



**CITY OF NAPA
PUBLIC WATER SYSTEM 2810003**

**TRIENNIAL WATER QUALITY REPORT
RELATIVE TO PUBLIC HEALTH GOALS**

JULY 2019

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SECTION I: BACKGROUND INFORMATION**BACKGROUND**

Provisions of the California Health and Safety Code (Reference No. 1) specify that larger (>10,000 service connections) water utilities prepare a special report by July 1 of the year in which it is due if their water quality measurements have exceeded any Public Health Goals (PHGs). PHGs are non-enforceable goals established by the Cal-EPA's Office of Environmental Health Hazard Assessment (OEHHA). The law also requires that where OEHHA has not adopted a PHG for a constituent, the water suppliers are to use the Maximum Contaminant Level Goals (MCLGs) adopted by United States Environmental Protection Agency (USEPA). Only constituents which have a California primary drinking water standard and for which either a PHG or MCLG has been set are to be addressed. (Reference No. 2 is a list of all regulated constituents with the Maximum Contaminant Level [MCLs] and PHGs or MCLGs.)

There are a few constituents that are routinely detected in water systems at levels usually well below the drinking water standards for which no PHG nor MCLG has yet been adopted by OEHHA or USEPA including Total Trihalomethanes. These will be addressed in a future required report after a PHG has been adopted.

The law specifies what information is to be provided in the report. (Reference No. 1)

If a constituent was detected in the System's water supply between 2016 and 2018 at a level exceeding an applicable PHG or MCLG, this report provides the information required by the law. Included is the numerical risk associated with the MCL and the PHG or MCLG, the category or type of risk to health that could be associated with each constituent, the best treatment technology available that could be used to reduce the constituent level, and an estimate of the cost to install that treatment if it is appropriate and feasible.

WHAT ARE PUBLIC HEALTH GOALS (PHGs)?

PHGs are non-enforceable goals set by the OEHHA, which is part of Cal-EPA, and are based solely on public health risk considerations. PHGs are not required to be met by any public water system and none of the practical risk-management factors that are considered by the USEPA or the State Water Resource Control Board Division (SWRCB) Division of Drinking Water (DDW) in setting drinking water standards are considered in setting the PHGs. These factors include analytical detection capability, treatment technology available, benefits and costs. MCLGs are the federal equivalent to PHGs.

The PHG describes concentrations of contaminants at which adverse health effects would not be expected to occur, even over a lifetime of exposure. PHGs are developed for chemical contaminants based on the best available toxicological data in the scientific literature. These documents and the analyses contained in them provide estimates of the levels of contaminants in drinking water that would pose no significant health risk to individuals consuming the water on a daily basis over a lifetime.

The California Safe Drinking Water Act of 1996 (amended Health and Safety Code, Section 116365) requires the OEHHA to adopt PHGs for contaminants in drinking water based exclusively on public health considerations. The Act requires OEHHA to adopt PHGs that meet the following criteria:

1. PHGs for acutely toxic substances shall be set at levels at which scientific evidence indicates that no known or anticipated adverse effects on health will occur, plus an adequate margin-of-safety.
2. PHGs for carcinogens or other substances which can cause chronic disease shall be based solely on health effects without regard to cost impacts and shall be set at levels which OEHHA has determined do not pose any significant risk to health.
3. To the extent the information is available, OEHHA shall consider possible synergistic effects resulting from exposure to two or more contaminants.
4. OEHHA shall consider the existence of groups in the population that are more susceptible to adverse effects of the contaminants than a normal healthy adult.
5. OEHHA shall consider the contaminant exposure and body burden levels that alter physiological function or structure in a manner that may significantly increase the risk of illness.
6. In cases of scientific ambiguity, OEHHA shall use criteria most protective of public health and shall incorporate uncertainty factors of noncarcinogenic substances for which scientific research indicates a safe dose-response threshold.
7. In cases where scientific evidence demonstrates that a safe dose-response threshold for a contaminant exists, then the PHG should be set at that threshold.
8. The PHG may be set at zero if necessary to satisfy the requirements listed above.
9. OEHHA shall consider exposure to contaminants in media other than drinking water, including food and air and the resulting body burden.
10. PHGs adopted by OEHHA shall be reviewed periodically and revised as necessary based on the availability of new scientific data.

PHGs adopted by OEHHA are for use by the SWRCB in establishing primary drinking water standards (State Maximum Contaminant Levels, or MCLs). MCLs are the regulatory definition of what is “safe” and are the criteria for being in compliance. Whereas PHGs are to be based solely on scientific and public health considerations without regard to economic cost considerations, drinking water standards adopted by SWRCB are to consider economic factors and technical feasibility.

For this reason, PHGs are only one part of the information used by DDW for establishing drinking water standards. PHGs established by OEHHA exert no regulatory burden and represent only non-mandatory goals. By federal law, MCLs established by DDW must be at least as stringent as the federal MCL if one exists. PHG documents are

developed for technical assistance to SWRCB, but may also benefit federal, state and local public health officials. While the PHGs are calculated for single chemicals only, they may, if the information is available, address hazards associated with the interactions of contaminants in mixtures.

Further, PHGs are derived for drinking water only and are not to be utilized as target levels for the contamination of environmental waters where additional concerns of bioaccumulation in fish and shellfish may pertain. Often environmental water contaminant criteria are more stringent than drinking water PHGs, to account for human exposures to a single chemical in multiple environmental media and from bioconcentration by plants and animals in the food chain.

WATER QUALITY DATA CONSIDERED:

The origins of the three source waters for the City of Napa are: Lake Hennessey, Lake Milliken and the Sacramento Delta. The water quality data collected by our water system between 2016 and 2018 for purposes of determining compliance with drinking water standards and PHG reporting requirements was considered. This data was all summarized in our Annual Drinking Water Quality Reports (Consumer Confidence Reports) that are available to customers on an annual basis by July 1st of each year following the monitoring year. If you required further information concerning contaminants and their potential health effects, please contact Erin Kebbas, Water Quality Manager, at (707) 253-0822.

GUIDELINES FOLLOWED:

The Association of California Water Agencies (ACWA) formed a workgroup, which prepared guidelines for water utilities to use in preparing these newly required reports. The most recent ACWA guidelines (ACWA, “2019 PHG Guidance”) were used in the preparation of our report. No guidance materials are available from DDW or OEHHA regarding preparation of this PHG report. Although OEHHA has a requirement to determine and provide information on “numerical health risk,” they otherwise have no involvement or authority regarding the report.

BEST AVAILABLE TREATMENT TECHNOLOGY AND COST ESTIMATES:

Both the USEPA and SWRCB adopt what are known as BATs or Best Available Technologies, which are the best known methods of reducing contaminant levels below the MCL. Cost can be estimated for such technologies. However, since many PHGs and all MCLGs are set much lower than the MCL, it is not always possible nor feasible to determine what treatment is needed to further reduce a constituent downward to or near the PHG or MCLG, many of which are set at zero. Estimating the costs to reduce a constituent to zero is difficult if not impossible because it is not possible to verify by analytical means that the level has been lowered to zero. In some cases, installing treatment to try and further reduce very low levels of one constituent may have adverse effects on other aspects of water quality.

SECTION II: CONSTITUENTS DETECTED THAT EXCEED PHGs OR MCLGs

The following is a discussion of the constituents that were detected in our drinking water at levels above the PHG or MCLG:

COLIFORM BACTERIA:

The MCL for coliform is 5% positive samples of all samples per month and the MCLG is zero. The reason for the coliform drinking water standard is to minimize the possibility of the water containing pathogens, which are organisms that cause waterborne disease. Because coliform is only a surrogate indicator of the potential presence of pathogens, it is not possible to state a specific numerical health risk. Which USEPA normally sets MCLGs “at a level where no known or anticipated adverse effects on persons would occur,” they indicated that they cannot do so with coliforms.

The City of Napa collected 25 samples for the analysis of total coliform bacteria each week from selected sites throughout the distribution system, as required by the SWRCB. Occasionally, samples were found to be positive for coliform bacteria but repeat samples were negative and follow up actions were taken. Of these samples, a maximum of 11.45% in 2016, 0.88% in 2017 and 0.97% in 2018 were positive in any month.

Coliform bacteria are indicator organisms that are found everywhere in nature and are not generally considered harmful. They are used because of the ease in monitoring and analysis. If a positive sample is found, it indicates a potential problem that needs to be investigated and follow up sampling performed. It is not at all unusual for a system to have an occasional positive sample. It is difficult, if not impossible, to assure that a system will never have a positive sample.

We add chlorine at our treatment plants to ensure that the water served is microbiologically safe. The chlorine residual levels are carefully controlled to provide the best health protection without causing the water to have undesirable taste and odor or increasing the disinfection byproduct level. This careful balance of treatment processes is essential to continue supplying our customers with safe drinking water.

Other equally important measures that we have implemented include: an effective cross-connection control program, water main flushing program, disinfection residual maintenance throughout the majority of the system, an effective monitoring and surveillance program and maintaining positive pressures in our distribution system to minimize the chance of constituent intrusion. Our system has already taken all of the steps described by SWRCB as BATs for coliform bacteria in Section 64447, Title 22, California Code of Regulations.

CONSTITUENT	PHG or (MCLG)	MCL	TRI-ANNUAL AVERAGE
Total Coliform Bacteria	(Zero)	5% of samples collected in month positive	4.4%

COPPER:

There is no MCL for copper. Instead, the 90th percentile value of all samples from household taps in the distribution system cannot exceed the Action Level (AL) of 1.3 mg/L for copper. After years of monitoring, the City of Napa has demonstrated copper does not exist in significant amounts within the distribution system and is granted triennial monitoring. Based on triennial sampling of our distribution system performed in 2015 and 2018, our 90th percentile value for copper was 0.34 mg/L and 0.30 mg/L, respectively.

The PHG for copper is 0.3 mg/L. The category of health risk for copper is *gastrointestinal irritation*. Numerical health risk data on copper have not yet been provided by OEHHA, the State agency responsible for providing that information. (Reference No. 2)

Our water system is in full compliance with the Federal and State Lead and Copper Rule. Based on our sampling results, it was determined according to State regulatory requirements that we meet the Action Levels for Copper. Therefore, we are deemed by SWRCB to have “optimized corrosion control” for our system.

Since we are meeting the “optimized corrosion control” requirements, it is not prudent to initiate additional corrosion control treatment as it involves the addition of other chemicals and could introduce other water quality issues throughout the pipe network. Therefore, no estimate of cost has been included.

CONSTITUENT	PHG or (MCLG)	AL	TRI-ANNUAL AVERAGE
Copper	0.3 mg/L	1.3 mg/L	0.32 mg/L

BROMATE:

The MCL for bromate is 0.010 mg/L. Bromate compliance is based on the highest running annual average (RAA) and not on a single sample result. Based on compliance sampling of our drinking water between 2016 and 2018, results varied from non-detect (“0”) to 0.005 mg/L. The tri-annual average result was 0.003 mg/L. Bromate is a byproduct formed when naturally occurring bromide reacts with ozone during the drinking water disinfection process. Ozone is instrumental in removing constituents from source water and is highly effective at addressing taste and odor associated with breakdown or lysis of algal cells. Bromide, and therefore the potential for bromate formation, only exists during periodic episodes of reduced water quality during peak seasonal rain events.

The PHG for bromate is 0.0001 mg/L. The category of health risk for bromate is *carcinogenicity* or capable of producing cancer.

Our water system is in full compliance with the State regulatory requirements for bromate. The best available treatment technology to remove bromate would be the addition of reverse osmosis (RO) to the treatment process. RO is a high cost treatment

train that generates large volumes of brine that must be hauled off for disposal. Costs vary according to water quality. The approximate cost of a RO system (Reference No. 5) is \$11M for initial capital investment and \$5M annually for ongoing operations and maintenance or over \$600 per customer to install and \$200 annually. The system would have to be installed as a polishing step in addition to ozone and the existing conventional treatment process and would be effective for bromate removal only as needed approximately 25% in a given year. The multi-million-dollar investment to treat below regulatory requirements and meet the interpolated PHG value is not recommended at this time.

