0	1	0	100.00
Montana	0	13	5	61.54
Nebraska	1	13	6	53.85
Nevada	1	25	15	40.00
New Hampshire	11	58	22	62.07
New Jersey	0	18	0	100.00
New Mexico	1	39	11	71.79
New York	5	19	5	73.68
North Carolina	0	2	0	100.00
North Dakota	0	8	0	100.00
Ohio	4	64	6	90.63
Oklahoma	5	12	5	58.33
Oregon	3	29	10	65.52
Pennsylvania	3	47	3	93.62
Rhode Island	NA	NA	NA	NA
South Carolina	0	1	0	100.00
South Dakota	1	11	2	81.82
Tennessee	NA	NA	NA	NA

Texas	77	120	81	32.50
Utah	0	16	0	100.00
Vermont	0	5	1	80.00
Virginia	0	5	0	100.00
Washington	0	44	1	97.73
West Virginia	0	2	0	100.00
Wisconsin	3	16	8	50.00
Wyoming	0	1	0	100.00

^aStates with “NA” values had no recorded health-based violations during this period but did have monitoring or reporting violations (not shown here).

^bAlaska and Hawaii excluded from the analysis.

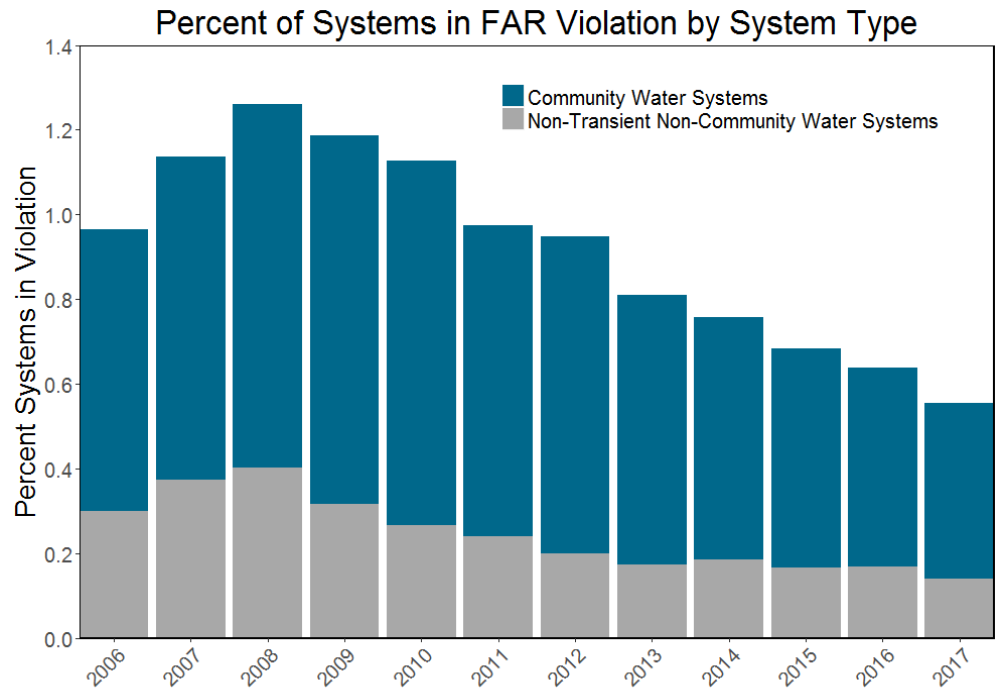


Figure S1. The percent of PWS (CWS and NTNCWS) in violation for arsenic (exceedance of MCL) by system type between 2006 and 2017.