CONSTITUENT	PHG or (MCLG)	MCL	TRI-ANNUAL AVERAGE
Bromate	0.0001 mg/L	0.010 mg/L	0.003 mg/L

SECTION III: RECOMMENDATIONS FOR FURTHER ACTION:

The drinking water quality of the City of Napa meets all SWRCB and USEPA drinking water standards set to protect public health.

To further reduce the levels of the constituents identified in this report that are already significantly below the health-based MCLs established to provide “safe drinking water,” additional costly treatment processes would be required. The costs associated with incorporating additional treatment processes may be better utilized to provide greater public health protection benefits if spent in other aspects such as transmission and distribution system maintenance, operation and water quality monitoring programs.

The effectiveness of maintaining significant reductions in constituent levels post treatment at these already low values is uncertain. The health protection benefits of these further hypothetical reductions are not clear and may not be quantifiable. Therefore, no action is proposed at this time.

REFERENCES:

- No. 1 Excerpt from California Health & Safety Code: Section 116470 (b)
- No. 2 Table of Regulated Constituents with MCLs, PHGs or MCLGs
- No. 3 Health Risk Information for Public Health Goal Exceedance Reports. Prepared by the Office of Environmental Health Hazard Assessment. February 2019
- No. 4 City of Napa’s 2016, 2017 and 2018 Water Quality Reports
- No. 5 Englehardt and Wu.” Review of Cost Versus Scale: Water and Wastewater Treatment and Reuse Processes.” Water Science & Technology. 69.2(2014). Page 226. IWA Publishing 2014.

California Health and Safety Code, Section 116470 (b)

(b) On or before July 1, 1998, and every three years thereafter, public water systems serving more than 10,000 service connections that detect one or more contaminants in drinking water that exceed the applicable public health goal, shall prepare a brief written report in plain language that does all of the following:

- (1) identifies each contaminant detected in drinking water that exceeds the applicable public health goal
- (2) Discloses the numerical public health risk, determined by the office, associated with the maximum contaminant level for each contaminant level for each contaminant identified paragraph (1) and the numerical public health risk determined by the office associated with the public health goal for that contaminant.
- (3) Identifies the category of risk to public health, including, but not limited to, carcinogenic, mutagenic, teratogenic, and acute toxicity, associated with exposure to the contaminant in drinking water, and includes a brief plainly worded description of these terms.
- (4) Describes the best available technology, if any is then available on a commercial basis, to remove the contaminant or reduce the concentration of the contaminant. The public water system may, solely at its own discretion, briefly describe actions that have been taken on its own, or by other entities, to prevent the introduction of the contaminant into drinking water supplies.
- (5) Estimates the aggregate cost and the cost per customer of utilizing the technology described in paragraph (4), if any, to reduce the concentration of that contaminant in drinking water to a level at or below the public health goal.
- (6) Briefly describes what action, if any, the local water purveyor intends to take to reduce the concentration of the contaminant in public drinking water supplies and the basis for that decision.

(c) Public water systems required to prepare a report pursuant to subdivision (b) shall hold a public hearing for the purpose of accepting and responding to public comment on the report. Public water systems may hold the public hearing as part of any regularly scheduled meeting.

(d) The department shall not require a public water system to take any action to reduce or eliminate any exceedance of a public health goal.

(e) Enforcement of this section does not require the department to amend a public water systems operating permit.

(f) Pending adoption of a public health goal by the Office of Environmental Health Hazard Assessment pursuant to subdivision (c) of Section 116365, and in lieu thereof, public water systems shall use the national maximum contaminant level goal adopted by the United States Environmental Protection Agency for the corresponding contaminant for purposes of complying with the notice and hearing requirements of this section.

(g) This section is intended to provide an alternative form for the federally required consumer confidence report as authorized by 42 U.S.C. section 300g-3(c).

MCLs, DLRs, and PHGs for Regulated Drinking Water Contaminants

(Units are in milligrams per liter (mg/L), unless otherwise noted.)

Last Update: March 13, 2019

This table includes:

California's maximum contaminant levels (MCLs)

Detection limits for purposes of reporting (DLRs)

[Public health goals \(PHGs\) from the Office of Environmental Health Hazard Assessment \(OEHHA\)](#)

Also, the PHG for NDMA (which is not yet regulated) is included at the bottom of this table.

For comparison:

[Federal MCLs and Maximum Contaminant Level Goals \(MCLGs\) \(US EPA\)](#)

Regulated Contaminant	MCL	DLR	PHG	Date of PHG	MCL	MCLG
Chemicals with MCLs in 22 CCR §64431—Inorganic Chemicals						
Aluminum	1	0.05	0.6	2001	--	--
Antimony	0.006	0.006	0.001	2016	0.006	0.006
Arsenic	0.010	0.002	0.000004	2004	0.010	zero
Asbestos (MFL = million fibers per liter; for fibers >10 microns long)	7 MFL	0.2 MFL	7 MFL	2003	7 MFL	7 MFL
Barium	1	0.1	2	2003	2	2
Beryllium	0.004	0.001	0.001	2003	0.004	0.004
Cadmium	0.005	0.001	0.00004	2006	0.005	0.005
Chromium, Total - OEHHA withdrew the 0.0025-mg/L PHG	0.05	0.01	withdrawn Nov. 2001	1999	0.1	0.1
Chromium, Hexavalent - 0.01-mg/L MCL & 0.001-mg/L DLR repealed September 2017	--	--	0.00002	2011	--	--
Cyanide	0.15	0.1	0.15	1997	0.2	0.2
Fluoride	2	0.1	1	1997	4.0	4.0
Mercury (inorganic)	0.002	0.001	0.0012	1999 (rev2005)	0.002	0.002
Nickel	0.1	0.01	0.012	2001	--	--
Nitrate (as nitrogen, N)	10 as N	0.4	45 as NO ₃ (=10 as N)	2018	10	10
Nitrite (as N)	1 as N	0.4	1 as N	2018	1	1
Nitrate + Nitrite (as N)	10 as N	--	10 as N	2018	--	--
Perchlorate	0.006	0.004	0.001	2015	--	--
Selenium	0.05	0.005	0.03	2010	0.05	0.05
Thallium	0.002	0.001	0.0001	1999 (rev2004)	0.002	0.0005
Copper and Lead, 22 CCR §64672.3						
<i>Values referred to as MCLs for lead and copper are not actually MCLs; instead, they are called "Action Levels" under the lead and copper rule</i>						
Copper	1.3	0.05	0.3	2008	1.3	1.3
Lead	0.015	0.005	0.0002	2009	0.015	zero

Radionuclides with MCLs in 22 CCR §64441 and §64443—Radioactivity

[units are picocuries per liter (pCi/L), unless otherwise stated; n/a = not applicable]

Gross alpha particle activity - OEHHA concluded in 2003 that a PHG was not practical	15	3	none	n/a	15	zero
Gross beta particle activity - OEHHA concluded in 2003 that a PHG was not practical	4 mrem/yr	4	none	n/a	4 mrem/yr	zero
Radium-226	--	1	0.05	2006		
Radium-228	--	1	0.019	2006		
Radium-226 + Radium-228	5	--	--	--	5	zero
Strontium-90	8	2	0.35	2006	--	--
Tritium	20,000	1,000	400	2006	--	--
Uranium	20	1	0.43	2001	30 µg/L	zero

Chemicals with MCLs in 22 CCR §64444—Organic Chemicals

(a) Volatile Organic Chemicals (VOCs)

Benzene	0.001	0.0005	0.00015	2001	0.005	zero
Carbon tetrachloride	0.0005	0.0005	0.0001	2000	0.005	zero
1,2-Dichlorobenzene	0.6	0.0005	0.6	1997 (rev2009)	0.6	0.6
1,4-Dichlorobenzene (p-DCB)	0.005	0.0005	0.006	1997	0.075	0.075
1,1-Dichloroethane (1,1-DCA)	0.005	0.0005	0.003	2003	--	--
1,2-Dichloroethane (1,2-DCA)	0.0005	0.0005	0.0004	1999 (rev2005)	0.005	zero
1,1-Dichloroethylene (1,1-DCE)	0.006	0.0005	0.01	1999	0.007	0.007
cis-1,2-Dichloroethylene	0.006	0.0005	0.013	2018	0.07	0.07
trans-1,2-Dichloroethylene	0.01	0.0005	0.05	2018	0.1	0.1
Dichloromethane (Methylene chloride)	0.005	0.0005	0.004	2000	0.005	zero
1,2-Dichloropropane	0.005	0.0005	0.0005	1999	0.005	zero
1,3-Dichloropropene	0.0005	0.0005	0.0002	1999 (rev2006)	--	--
Ethylbenzene	0.3	0.0005	0.3	1997	0.7	0.7
Methyl tertiary butyl ether (MTBE)	0.013	0.003	0.013	1999	--	--
Monochlorobenzene	0.07	0.0005	0.07	2014	0.1	0.1
Styrene	0.1	0.0005	0.0005	2010	0.1	0.1
1,1,2,2-Tetrachloroethane	0.001	0.0005	0.0001	2003	0.1	0.1
Tetrachloroethylene (PCE)	0.005	0.0005	0.00006	2001	0.005	zero
Toluene	0.15	0.0005	0.15	1999	1	1
1,2,4-Trichlorobenzene	0.005	0.0005	0.005	1999	0.07	0.07
1,1,1-Trichloroethane (1,1,1-TCA)	0.200	0.0005	1	2006	0.2	0.2
1,1,2-Trichloroethane (1,1,2-TCA)	0.005	0.0005	0.0003	2006	0.005	0.003
Trichloroethylene (TCE)	0.005	0.0005	0.0017	2009	0.005	zero
Trichlorofluoromethane (Freon 11)	0.15	0.005	1.3	2014	--	--
1,1,2-Trichloro-1,2,2-Trifluoroethane (Freon 113)	1.2	0.01	4	1997 (rev2011)	--	--
Vinyl chloride	0.0005	0.0005	0.00005	2000	0.002	zero
Xylenes	1.750	0.0005	1.8	1997	10	10

(b) Non-Volatile Synthetic Organic Chemicals (SOCs)						
Alachlor	0.002	0.001	0.004	1997	0.002	zero
Atrazine	0.001	0.0005	0.00015	1999	0.003	0.003
Bentazon	0.018	0.002	0.2	1999 (rev2009)	--	--
Benzo(a)pyrene	0.0002	0.0001	0.000007	2010	0.0002	zero
Carbofuran	0.018	0.005	0.0007	2016	0.04	0.04
Chlordane	0.0001	0.0001	0.00003	1997 (rev2006)	0.002	zero
Dalapon	0.2	0.01	0.79	1997 (rev2009)	0.2	0.2
1,2-Dibromo-3-chloropropane (DBCP)	0.0002	0.00001	0.0000017	1999	0.0002	zero
2,4-Dichlorophenoxyacetic acid (2,4-D)	0.07	0.01	0.02	2009	0.07	0.07
Di(2-ethylhexyl)adipate	0.4	0.005	0.2	2003	0.4	0.4
Di(2-ethylhexyl)phthalate (DEHP)	0.004	0.003	0.012	1997	0.006	zero
Dinoseb	0.007	0.002	0.014	1997 (rev2010)	0.007	0.007
Diquat	0.02	0.004	0.006	2016	0.02	0.02
Endothal	0.1	0.045	0.094	2014	0.1	0.1
Endrin	0.002	0.0001	0.0003	2016	0.002	0.002
Ethylene dibromide (EDB)	0.00005	0.00002	0.00001	2003	0.00005	zero
Glyphosate	0.7	0.025	0.9	2007	0.7	0.7
Heptachlor	0.00001	0.00001	0.000008	1999	0.0004	zero
Heptachlor epoxide	0.00001	0.00001	0.000006	1999	0.0002	zero
Hexachlorobenzene	0.001	0.0005	0.00003	2003	0.001	zero
Hexachlorocyclopentadiene	0.05	0.001	0.002	2014	0.05	0.05
Lindane	0.0002	0.0002	0.000032	1999 (rev2005)	0.0002	0.0002
Methoxychlor	0.03	0.01	0.00009	2010	0.04	0.04
Molinate	0.02	0.002	0.001	2008	--	--
Oxamyl	0.05	0.02	0.026	2009	0.2	0.2
Pentachlorophenol	0.001	0.0002	0.0003	2009	0.001	zero
Picloram	0.5	0.001	0.166	2016	0.5	0.5
Polychlorinated biphenyls (PCBs)	0.0005	0.0005	0.00009	2007	0.0005	zero
Simazine	0.004	0.001	0.004	2001	0.004	0.004
Thiobencarb	0.07	0.001	0.042	2016	--	--
Toxaphene	0.003	0.001	0.00003	2003	0.003	zero
1,2,3-Trichloropropane	0.000005	0.000005	0.0000007	2009	--	--
2,3,7,8-TCDD (dioxin)	3×10^{-8}	5×10^{-9}	5×10^{-11}	2010	3×10^{-8}	zero
2,4,5-TP (Silvex)	0.05	0.001	0.003	2014	0.05	0.05
Chemicals with MCLs in 22 CCR §64533—Disinfection Byproducts						
Total Trihalomethanes	0.080	--	--	--	0.080	--
Bromodichloromethane	--	0.0010	0.00006	2018 draft	--	zero
Bromoform	--	0.0010	0.0005	2018 draft	--	zero
Chloroform	--	0.0010	0.0004	2018 draft	--	0.07
Dibromochloromethane	--	0.0010	0.0001	2018 draft	--	0.06
Haloacetic Acids (five) (HAA5)	0.060	--	--	--	0.060	--
Monochloroacetic Acid	--	0.0020	--	--	--	0.07
Dichloroacetic Acid	--	0.0010	--	--	--	zero

Chemicals with MCLs in 22 CCR §64533 —Disinfection Byproducts						
Trichloroacetic Acid	--	0.0010	--	--	--	0.02
Monobromoacetic Acid	--	0.0010	--	--	--	--
Dibromoacetic Acid	--	0.0010	--	--	--	--
Bromate	0.010	0.0050**	0.0001	2009	0.01	zero
Chlorite	1.0	0.020	0.05	2009	1	0.8
Chemicals with PHGs established in response to DDW requests. These are not currently regulated drinking water contaminants.						
N-Nitrosodimethylamine (NDMA)	--	--	0.000003	2006	--	--
*OEHHA's review of this chemical during the year indicated (rev20XX) resulted in no change in the PHG. **The DLR for Bromate is 0.0010 mg/L for analysis performed using EPA Method 317.0 Revision 2.0, 321.8, or 326.0.						

Public Health Goals

Health Risk Information for Public Health Goal Exceedance Reports

February 2019



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Prepared by

Office of Environmental Health Hazard Assessment
California Environmental Protection Agency

February 2019

Under the Calderon-Sher Safe Drinking Water Act of 1996 (the Act), public water systems with more than 10,000 service connections are required to prepare a report every three years for contaminants that exceed their respective Public Health Goals (PHGs).¹ This document contains health risk information on regulated drinking water contaminants to assist public water systems in preparing these reports. A PHG is the concentration of a contaminant in drinking water that poses no significant health risk if consumed for a lifetime. PHGs are developed and published by the Office of Environmental Health Hazard Assessment (OEHHA) using current risk assessment principles, practices and methods.²

The water system's report is required to identify the health risk category (e.g., carcinogenicity or neurotoxicity) associated with exposure to each regulated contaminant in drinking water and to include a brief, plainly worded description of these risks. The report is also required to disclose the numerical public health risk, if available, associated with the California Maximum Contaminant Level (MCL) and with the PHG for each contaminant. This health risk information document is prepared by OEHHA every three years to assist the water systems in providing the required information in their reports.

Numerical health risks: Table 1 presents health risk categories and cancer risk values for chemical contaminants in drinking water that have PHGs.

The Act requires that OEHHA publish PHGs based on health risk assessments using the most current scientific methods. As defined in statute, PHGs for non-carcinogenic

¹ Health and Safety Code Section 116470(b)

² Health and Safety Code Section 116365

chemicals in drinking water are set at a concentration “at which no known or anticipated adverse health effects will occur, with an adequate margin of safety.” For carcinogens, PHGs are set at a concentration that “does not pose any significant risk to health.” PHGs provide one basis for revising MCLs, along with cost and technological feasibility. OEHHA has been publishing PHGs since 1997 and the entire list published to date is shown in Table 1.

Table 2 presents health risk information for contaminants that do not have PHGs but have state or federal regulatory standards. The Act requires that, for chemical contaminants with California MCLs that do not yet have PHGs, water utilities use the federal Maximum Contaminant Level Goal (MCLG) for the purpose of complying with the requirement of public notification. MCLGs, like PHGs, are strictly health based and include a margin of safety. One difference, however, is that the MCLGs for carcinogens are set at zero because the US Environmental Protection Agency (US EPA) assumes there is no absolutely safe level of exposure to such chemicals. PHGs, on the other hand, are set at a level considered to pose no *significant* risk of cancer; this is usually no more than a one-in-one-million excess cancer risk (1×10^{-6}) level for a lifetime of exposure. In Table 2, the cancer risks shown are based on the US EPA’s evaluations.

For more information on health risks: The adverse health effects for each chemical with a PHG are summarized in a PHG technical support document. These documents are available on the OEHHA website (<http://www.oehha.ca.gov>). Also, technical fact sheets on most of the chemicals having federal MCLs can be found at <http://www.epa.gov/your-drinking-water/table-regulated-drinking-water-contaminants>.

Table 1: Health Risk Categories and Cancer Risk Values for Chemicals with California Public Health Goals (PHGs)

Chemical	Health Risk Category ¹	California PHG (mg/L) ²	Cancer Risk ³ at the PHG	California MCL ⁴ (mg/L)	Cancer Risk at the California MCL
Alachlor	carcinogenicity (causes cancer)	0.004	NA ^{5,6}	0.002	NA
Aluminum	neurotoxicity and immunotoxicity (harms the nervous and immune systems)	0.6	NA	1	NA
Antimony	digestive system toxicity (causes vomiting)	0.02	NA	0.006	NA
Arsenic	carcinogenicity (causes cancer)	0.000004 (4×10 ⁻⁶)	1×10 ⁻⁶ (one per million)	0.01	2.5×10 ⁻³ (2.5 per thousand)
Asbestos	carcinogenicity (causes cancer)	7 MFL ⁷ (fibers >10 microns in length)	1×10 ⁻⁶	7 MFL (fibers >10 microns in length)	1×10 ⁻⁶ (one per million)
Atrazine	carcinogenicity (causes cancer)	0.00015	1×10 ⁻⁶	0.001	7×10 ⁻⁶ (seven per million)

¹ Based on the OEHHA PHG technical support document unless otherwise specified. The categories are the hazard traits defined by OEHHA for California's Toxics Information Clearinghouse (online at:

http://oehha.ca.gov/multimedia/green/pdf/GC_Regtext011912.pdf).

² mg/L = milligrams per liter of water or parts per million (ppm)

³ Cancer Risk = Upper bound estimate of excess cancer risk from lifetime exposure. Actual cancer risk may be lower or zero. 1×10⁻⁶ means one excess cancer case per million people exposed.

⁴ MCL = maximum contaminant level.

⁵ NA = not applicable. Cancer risk cannot be calculated.

⁶ The PHG for alachlor is based on a threshold model of carcinogenesis and is set at a level that is believed to be without any significant cancer risk to individuals exposed to the chemical over a lifetime.

⁷ MFL = million fibers per liter of water.

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Chemical	Health Risk Category ¹	California PHG (mg/L) ²	Cancer Risk ³ at the PHG	California MCL ⁴ (mg/L)	Cancer Risk at the California MCL
Barium	cardiovascular toxicity (causes high blood pressure)	2	NA	1	NA
Bentazon	hepatotoxicity and digestive system toxicity (harms the liver, intestine, and causes body weight effects ⁸)	0.2	NA	0.018	NA
Benzene	carcinogenicity (causes leukemia)	0.00015	1×10^{-6}	0.001	7×10^{-6} (seven per million)
Benzo[a]pyrene	carcinogenicity (causes cancer)	0.000007 (7×10^{-6})	1×10^{-6}	0.0002	3×10^{-5} (three per hundred thousand)
Beryllium	digestive system toxicity (harms the stomach or intestine)	0.001	NA	0.004	NA
Bromate	carcinogenicity (causes cancer)	0.0001	1×10^{-6}	0.01	1×10^{-4} (one per ten thousand)
Cadmium	nephrotoxicity (harms the kidney)	0.00004	NA	0.005	NA
Carbofuran	reproductive toxicity (harms the testis)	0.0007	NA	0.018	NA

⁸ Body weight effects are an indicator of general toxicity in animal studies.

Table 1: Health Risk Categories and Cancer Risk Values for Chemicals with California Public Health Goals (PHGs)

Chemical	Health Risk Category ¹	California PHG (mg/L) ²	Cancer Risk ³ at the PHG	California MCL ⁴ (mg/L)	Cancer Risk at the California MCL
Carbon tetrachloride	carcinogenicity (causes cancer)	0.0001	1×10^{-6}	0.0005	5×10^{-6} (five per million)
Chlordane	carcinogenicity (causes cancer)	0.00003	1×10^{-6}	0.0001	3×10^{-6} (three per million)
Chlorite	hematotoxicity (causes anemia) neurotoxicity (causes neurobehavioral effects)	0.05	NA	1	NA
Chromium, hexavalent	carcinogenicity (causes cancer)	0.00002	1×10^{-6}	none	NA
Copper	digestive system toxicity (causes nausea, vomiting, diarrhea)	0.3	NA	1.3 (AL ⁹)	NA
Cyanide	neurotoxicity (damages nerves) endocrine toxicity (affects the thyroid)	0.15	NA	0.15	NA
Dalapon	nephrotoxicity (harms the kidney)	0.79	NA	0.2	NA
Di(2-ethylhexyl) adipate (DEHA)	developmental toxicity (disrupts development)	0.2	NA	0.4	NA
Diethylhexyl-phthalate (DEHP)	carcinogenicity (causes cancer)	0.012	1×10^{-6}	0.004	3×10^{-7} (three per ten million)

⁹ AL = action level. The action levels for copper and lead refer to a concentration measured at the tap. Much of the copper and lead in drinking water is derived from household plumbing (The Lead and Copper Rule, Title 22, California Code of Regulations [CCR] section 64672.3).