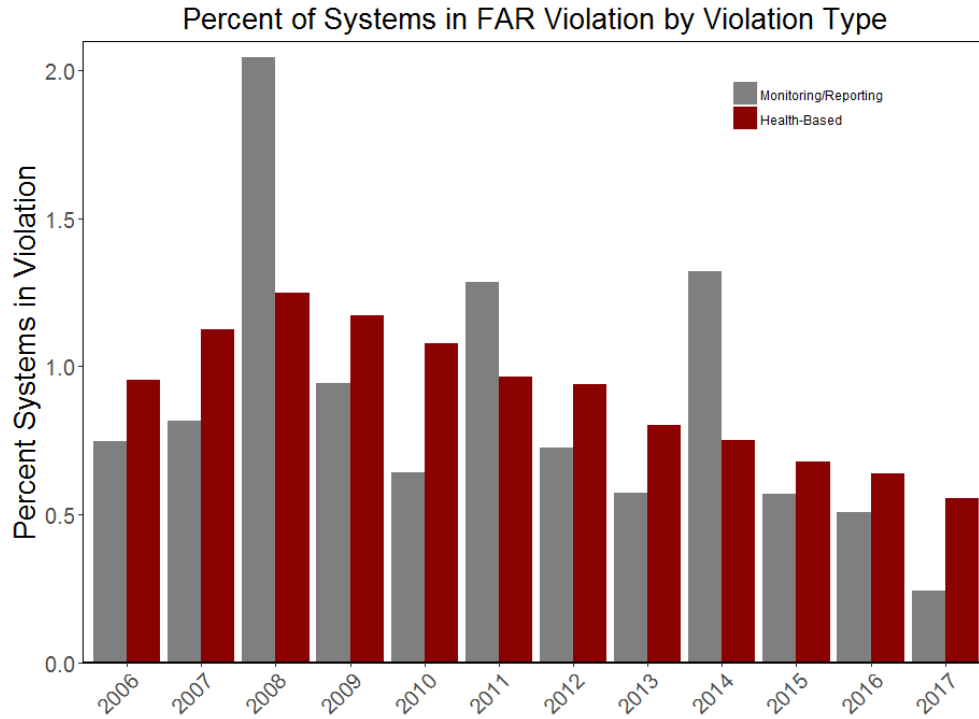


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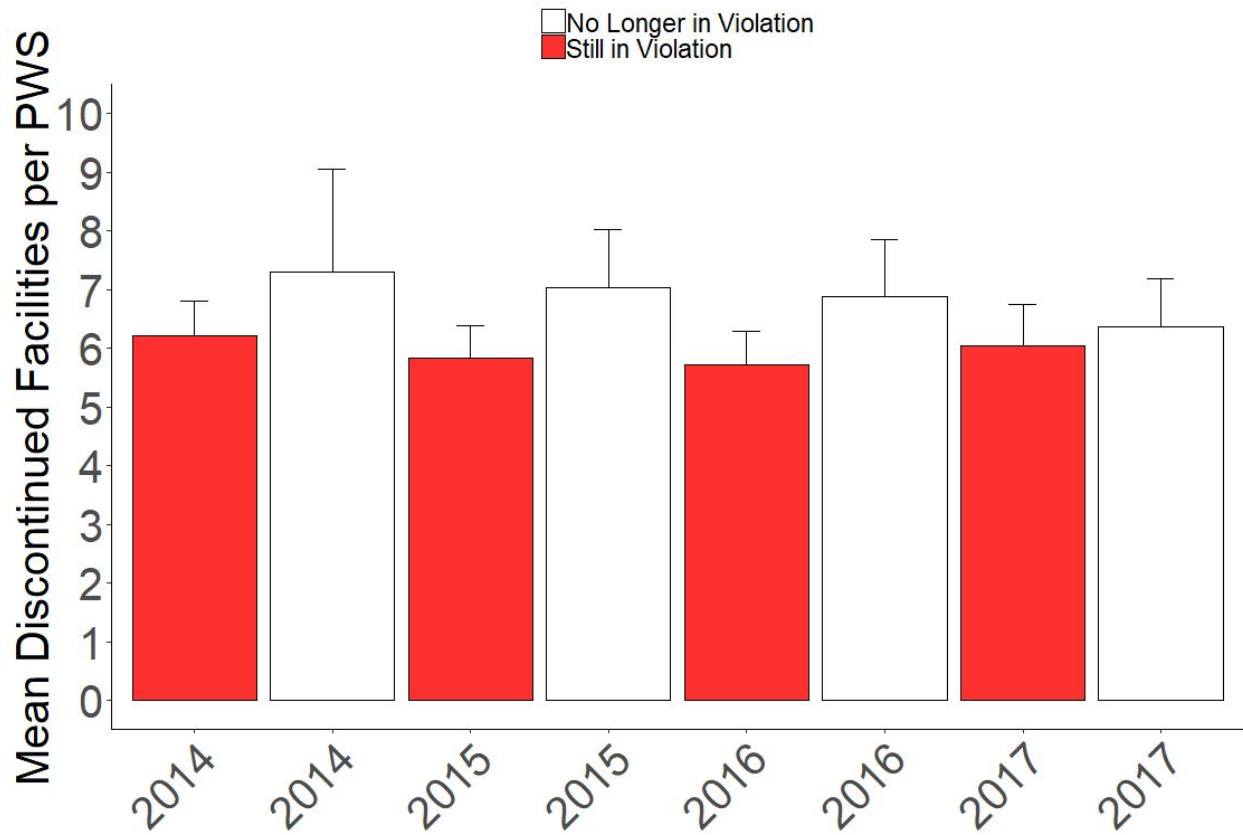


Figure S3. The mean number of discontinued facilities for PWS from 2014 to 2017, stratified by those in violation and those no longer in violation. Differences between groups each year were not significant.

Year 2013 is not included as in other graphs (Figure 4b and 4c) because necessary facility inventory data is not available prior to 2013 and assessments are performed using the facilities of the prior year as the index. For example, the bars for year 2014 are for facilities that were active in 2013, but discontinued in 2014, while 2015 is looking at facilities active in 2014, but no longer active in 2015.