Table 1: Health Risk Categories and Cancer Risk Values for Chemicals with California Public Health Goals (PHGs)

Chemical	Health Risk Category ¹	California PHG (mg/L) ²	Cancer Risk ³ at the PHG	California MCL ⁴ (mg/L)	Cancer Risk at the California MCL
1,2-Dibromo-3-chloropropane (DBCP)	carcinogenicity (causes cancer)	0.0000017 (1.7×10 ⁻⁶)	1×10 ⁻⁶	0.0002	1×10 ⁻⁴ (one per ten thousand)
1,2-Dichloro-benzene (o-DCB)	hepatotoxicity (harms the liver)	0.6	NA	0.6	NA
1,4-Dichloro-benzene (p-DCB)	carcinogenicity (causes cancer)	0.006	1×10 ⁻⁶	0.005	8×10 ⁻⁷ (eight per ten million)
1,1-Dichloro-ethane (1,1-DCA)	carcinogenicity (causes cancer)	0.003	1×10 ⁻⁶	0.005	2×10 ⁻⁶ (two per million)
1,2-Dichloro-ethane (1,2-DCA)	carcinogenicity (causes cancer)	0.0004	1×10 ⁻⁶	0.0005	1×10 ⁻⁶ (one per million)
1,1-Dichloro-ethylene (1,1-DCE)	hepatotoxicity (harms the liver)	0.01	NA	0.006	NA
1,2-Dichloro-ethylene, cis	nephrotoxicity (harms the kidney)	0.013	NA	0.006	NA
1,2-Dichloro-ethylene, trans	immunotoxicity (harms the immune system)	0.05	NA	0.01	NA
Dichloromethane (methylene chloride)	carcinogenicity (causes cancer)	0.004	1×10 ⁻⁶	0.005	1×10 ⁻⁶ (one per million)

Table 1: Health Risk Categories and Cancer Risk Values for Chemicals with California Public Health Goals (PHGs)

Chemical	Health Risk Category ¹	California PHG (mg/L) ²	Cancer Risk ³ at the PHG	California MCL ⁴ (mg/L)	Cancer Risk at the California MCL
2,4-Dichloro-phenoxyacetic acid (2,4-D)	hepatotoxicity and nephrotoxicity (harms the liver and kidney)	0.02	NA	0.07	NA
1,2-Dichloro-propane (propylene dichloride)	carcinogenicity (causes cancer)	0.0005	1×10^{-6}	0.005	1×10^{-5} (one per hundred thousand)
1,3-Dichloro-propene (Telone II®)	carcinogenicity (causes cancer)	0.0002	1×10^{-6}	0.0005	2×10^{-6} (two per million)
Dinoseb	reproductive toxicity (harms the uterus and testis)	0.014	NA	0.007	NA
Diquat	ocular toxicity (harms the eye) developmental toxicity (causes malformation)	0.006	NA	0.02	NA
Endothall	digestive system toxicity (harms the stomach or intestine)	0.094	NA	0.1	NA
Endrin	neurotoxicity (causes convulsions) hepatotoxicity (harms the liver)	0.0003	NA	0.002	NA
Ethylbenzene (phenylethane)	hepatotoxicity (harms the liver)	0.3	NA	0.3	NA
Ethylene dibromide (1,2-Dibromoethane)	carcinogenicity (causes cancer)	0.00001	1×10^{-6}	0.00005	5×10^{-6} (five per million)

Table 1: Health Risk Categories and Cancer Risk Values for Chemicals with California Public Health Goals (PHGs)

Chemical	Health Risk Category ¹	California PHG (mg/L) ²	Cancer Risk ³ at the PHG	California MCL ⁴ (mg/L)	Cancer Risk at the California MCL
Fluoride	musculoskeletal toxicity (causes tooth mottling)	1	NA	2	NA
Glyphosate	nephrotoxicity (harms the kidney)	0.9	NA	0.7	NA
Heptachlor	carcinogenicity (causes cancer)	0.000008 (8×10^{-6})	1×10^{-6}	0.00001	1×10^{-6} (one per million)
Heptachlor epoxide	carcinogenicity (causes cancer)	0.000006 (6×10^{-6})	1×10^{-6}	0.00001	2×10^{-6} (two per million)
Hexachlorobenzene	carcinogenicity (causes cancer)	0.00003	1×10^{-6}	0.001	3×10^{-5} (three per hundred thousand)
Hexachlorocyclopentadiene (HCCPD)	digestive system toxicity (causes stomach lesions)	0.002	NA	0.05	NA
Lead	developmental neurotoxicity (causes neurobehavioral effects in children) cardiovascular toxicity (causes high blood pressure) carcinogenicity (causes cancer)	0.0002	$<1 \times 10^{-6}$ (PHG is not based on this effect)	0.015 (AL ⁸)	2×10^{-6} (two per million)
Lindane (γ-BHC)	carcinogenicity (causes cancer)	0.000032	1×10^{-6}	0.0002	6×10^{-6} (six per million)
Mercury (inorganic)	nephrotoxicity (harms the kidney)	0.0012	NA	0.002	NA

Table 1: Health Risk Categories and Cancer Risk Values for Chemicals with California Public Health Goals (PHGs)

Chemical	Health Risk Category ¹	California PHG (mg/L) ²	Cancer Risk ³ at the PHG	California MCL ⁴ (mg/L)	Cancer Risk at the California MCL
Methoxychlor	endocrine toxicity (causes hormone effects)	0.00009	NA	0.03	NA
Methyl tertiary-butyl ether (MTBE)	carcinogenicity (causes cancer)	0.013	1×10^{-6}	0.013	1×10^{-6} (one per million)
Molinate	carcinogenicity (causes cancer)	0.001	1×10^{-6}	0.02	2×10^{-5} (two per hundred thousand)
Monochlorobenzene (chlorobenzene)	nephrotoxicity (harms the kidney)	0.07	NA	0.07	NA
Nickel	developmental toxicity (causes increased neonatal deaths)	0.012	NA	0.1	NA
Nitrate	hematotoxicity (causes methemoglobinemia)	45 as nitrate	NA	10 as nitrogen (=45 as nitrate)	NA
Nitrite	hematotoxicity (causes methemoglobinemia)	3 as nitrite	NA	1 as nitrogen (=3 as nitrite)	NA
Nitrate and Nitrite	hematotoxicity (causes methemoglobinemia)	10 as nitrogen ¹⁰	NA	10 as nitrogen	NA

¹⁰ The joint nitrate/nitrite PHG of 10 mg/L (10 ppm, expressed as nitrogen) does not replace the individual values, and the maximum contribution from nitrite should not exceed 1 mg/L nitrite-nitrogen.

Table 1: Health Risk Categories and Cancer Risk Values for Chemicals with California Public Health Goals (PHGs)

Chemical	Health Risk Category ¹	California PHG (mg/L) ²	Cancer Risk ³ at the PHG	California MCL ⁴ (mg/L)	Cancer Risk at the California MCL
N-nitroso-dimethyl-amine (NDMA)	carcinogenicity (causes cancer)	0.000003 (3×10^{-6})	1×10^{-6}	none	NA
Oxamyl	general toxicity (causes body weight effects)	0.026	NA	0.05	NA
Pentachloro-phenol (PCP)	carcinogenicity (causes cancer)	0.0003	1×10^{-6}	0.001	3×10^{-6} (three per million)
Perchlorate	endocrine toxicity (affects the thyroid) developmental toxicity (causes neurodevelopmental deficits)	0.001	NA	0.006	NA
Picloram	hepatotoxicity (harms the liver)	0.166	NA	0.5	NA
Polychlorinated biphenyls (PCBs)	carcinogenicity (causes cancer)	0.00009	1×10^{-6}	0.0005	6×10^{-6} (six per million)
Radium-226	carcinogenicity (causes cancer)	0.05 pCi/L	1×10^{-6}	5 pCi/L (combined $Ra^{226+228}$)	1×10^{-4} (one per ten thousand)
Radium-228	carcinogenicity (causes cancer)	0.019 pCi/L	1×10^{-6}	5 pCi/L (combined $Ra^{226+228}$)	3×10^{-4} (three per ten thousand)
Selenium	integumentary toxicity (causes hair loss and nail damage)	0.03	NA	0.05	NA

Table 1: Health Risk Categories and Cancer Risk Values for Chemicals with California Public Health Goals (PHGs)

Chemical	Health Risk Category ¹	California PHG (mg/L) ²	Cancer Risk ³ at the PHG	California MCL ⁴ (mg/L)	Cancer Risk at the California MCL
Silvex (2,4,5-TP)	hepatotoxicity (harms the liver)	0.003	NA	0.05	NA
Simazine	general toxicity (causes body weight effects)	0.004	NA	0.004	NA
Strontium-90	carcinogenicity (causes cancer)	0.35 pCi/L	1×10^{-6}	8 pCi/L	2×10^{-5} (two per hundred thousand)
Styrene (vinylbenzene)	carcinogenicity (causes cancer)	0.0005	1×10^{-6}	0.1	2×10^{-4} (two per ten thousand)
1,1,2,2-Tetrachloroethane	carcinogenicity (causes cancer)	0.0001	1×10^{-6}	0.001	1×10^{-5} (one per hundred thousand)
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD, or dioxin)	carcinogenicity (causes cancer)	5×10^{-11}	1×10^{-6}	3×10^{-8}	6×10^{-4} (six per ten thousand)
Tetrachloroethylene (perchloroethylene, or PCE)	carcinogenicity (causes cancer)	0.00006	1×10^{-6}	0.005	8×10^{-5} (eight per hundred thousand)
Thallium	integumentary toxicity (causes hair loss)	0.0001	NA	0.002	NA

Table 1: Health Risk Categories and Cancer Risk Values for Chemicals with California Public Health Goals (PHGs)

Chemical	Health Risk Category ¹	California PHG (mg/L) ²	Cancer Risk ³ at the PHG	California MCL ⁴ (mg/L)	Cancer Risk at the California MCL
Thiobencarb	general toxicity (causes body weight effects) hematotoxicity (affects red blood cells)	0.042	NA	0.07	NA
Toluene (methylbenzene)	hepatotoxicity (harms the liver) endocrine toxicity (harms the thymus)	0.15	NA	0.15	NA
Toxaphene	carcinogenicity (causes cancer)	0.00003	1×10^{-6}	0.003	1×10^{-4} (one per ten thousand)
1,2,4-Trichlorobenzene	endocrine toxicity (harms adrenal glands)	0.005	NA	0.005	NA
1,1,1-Trichloroethane	neurotoxicity (harms the nervous system), reproductive toxicity (causes fewer offspring) hepatotoxicity (harms the liver) hematotoxicity (causes blood effects)	1	NA	0.2	NA
1,1,2-Trichloroethane	carcinogenicity (causes cancer)	0.0003	1×10^{-6}	0.005	2×10^{-5} (two per hundred thousand)
Trichloroethylene (TCE)	carcinogenicity (causes cancer)	0.0017	1×10^{-6}	0.005	3×10^{-6} (three per million)

Table 1: Health Risk Categories and Cancer Risk Values for Chemicals with California Public Health Goals (PHGs)

Chemical	Health Risk Category ¹	California PHG (mg/L) ²	Cancer Risk ³ at the PHG	California MCL ⁴ (mg/L)	Cancer Risk at the California MCL
Trichlorofluoromethane (Freon 11)	accelerated mortality (increase in early death)	1.3	NA	0.15	NA
1,2,3-Trichloropropane (1,2,3-TCP)	carcinogenicity (causes cancer)	0.0000007 (7×10^{-7})	1×10^{-6}	0.000005 (5×10^{-6})	7×10^{-6} (seven per million)
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113)	hepatotoxicity (harms the liver)	4	NA	1.2	NA
Tritium	carcinogenicity (causes cancer)	400 pCi/L	1×10^{-6}	20,000 pCi/L	5×10^{-5} (five per hundred thousand)
Uranium	carcinogenicity (causes cancer)	0.43 pCi/L	1×10^{-6}	20 pCi/L	5×10^{-5} (five per hundred thousand)
Vinyl chloride	carcinogenicity (causes cancer)	0.00005	1×10^{-6}	0.0005	1×10^{-5} (one per hundred thousand)
Xylene	neurotoxicity (affects the senses, mood, and motor control)	1.8 (single isomer or sum of isomers)	NA	1.75 (single isomer or sum of isomers)	NA

Table 2: Health Risk Categories and Cancer Risk Values for Chemicals without California Public Health Goals

Chemical	Health Risk Category ¹	US EPA MCLG ² (mg/L)	Cancer Risk ³ @ MCLG	California MCL ⁴ (mg/L)	Cancer Risk @ California MCL
Disinfection byproducts (DBPs)					
Chloramines	acute toxicity (causes irritation) digestive system toxicity (harms the stomach) hematotoxicity (causes anemia)	4 ^{5,6}	NA ⁷	none	NA
Chlorine	acute toxicity (causes irritation) digestive system toxicity (harms the stomach)	4 ^{5,6}	NA	none	NA
Chlorine dioxide	hematotoxicity (causes anemia) neurotoxicity (harms the nervous system)	0.8 ^{5,6}	NA	none	NA
Disinfection byproducts: haloacetic acids (HAA5)					
Monochloroacetic acid (MCA)	general toxicity (causes body and organ weight changes ⁸)	0.07	NA	none	NA
Dichloroacetic acid (DCA)	carcinogenicity (causes cancer)	0	0	none	NA

¹ Health risk category based on the US EPA MCLG document or California MCL document unless otherwise specified.

² MCLG = maximum contaminant level goal established by US EPA.

³ Cancer Risk = Upper estimate of excess cancer risk from lifetime exposure. Actual cancer risk may be lower or zero. 1×10^{-6} means one excess cancer case per million people exposed.

⁴ California MCL = maximum contaminant level established by California.

⁵ Maximum Residual Disinfectant Level Goal, or MRDLG.

⁶ The federal Maximum Residual Disinfectant Level (MRDL), or highest level of disinfectant allowed in drinking water, is the same value for this chemical.

⁷ NA = not available.

⁸ Body weight effects are an indicator of general toxicity in animal studies.

Table 2: Health Risk Categories and Cancer Risk Values for Chemicals without California Public Health Goals

Chemical	Health Risk Category ¹	US EPA MCLG ² (mg/L)	Cancer Risk ³ @ MCLG	California MCL ⁴ (mg/L)	Cancer Risk @ California MCL
Trichloroacetic acid (TCA)	hepatotoxicity (harms the liver)	0.02	NA	none	NA
Monobromoacetic acid (MBA)	NA	none	NA	none	NA
Dibromoacetic acid (DBA)	NA	none	NA	none	NA
Total haloacetic acids (sum of MCA, DCA, TCA, MBA, and DBA)	general toxicity, hepatotoxicity and carcinogenicity (causes body and organ weight changes, harms the liver and causes cancer)	none	NA	0.06	NA
Disinfection byproducts: trihalomethanes (THMs)					
Bromodichloromethane (BDCM)	carcinogenicity (causes cancer)	0	0	none	NA
Bromoform	carcinogenicity (causes cancer)	0	0	none	NA
Chloroform	hepatotoxicity and nephrotoxicity (harms the liver and kidney)	0.07	NA	none	NA
Dibromochloromethane (DBCM)	hepatotoxicity, nephrotoxicity, and neurotoxicity (harms the liver, kidney, and nervous system)	0.06	NA	none	NA

Table 2: Health Risk Categories and Cancer Risk Values for Chemicals without California Public Health Goals

Chemical	Health Risk Category ¹	US EPA MCLG ² (mg/L)	Cancer Risk ³ @ MCLG	California MCL ⁴ (mg/L)	Cancer Risk @ California MCL
Total trihalomethanes (sum of BDCM, bromoform, chloroform and DBCM)	carcinogenicity (causes cancer), hepatotoxicity, nephrotoxicity, and neurotoxicity (harms the liver, kidney, and nervous system)	none	NA	0.08	NA
Radionuclides					
Gross alpha particles ⁹	carcinogenicity (causes cancer)	0 (²¹⁰ Po included)	0	15 pCi/L ¹⁰ (includes ²²⁶ Ra but not radon and uranium)	up to 1x10 ⁻³ (for ²¹⁰ Po, the most potent alpha emitter)
Beta particles and photon emitters ⁹	carcinogenicity (causes cancer)	0 (²¹⁰ Pb included)	0	50 pCi/L (judged equiv. to 4 mrem/yr)	up to 2x10 ⁻³ (for ²¹⁰ Pb, the most potent beta-emitter)

⁹ MCLs for gross alpha and beta particles are screening standards for a group of radionuclides. Corresponding PHGs were not developed for gross alpha and beta particles. See the OEHHA memoranda discussing the cancer risks at these MCLs at <http://www.oehha.ca.gov/water/reports/grossab.html>.

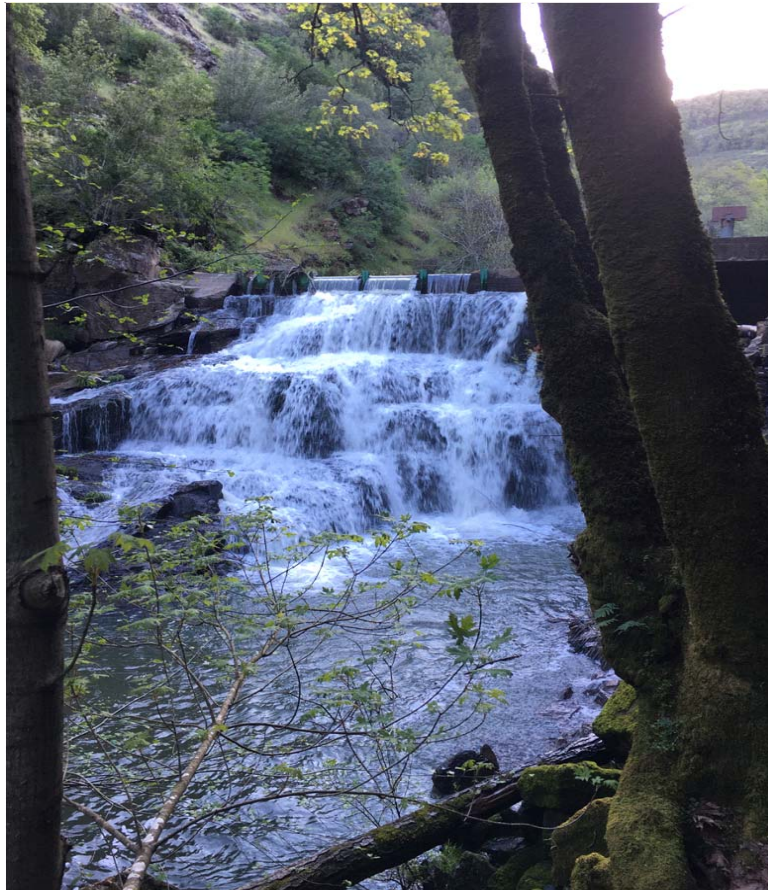
¹⁰ pCi/L = picocuries per liter of water.

2016 DRINKING WATER QUALITY REPORT



CITY OF
NAPA

Este informe contiene información muy importante sobre su agua potable. Tradúzcalo o hable con alguien que lo entienda bien. Para recibir información en Español comuníquese con Bea Manriquez al (707) 257-9520 extensión 7743.



Milliken Diversion Dam

A primary purpose of this drinking water quality report is to provide Napa's water consumers with detailed information regarding where your water comes from, what it contains and how it compares to Federal and State standards for the period January 1, 2016 - December 31, 2016.

In order to ensure that tap water is safe to drink, the US Environmental Protection Agency (USEPA) and the State Water Resource Control Board (SWRCB) prescribe regulations that limit the amount of certain contaminants in water provided by the public water systems.

Drinking Water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of some contaminants does not necessarily indicate that the water poses a

health risk. If the product is bottled in California, SWRCB regulations establish limits for contaminants in bottled water that must provide the same protection for public health. These limits may not be as stringent if bottled in other states.

More information about contaminants and potential health effects can be obtained by calling the USEPA's Safe Drinking Water (SDW) Hotline at (800) 426-4791.

**This table below summarizes the drinking water contaminants that were detected in the period
January 1, 2016 - December 31, 2016. ATTACHMENT 1**

CONTAMINANT	UNITS	MCL (NL)	PHG (MCLG)	AVERAGE	RANGE	CONTAMINANT SOURCES	
SECONDARY INORGANIC CONTAMINANTS							
Total Dissolved Solids	ppm	1000	NA	233	150 - 611	Runoff/leaching from natural deposits	
Specific Conductance	uS/cm	1600	NA	423	244 - 749	Substances that form ions when in water; seawater influence	
Manganese	ppb	50	NA	16	ND - 32	Leaching from natural deposits	
Chloride	ppm	500	NA	17	13 - 72	Runoff/leaching from natural deposits; seawater influence	
Sulfate	ppm	500	NA	61	55 - 67	Runoff/leaching from natural deposits; industrial wastes	
UNREGULATED CONTAMINANTS							
Boron	ppm	(1)	NA	0.13	0.11 - 0.15	Unregulated contaminant monitoring helps EPA & the State determine where certain contaminants occur & whether they need to be regulated	
OTHER CONTAMINANTS							
Sodium	ppm	NA	NA	25	19 - 30	Naturally-occurring in ground and surface water	
Hardness	ppm	NA	NA	101	62 - 140		
MICROBIOLOGICAL CONTAMINANTS							
COLIFORM BACTERIA							
Minimum # of Monthly Samples Required: 92					Maximum % of Postive Samples Allowed(MCL): < 5.0%		
CONTAMINANT	TOTAL # OF SAMPLES TAKEN			HIGHEST MONTHLY % POSITIVE*		TOTAL % POSITIVE	CONTAMINANT SOURCES
Total Coliform Bacteria	1341			11.45		1.49	Naturally present in the environment
FILTER PERFORMANCE							
TURBIDITY (THE STANDARD MEASURE OF THE CLARITY IN WATER)							
CONTAMINANT	PERFORMANCE STANDARD (TT)			HIGHEST DETECTED MEASUREMENT (NTU)		LOWEST % OF SAMPLES < 0.3	CONTAMINANT SOURCES
Turbidity	TT = 1.0; Minimum 95% of samples each month < 0.3			0.50		100.0	Soil runoff
DISINFECTION BYPRODUCTS, DISINFECTANT RESIDUALS and DISINFECTION BYPRODUCT PRECURSORS							
TRIHALOMETHANES (THMs)* AND HALOACETIC ACIDS (HAAs)							
CONTAMINANT	UNITS	MCL	PHG (MCLG)	HIGHEST LRAA (RAA)	RANGE	CONTAMINANT SOURCES	
THM	ppb	80	NA	72.1	24.8 - 78.3	Byproduct of drinking water disinfection via reaction between organic carbon and chlorine	
HAA	ppb	60	NA	21.4	ND - 29.0		
Bromate	ppb	10	0.1	(4)	2 - 5		
CHLORINE (Cl ₂)							
CONTAMINANT	UNITS	MRDL	MRDLG	AVERAGE	RANGE	CONTAMINANT SOURCES	
Chlorine	ppm	4.0	4.0	0.53	ND - 1.42	Drinking water disinfectant added for treatment	
TOTAL ORGANIC CARBON (TOC)							
CONTAMINANT	COMPLIANCE RATIO	MCL	PHG	AVERAGE	RANGE	CONTAMINANT SOURCES	
TOC	> 1.00	TT	NA	2.04	1.58 - 2.68	Various natural and man-made sources	
DETECTION OF LEAD AND COPPER IN CUSTOMER TAPS (collected in July 2015)							
CONTAMINANT	UNITS	AL	PHG	90 TH PERCENTILE DETECTED	# SITES EXCEEDING AL	# SITES SAMPLED	CONTAMINANT SOURCES
Lead	ppb	15	0.2	ND	1	37	Plumbing corrosion; erosion of natural deposits
Copper	ppm	1.3	0.3	0.34	0	37	

**During May 2016, the City of Napa conducted a Level 1 Assessment and there were no corrective actions required*

WATER QUALITY GLOSSARY

AL - Regulatory Action Level: The concentration of a contaminant, which, if exceeded, triggers a treatment or other requirements that a water system must follow.

Level 1 Assessment: A Level 1 assessment is a study of the water system to identify potential problems and determine (if possible) why total coliform bacteria have been found in our water system

LRAA - Locational Running Annual Average

MCL - Maximum Contaminant Level: The highest level of contaminant that is allowed in drinking water. Primary MCLs are set as close to the PHGs (or MCLGs) as is economically & technologically feasible. Secondary MCLs are set to protect the odor, taste & appearance.

MCLG - Maximum Contaminant Level Goal: The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs are set by the USEPA.

MRDL - Maximum Residual Disinfectant Level: The highest level of a disinfectant allowed in drinking water.

There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

MRDLG - Maximum Residual Disinfectant Level Goal: The level of a disinfectant added for water treatment below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.

NA - Not Applicable

ND - Not Detected

NL - Notification Level

NTU - Nephelometric Turbidity Units

PHG - Public Health Goal: The level of a contaminant in drinking water below which there is no known or expected risk to health. PHGs are set by the CA EPA.

ppb - parts per billion: micrograms per liter (ug/L)

ppm - parts per million: milligrams per liter (mg/L); 17.1 ppm = 1 grain/gal

PDWS - Primary Drinking Water Standard: MCLs & MRDLs for contaminants that affect health along with their monitoring and reporting requirement, & water treatment requirements.

TT - Treatment Technique: A required process intended to reduce the level of a contaminant in drinking water.

uS/cm: microsiemens per centimeter

PROTECTING OUR WATERSHEDS

The City of Napa is devoted to protecting the land surrounding our local source waters in order to maintain the quality and purity of water used for Napa's drinking water consumers. In the long-term, protecting our watersheds is one of the least costly and most important actions we can take to reduce the risk of unwanted constituents in our drinking water. Algal growth due to the addition of nutrients is the number one cause of taste and odor affecting your tap water. Nutrients in the watershed are increased artificially by wastewater systems as well as fertilizers and runoff from agricultural practices. Every five years, the City of Napa conducts Source Water Assessments to evaluate the quality of the water used as drinking water supplies and to examine activities associated with the specific waterway and surrounding areas to determine their contribution to contamination.

These potential contributors are then compiled into a Vulnerability Summary. Results from the Vulnerability Summaries show the most significant potential sources of contaminants for the City of Napa's source waters are:

Lake Hennessey (completed December 2012): Pacific Union College WasteWater Treatment Plant, vineyards, fires, invasive species, potential hazardous material spills due to traffic accidents (on Highway 128 near lake), septic tank systems (in Angwin), and grazing and wild animals.

Lake Milliken (completed December 2012): Fires, vineyards, grazing and wild animals.

Sacramento Delta (updated June 2012): Recreational use, urban and agricultural runoff, grazing animals, herbicide application and seawater intrusion.

Copies of the complete assessments are available through the SWRCB DDW Santa Rosa District Office, 50 D Street, Suite 200, Santa Rosa, CA 95404 or Ms. Amy Little, Associate Sanitary Engineer, SWRCB at (707) 576-2145.

SOURCE WATER

The sources of drinking water (both tap water and bottled water) include rivers, lakes, streams, ponds, reservoirs, springs and wells. As water travels over the surface of the land or through the ground, it dissolves naturally-occurring minerals and, in some cases, radioactive material, and can pick up substances resulting from the presence of animals

or human activity.

The City of Napa's source water, depending on which water treatment plant is in operation, comes from:

- 1) Barker Slough in the Sacramento Delta via the North Bay Aqueduct (treated by the Edward I. Barwick Jamieson Canyon Water Treatment Plant),
- 2) Lake Hennessey (treated by the Hennessey Water Treatment Plant), and
- 3) Lake Milliken (treated by the Milliken Water Treatment Plant).

Contaminants that may be present in source water include:

Microbial contaminants, such as viruses and bacteria, that may come from sewage treatment plants, septic systems, agricultural livestock operations and wildlife.

Inorganic contaminants, such as salts and metals, that can be naturally-occurring or result from urban stormwater runoff, industrial or domestic wastewater discharges, oil and gas production, mining or farming.

Pesticides and herbicides, that may come from a variety of sources such as agriculture, urban stormwater runoff and residential uses.

Organic chemical contaminants, including synthetic and volatile organic chemicals, that are byproducts of industrial processes and petroleum production, and can also come from gas stations, urban stormwater runoff, agricultural application, and septic systems.

Radioactive contaminants, that can be naturally-occurring or be the result of oil and gas production and

mining activities.

Watershed Protection



Lake Hennessey

The City of Napa encourages citizens to participate in our City Council meetings, which take place on the first and third Tuesday of each month at 3:30-5:00 pm and again at 6:30-9:00 pm, in our Council Chambers at City Hall, 955 School Street. For more information concerning City activities, please see our web site at <http://cityofnapa.org>.



COLIFORMS

This report reflects changes in drinking water regulatory requirements during 2016. All water systems are required to comply with the state Total Coliform Rule. Beginning April 1, 2016, all water systems are also required to comply with the federal Revised Total Coliform Rule. The new federal rule maintains the purpose to protect public health by ensuring the integrity of the drinking water distribution system and monitoring for the presence of coliforms. Coliforms are bacteria that are naturally present in the environment and are used as an indicator that other, potentially harmful, waterborne pathogens may be present or that a potential pathway exists through which contamination may enter the drinking water distribution system. When this occurs, we are required to conduct assessments to identify problems and to correct any problems that were found during these assessments. During the past year we were required to conduct a Level I assessment. There were no problems found nor corrective actions required.

SENSITIVE POPULATIONS

Some people may be more vulnerable to contaminants in drinking water than the general population. Immuno-compromised persons such as persons with cancer undergoing chemotherapy, persons who have undergone organ transplants, people with HIV/AIDS or other immune system disorders, some elderly, and infants can be particularly at risk from infections. These people should seek advice about drinking water from their health care providers. USEPA/Centers for Disease Control (CDC) guidelines on appropriate means to lessen the risk of infection by *Cryptosporidium* and other microbial contaminants are available from the SDW Hotline at (800) 426-4791.

Water is a Natural Resource.

TRIHALOMETHANES & HALOACETIC ACIDS

Similar to *Sensitive Populations* above, scientists can not disprove that some people who drink water containing THMs and/or HAAs in excess of the MCL over many years (studies interpolate exposures to seventy years) may experience liver, kidney or central nervous system problems, and may have an increased risk of getting cancer. These diseases, however, are not only caused by chemicals in drinking water, but also by food, air and other environmental factors.

LEAD & COPPER

If present, elevated levels of lead can cause serious health problems, especially for pregnant women and young children. Lead in drinking water is primarily from materials and components associated with service lines and home plumbing. Unlike other regions of the US where lead was prevalent, it was not the predominant construction material used in the City of Napa for water service installations. Additionally, years of monitoring shows the existing

public system pipe network does not contribute lead to the drinking water. The City of Napa is responsible for providing high quality drinking water and can advise, but cannot control, the variety of materials used in private plumbing components. When your water has been sitting for several hours, you can minimize the potential for lead exposure by flushing your tap for 30 seconds to 2 minutes before using water for drinking or cooking. If you are concerned about lead in your water, you may wish to have your water tested. Information on lead in drinking water, testing methods, and steps you can take to minimize exposure is available from the SDW Hotline or at <http://www.epa.gov/lead>. To be in compliance with the Lead and Copper Rule, the level detected at the 90th percentile must be below the AL. The next round of lead and copper testing is in July 2018.

FOR MORE INFORMATION

If you have questions after reading this report regarding drinking water quality, please call Erin Kebbas at (707) 253-0822. For questions concerning the City of Napa Water Division, in general, please call (707) 257-9521. See our website for up to date information on programs: www.cityofnapa.org/water. For emergencies or customer use during weekends and holidays, please call (707) 253-4451.



2017 ANNUAL DRINKING WATER QUALITY REPORT

Quality First

Once again we are pleased to present our drinking water quality report. A primary purpose of this drinking water quality report is to provide Napa's water consumers with detailed information regarding where your water comes from, what it contains, and how it compares to Federal and State standards for the period January 1, 2017 -- December 30, 2017.

As in years past, we are committed to delivering the best-quality drinking water possible. To that end, we remain vigilant in meeting the challenges of new regulations, source water protection, water conservation, and community outreach and education, while continuing to serve the needs of all of our water users. Thank you for allowing us the opportunity to serve you and your family.

Where Does My Water Come From?

The City of Napa's customers are fortunate because we enjoy an abundant water supply from three sources. Depending on which water treatment plant is in operation, the source water comes from: 1) Barker Slough in the Sacramento Delta via the North Bay Aqueduct (treated by the Edward I. Barwick Jamieson Canyon Water Treatment Plant), 2) Lake Hennessey (treated by the Hennessey Water Treatment Plant) and 3) Lake Milliken (treated by the Milliken Water Treatment Plant).

Count on Us

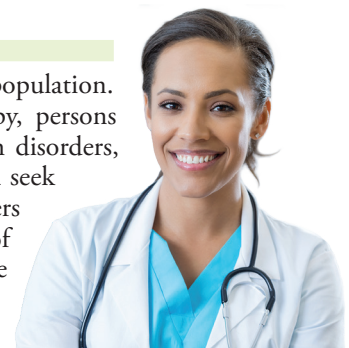
Delivering high-quality drinking water to our customers involves far more than just pushing water through pipes. Water treatment is a complex process. Because tap water is highly regulated by state and federal laws, water treatment plant and system operators must be licensed and are required to commit to long-term, on-the-job training before becoming fully qualified. Our licensed water professionals monitor the treatment process 24 hours a day, 7 days a week. Some of the tasks they complete on a regular basis include:

- Operating and maintaining equipment to purify and clarify water;
- Monitoring and inspecting machinery, meters, gauges, and operating conditions;
- Conducting inspections and detailed water tests using calibrated instruments and evaluating the results;
- Maintaining optimal water chemistry;
- Applying data to formulas that determine treatment requirements, flow levels, and concentration levels;
- Documenting and reporting test results and system operations to regulatory agencies; and
- Serving our community through customer support, education, and outreach.

So, the next time you turn on your faucet, think of the skilled professionals who stand behind each drop.

Important Health Information

Some people may be more vulnerable to contaminants in drinking water than the general population. Immunocompromised persons such as persons with cancer undergoing chemotherapy, persons who have undergone organ transplants, people with HIV/AIDS or other immune system disorders, some elderly, and infants may be particularly at risk from infections. These people should seek advice about drinking water from their health care providers. The U.S. EPA/CDC (Centers for Disease Control and Prevention) guidelines on appropriate means to lessen the risk of infection by *Cryptosporidium* and other microbial contaminants are available from the Safe Drinking Water Hotline at (800) 426-4791 or <http://water.epa.gov/drink/hotline>.



Community Participation

The City of Napa encourages citizens to participate in our City Council meetings which take place on the first and third Tuesday of each month at 3:30 - 5:00 pm and again at 6:30 - 9:00 pm, in our Council Chambers at City Hall, 955 School Street. For more information concerning City activities, please see our website at <http://cityofnapa.org>.



Substances That Could Be in Water

The sources of drinking water (both tap water and bottled water) include rivers, lakes, streams, ponds, reservoirs, springs, and wells. As water travels over the surface of the land or through the ground, it dissolves naturally occurring minerals and, in some cases, radioactive material, and can pick up substances resulting from the presence of animals or from human activity.

In order to ensure that tap water is safe to drink, the U.S. Environmental Protection Agency (U.S. EPA) and the State Water Resources Control Board (State Board) prescribe regulations that limit the amount of certain contaminants in water provided by public water systems. The U.S. Food and Drug Administration regulations and California law also establish limits for contaminants in bottled water that provide the same protection for public health. Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of contaminants does not necessarily indicate that water poses a health risk.

Contaminants that may be present in source water include:

Microbial Contaminants, such as viruses and bacteria, that may come from sewage treatment plants, septic systems, agricultural livestock operations, and wildlife;

Inorganic Contaminants, such as salts and metals, that can be naturally occurring or can result from urban stormwater runoff, industrial or domestic wastewater discharges, oil and gas production, mining, or farming;

Pesticides and Herbicides, that may come from a variety of sources such as agriculture, urban stormwater runoff, and residential uses;

Organic Chemical Contaminants, including synthetic and volatile organic chemicals, which are by-products of industrial processes and petroleum production, and which can also come from gas stations, urban stormwater runoff, agricultural applications, and septic systems;

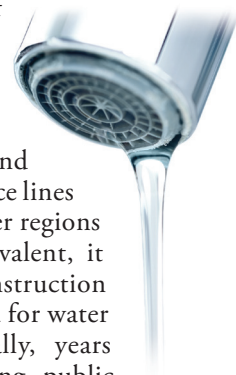
Radioactive Contaminants, that can be naturally occurring or can be the result of oil and gas production and mining activities.

More information about contaminants and potential health effects can be obtained by calling the U.S. EPA's Safe Drinking Water Hotline at (800) 426-4791.

Water treatment is a highly technical process to ensure your tap water is safe.

Lead in Home Plumbing

If present, elevated levels of lead can cause serious health problems, especially for pregnant women and young children. Lead in drinking water is primarily from materials and components associated with service lines and home plumbing. Unlike other regions of the U.S. where lead was prevalent, it was not the predominant construction material used in the City of Napa for water service installations. Additionally, years of monitoring show the existing public system pipe network does not contribute lead to the drinking water. The next lead and copper collection is scheduled for July 2018.



The City of Napa is responsible for providing high-quality drinking water, but cannot control the variety of materials used in plumbing components. When your water has been sitting for several hours, you can minimize the potential for lead exposure by flushing your tap for 30 seconds to 2 minutes before using water for drinking or cooking. (If you do so, you may wish to collect the flushed water and reuse it for another beneficial purpose, such as watering plants.) If you are concerned about lead in your water, you may wish to have your water tested. Information on lead in drinking water, testing methods, and steps you can take to minimize exposure is available from the Safe Drinking Water Hotline or at www.epa.gov/lead.

QUESTIONS?

For more information about this report, or for any questions relating to your drinking water, please call Erin Kebbas, Water Quality Manager, at (707) 253-0822. For questions concerning the City of Napa Water Division in general, please call (707) 257-9521. See our website for up-to-date information on programs: www.cityofnapa.org/water. For emergencies or customer use during weekends and holidays, please call (707) 253-4451.

Protecting our Watersheds

The City of Napa is devoted to protecting the land surrounding our local source waters in order to maintain the quality and purity of water used for your drinking water. In the long-term protecting our watersheds is one of the least costly and most important actions we can take to reduce the risk of unwanted constituents in our drinking water. Algal growth due to the presence of nutrients is the number one cause of taste and odor affecting your tap water. Nutrients in the watershed are increased artificially by wastewater systems as well as fertilizers and runoff from agricultural practices. Every five years, the City of Napa conducts Source Water Assessments to evaluate the quality of the water used as drinking water supply and to examine activities associated with the specific waterway and surrounding areas to determine their contribution to contamination.

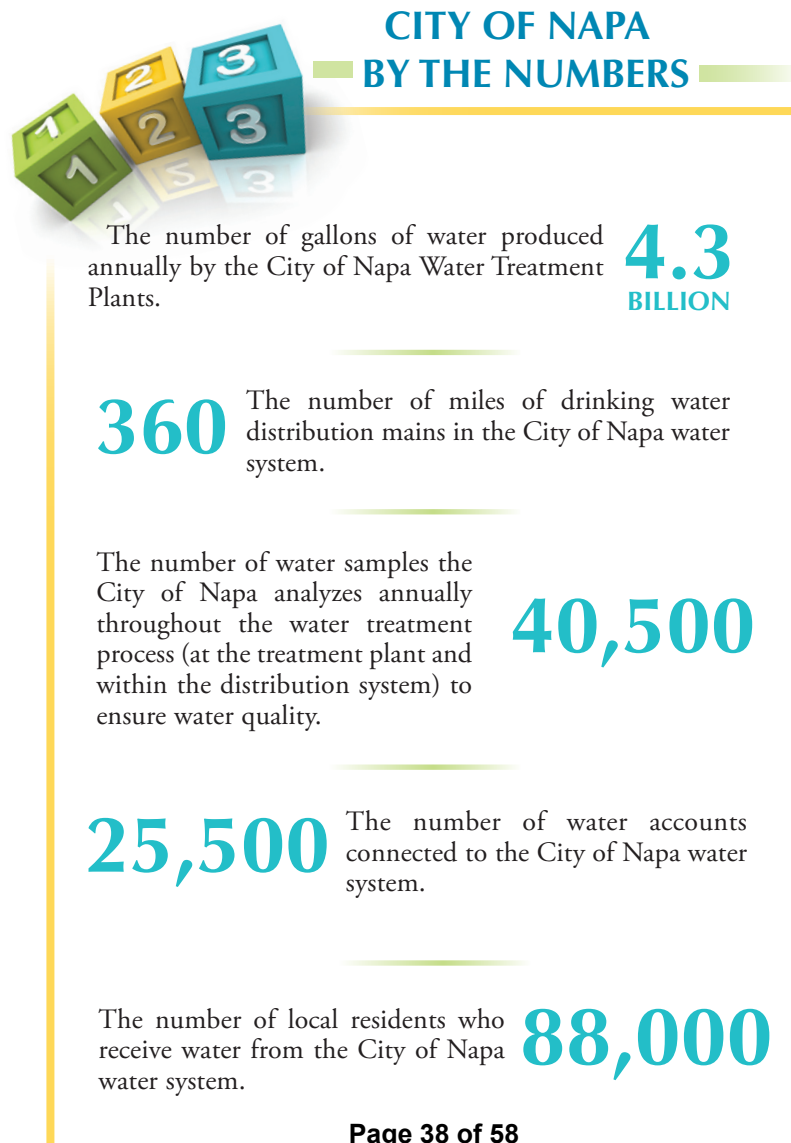
These potential contributors are then compiled into a Vulnerability Summary. Results from the Vulnerability Summaries show the most significant potential sources of contaminants for the City of Napa's source waters are:

Lake Hennessey (completed December 2017): Pacific Union College Wastewater Treatment Plant, vineyards, fires, invasive species, potential hazardous material spills due to traffic accidents (on Highway 128 near lake), septic tank systems (in close proximity to creeks) and grazing and wild animals.

Lake Milliken (completed December 2017): Fires, vineyards, grazing and wild animals.

Sacramento Delta (updated 2017): Recreational use, urban and agricultural runoff, grazing animals, herbicide application and seawater intrusion.

Copies of the complete assessments are available through the SWRCB DDW Santa Rosa District Office, 50 D Street, Suite 200, Santa Rosa, CA 95404 or Ms. Amy Little, Associate Sanitary Engineer, SWRCB at (707) 576-2145.



Our water is monitored for many different kinds of substances on a very strict sampling schedule. The information in the data tables shows only those substances that were detected between January 1 and December 31, 2017. Remember that detecting a substance does not necessarily mean the water is unsafe to drink; our goal is to consistently keep all detects below their respective maximum allowed levels. The State recommends monitoring for certain substances less than once per year because the concentrations of these substances do not change frequently. In these cases, the most recent sample data are included, along with the year in which the sample was taken. **Your water met all U.S. EPA and State standards in 2017.**

REGULATED SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	MCL [MRDL]	PHG (MCLG) [MRDLG]	AMOUNT DETECTED (LRAA) [RAA]	RANGE LOW-HIGH	IN COMPLIANCE	TYPICAL SOURCE
Bromate (ppb)	10	0.1	[2]	2–2	Yes	By-product of drinking water disinfection
Chlorine (ppm)	[4.0 (as Cl ₂)]	[4.0 (as Cl ₂)]	[0.77]	0.02–1.68	Yes	Drinking water disinfectant added for treatment
Control of DBP precursors [TOC] (removal ratio)	TT = >1.0	NA	1.93	0.99–3.58	Yes	Various natural and man-made sources
HAAs [Haloacetic Acids]¹ (ppb)	60	NA	(31.3)	ND–38.0	Yes	By-product of drinking water disinfection
TTHMs [Total Trihalomethanes]¹ (ppb)	80	NA	(76.8)	21.4–112.1	Yes	By-product of drinking water disinfection
Total Coliform Bacteria (positive samples)	Maximum % of positive samples: <5.0	NA	2/1316 [0.15%]	Highest monthly % positive = 0.88%	Yes	Naturally present in the environment

Filter Performance (Turbidity—the Standard Measure of Clarity in Water)

SUBSTANCE (UNIT OF MEASURE)	MCL	PHG	AMOUNT DETECTED	IN COMPLIANCE	TYPICAL SOURCE
Turbidity (NTU, highest detected measurement)	TT = 1.0	NA	0.524	Yes	Soil runoff
Turbidity (lowest % of samples <0.3)	TT = Minimum 95% of samples each month <0.3	NA	99.9	Yes	Soil runoff

Tap Water Samples Collected for Copper and Lead Analyses from Sample Sites throughout the Community

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AL	PHG (MCLG)	AMOUNT DETECTED (90TH%TILE)	SITES ABOVE AL/ TOTAL SITES	IN COMPLIANCE	TYPICAL SOURCE
Copper (ppm)	2015	1.3	0.3	0.34	0/37	Yes	Internal corrosion of household plumbing systems; erosion of natural deposits; leaching from wood preservatives
Lead (ppb)	2015	15	0.2	ND	1/37	Yes	Internal corrosion of household water plumbing systems; discharge from industrial manufacturers; erosion of natural deposits

SECONDARY SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	SMCL	PHG (MCLG)	AVERAGE	RANGE LOW-HIGH	IN COMPLIANCE	TYPICAL SOURCE
Chloride (ppm)	500	NS	14	8–25	Yes	Runoff/leaching from natural deposits; seawater influence
Specific Conductance (μS/cm)	1,600	NS	287	140–390	Yes	Substances that form ions when in water; seawater influence
Sulfate (ppm)	500	NS	49	16–78	Yes	Agricultural runoff/leaching from natural deposits; industrial wastes
Total Dissolved Solids (ppm)	1,000	NS	167	100–220	Yes	Runoff/leaching from natural deposits

UNREGULATED AND OTHER SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	MCL (NL)	PHG	AVERAGE	RANGE LOW-HIGH	TYPICAL SOURCE
Boron (ppm)	(1)	NA	0.06	ND–0.17	Unregulated contaminant monitoring helps EPA & the State determine where certain contaminants occur & whether the contaminants need to be regulated
Hardness (ppm)	NA	NA	83	30–130	Naturally occurring in ground and source water
Sodium (ppm)	NA	NA	20	11–37	Naturally occurring in ground and source water

¹ Scientists cannot dispute that people who drink water containing THMs and/or HAAs in excess of the MCL over many years (studies interpolate exposures to seventy years) may experience liver, kidney or central nervous system problems and may have an increased risk of getting cancer. These diseases, however, are not only caused by chemicals in drinking water, but also by food, air and other environmental factors.

Definitions

μS/cm (microsiemens per centimeter): A unit expressing the amount of electrical conductivity of a solution.

AL (Regulatory Action Level): The concentration of a contaminant which, if exceeded, triggers treatment or other requirements that a water system must follow.

DBP: Disinfection By-Product

LRAA (Locational Running Annual Average): The average of sample analytical results for samples taken at a particular monitoring location during the previous four calendar quarters. Amount Detected values for TTHMs and HAAs are reported as the highest LRAAs.

MCL (Maximum Contaminant Level): The highest level of a contaminant that is allowed in drinking water. Primary MCLs are set as close to the PHGs (or MCLGs) as is economically and technologically feasible. Secondary MCLs (SMCLs) are set to protect the odor, taste and appearance of drinking water.

MCLG (Maximum Contaminant Level Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs are set by the U.S. EPA.

MRDL (Maximum Residual Disinfectant Level): The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

MRDLG (Maximum Residual Disinfectant Level Goal): The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.

NA: Not applicable.

ND (Not detected): Indicates that the substance was not found by laboratory analysis.

NL: Notification level.

NS: No standard.

NTU (Nephelometric Turbidity Units): Measurement of the clarity, or turbidity, of water. Turbidity in excess of 5 NTU is just noticeable to the average person.

PDWS (Primary Drinking Water Standard): MCLs and MRDLs for contaminants that affect health along with their monitoring and reporting requirements, and water treatment requirements.

PHG (Public Health Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. PHGs are set by the California EPA.

ppb (parts per billion): One part substance per billion parts water (or micrograms per liter).

ppm (parts per million): One part substance per million parts water (or milligrams per liter).

removal ratio: A ratio between the percentage of a substance actually removed to the percentage of the substance required to be removed. Must be greater than 1.0 to be in compliance.

TT (Treatment Technique): A performance standard intended to reduce the level of a contaminant in drinking water.

TOC: Total Organic Carbon

ANNUAL WATER QUALITY REPORT

REPORTING YEAR 2018



Presented By
City of Napa

Our Mission Continues

We are once again pleased to present our annual water quality report covering all testing performed between January 1 and December 31, 2018. Over the years, we have dedicated ourselves to producing drinking water that meets all State and Federal standards. We continually strive to adopt new methods for delivering the best-quality drinking water to you. As new challenges to drinking water safety emerge, we remain vigilant in meeting the goals of source water protection, water conservation, and community education while continuing to serve the needs of all our water users.

Please remember that we are always available should you ever have any questions or concerns about your water.

Where Does My Water Come From?

The City of Napa's customers are fortunate because we enjoy an abundant water supply from 3 sources. Depending on which water treatment plant is in operation, the source comes from: (1) Barker Slough in the Sacramento Delta via the North Bay Aqueduct (treated by the Edward I. Barwick Jamieson Canyon Water Treatment Plant), (2) Lake Hennessey (treated by the Hennessey Water Treatment Plant), or (3) Lake Milliken (treated by the Milliken Water Treatment Plant).

Count on Us

Delivering high-quality drinking water to our customers involves far more than just pushing water through pipes. Water treatment is a complex, time-consuming process. Because tap water is highly regulated by State and Federal laws, water treatment plant and system operators must be licensed and are required to commit to long-term, on-the-job training before becoming fully qualified. Our licensed water professionals' technical knowledge includes a wide range of subjects, including mathematics, biology, chemistry, and physics. Some of the tasks they complete on a regular basis include:

- Operating and maintaining equipment to purify and clarify water;
- Monitoring and inspecting machinery, meters, gauges, and operating conditions;
- Conducting tests and inspections on water and evaluating the results;
- Maintaining optimal water chemistry;
- Applying data to formulas that determine treatment requirements, flow levels, and concentration levels;
- Documenting and reporting test results and system operations to regulatory agencies; and
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Community Participation

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In order to ensure that tap water is safe to drink, the U.S. Environmental Protection Agency (U.S. EPA) and the State Water Resources Control Board (State Board) prescribe regulations that limit the amount of certain contaminants in water provided by public water systems. The U.S. Food and Drug Administration regulations and California law also establish limits for contaminants in bottled water that provide the same protection for public health. Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of contaminants does not necessarily indicate that water poses a health risk.

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Pesticides and Herbicides, that may come from a variety of sources such as agriculture, urban stormwater runoff, and residential uses;

Organic Chemical Contaminants, including synthetic and volatile organic chemicals, that are by-products of industrial processes and petroleum production and can also come from gas stations, urban stormwater runoff, agricultural applications, and septic systems;

Radioactive Contaminants, that can be naturally occurring or can be the result of oil and gas production and mining activities.

More information about contaminants and potential health effects can be obtained by calling the U.S. EPA's Safe Drinking Water Hotline at (800) 426-4791.

We remain vigilant in
delivering the best-quality
drinking water

Lead in Home Plumbing

If present, elevated levels of lead can cause serious health problems, especially for pregnant women and young children. Lead in drinking water is primarily from materials and components associated with service lines and home plumbing. Unlike other regions of the U.S. where lead was prevalent, it was not the predominant construction material used in the City of Napa for water service installations.

In addition, years of monitoring show that the existing public system pipe network does not contribute lead to our drinking water. Our next lead and copper collection is scheduled for July 2021. The City of Napa is responsible for providing high-quality drinking water, but we cannot control the variety of materials used in plumbing components. When your water has been sitting for several hours, you can minimize the potential for lead exposure by flushing your tap for 30 seconds to 2 minutes before using water for drinking or cooking. (If you do so, you may wish to collect the flushed water and reuse it for another beneficial purpose, such as watering plants.) If you are concerned about lead in your water, you may wish to have your water tested. Information on lead in drinking water, testing methods, and steps you can take to minimize exposure is available from the Safe Drinking Water Hotline at (800) 426-4791 or at www.epa.gov/safewater/lead.

QUESTIONS?

For more information about this report, or for any questions relating to your drinking water, please call Erin Kebbas, Water Quality Manager, at (707) 253-0822. For questions concerning the City of Napa Water Division, in general, please call (707) 257-9521. See our Web site for up-to-date information on programs: www.cityofnapa.org/water. For emergencies or customer use during weekends and holidays, please call (707) 253-4451.

Protecting Our Watersheds

The City of Napa is devoted to protecting the land surrounding our local source waters in order to maintain the quality and purity of water used for Napa's drinking water consumers. In the long term, protecting our watersheds is one of the least costly and most important actions we can take to reduce the risk of unwanted constituents in our drinking water. Algal growth due to the addition of nutrients is the number one cause of taste and odor affecting your tap water. Nutrients in the watershed are increased artificially by wastewater systems as well as fertilizers and runoff from agricultural practices. Every five years, the City of Napa conducts Source Water Assessments to evaluate the quality of the water used as the drinking water supply and to examine activities associated with the specific waterway and surrounding areas to determine their contribution to contamination.

These potential contributors are then compiled into a Vulnerability Summary. Results from the Vulnerability Summaries show the following as the most significant potential sources of contaminants for the City of Napa's source waters:

Lake Hennessey (completed April 2018): Pacific Union College Wastewater Treatment Plant, vineyards, fires, invasive species, potential hazardous material spills due to traffic accidents (on Highway 128 near lake), septic tank systems, grazing, and wild animals.

Lake Milliken (completed April 2018): Fires, vineyards, grazing, and wild animals.

Sacramento Delta (updated 2017): Recreational use, urban and agricultural runoff, grazing animals, herbicide application, and seawater intrusion.

Copies of the complete assessments are available through the SWRCB DDW Santa Rosa District Office, 50 D Street, Suite 200, Santa Rosa, CA 95404 or from Ms. Amy Little, Associate Sanitary Engineer, SWRCB, at (707) 576-2145.



Benefits of Chlorination

Disinfection, a chemical process used to control disease-causing microorganisms by killing or inactivating them, is unquestionably the most important step in drinking water treatment. By far the most common method of disinfection in North America is chlorination.

Before communities began routinely treating drinking water with chlorine (starting with Chicago and Jersey City in 1908), cholera, typhoid fever, dysentery, and hepatitis A killed thousands of U.S. residents annually. Drinking water chlorination and filtration have helped to virtually eliminate these diseases in the U.S. Significant strides in public health are directly linked to the adoption of drinking water chlorination. In fact, the filtration of drinking water plus the use of chlorine is probably the most significant public health advancement in human history.

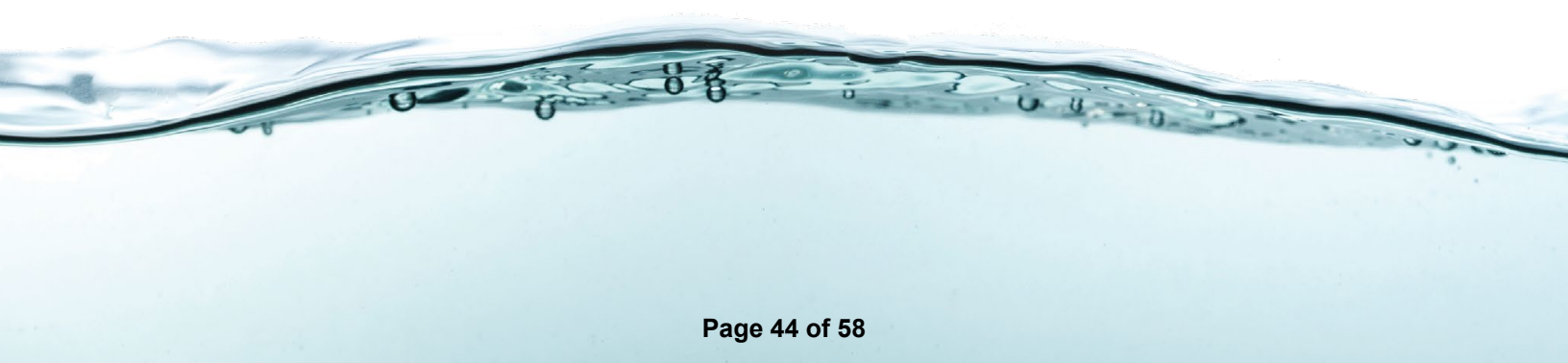
How chlorination works:

Potent Germicide Reduction in the level of many disease-causing microorganisms in drinking water to almost immeasurable levels.

Taste and Odor Reduction of many disagreeable tastes and odors like foul-smelling algae secretions, sulfides, and odors from decaying vegetation.

Biological Growth Elimination of slime bacteria, molds, and algae that commonly grow in water supply reservoirs, on the walls of water mains, and in storage tanks.

Chemical Removal of hydrogen sulfide (which has a rotten egg odor), ammonia, and other nitrogenous compounds that have unpleasant tastes and hinder disinfection. It also helps to remove iron and manganese from raw water.



Our water is monitored for hundreds of different kinds of substances (including but not limited to metals or inorganic chemicals, volatile organic chemicals, man-made substances and disinfection by-products) on a very strict schedule and our goal is to keep any detections below their respective maximum allowed levels. Remember that detecting a substance does not mean the water is unsafe to drink. Here we show only those substances that were detected in our water in 2018. **Your water met all U.S. EPA and State standards in 2018.**

We participated in the 4th stage of the U.S. EPA's Unregulated Contaminant Monitoring Rule (UCMR4) program by performing additional tests on our drinking water. UCMR4 sampling benefits the environment and public health by providing the EPA with data on the occurrence of contaminants suspected to be in drinking water, in order to determine if the EPA needs to introduce new regulatory standards to improve drinking water quality. Unregulated contaminant monitoring data are available to the public, so please feel free to contact us if you are interested in obtaining that information. If you would like more information on the U.S. EPA's Unregulated Contaminant Monitoring Rule, please call the Safe Drinking Water Hotline at (800) 426-4791.

REGULATED SUBSTANCES							
SUBSTANCE (UNIT OF MEASURE)	MCL [MRDL]	PHG (MCLG) [MRDLG]	AMOUNT DETECTED (LRAA) [RAA]	RANGE LOW-HIGH	IN COMPLIANCE	TYPICAL SOURCE	
Bromate (ppb)	10	0.1	[2.0]	0.0–2.8	Yes	By-product of drinking water disinfection	
Chlorine (ppm)	[4.0 (as Cl ₂)]	[4.0 (as Cl ₂)]	[0.78]	0.00–1.81	Yes	Drinking water disinfectant added for treatment	
Control of DBP precursors [TOC] (removal ratio)	TT	NA	2.09	0.63–3.27	Yes	Various natural and man-made sources	
Haloacetic Acids (ppb)	60	NA	(31.5)	0.0–37.2	Yes	By-product of drinking water disinfection	
TTHMs [Total Trihalomethanes] (ppb)	80	NA	(55.6)	28.6–63.3	Yes	By-product of drinking water disinfection	
Total Coliform Bacteria (positive samples)	Maximum % of positive samples: <5.0	NA	1/1328 [0.08%]	Highest monthly % positive = 0.97%	Yes	Naturally present in the environment	
Filter Performance (Turbidity—the Standard Measure of Clarity in Water)							
SUBSTANCE (UNIT OF MEASURE)	MCL			PHG	AMOUNT DETECTED	IN COMPLIANCE	TYPICAL SOURCE
Turbidity (NTU, highest detected measurement)	TT = 1.0			NA	0.18	Yes	Soil runoff
Turbidity (lowest % of samples <0.3)	TT = Minimum 95% of samples each month <0.3			NA	100	Yes	Soil runoff
Tap Water Samples Collected for Copper and Lead Analyses from Sample Sites throughout the Community							
SUBSTANCE (UNIT OF MEASURE)	AL	PHG (MCLG)	AMOUNT DETECTED (90TH%TILE)	SITES ABOVE AL/ TOTAL SITES	IN COMPLIANCE	TYPICAL SOURCE	
Copper (ppm)	1.3	0.3	0.30	0/31	Yes	Internal corrosion of household plumbing systems; erosion of natural deposits; leaching from wood preservatives	
Lead (ppb)	15	0.2	ND	0/31	Yes	Internal corrosion of household water plumbing systems; discharge from industrial manufacturers; erosion of natural deposits	

SUBSTANCE (UNIT OF MEASURE)	SMCL	PHG (MCLG)	AVERAGE	RANGE LOW-HIGH	IN COMPLIANCE	TYPICAL SOURCE
Chloride (ppm)	500	NS	22	10–46	Yes	Runoff/leaching from natural deposits; seawater influence
Specific Conductance (µS/cm)	1,600	NS	300	240–360	Yes	Substances that form ions when in water; seawater influence
Sulfate (ppm)	500	NS	54	38–69	Yes	Runoff/leaching from natural deposits; agricultural and industrial wastes
Total Dissolved Solids (ppm)	1,000	NS	302	120–396	Yes	Runoff/leaching from natural deposits
Turbidity (NTU)	5	NS	0.12	0.00–2.43	Yes	Soil runoff

UNREGULATED AND OTHER SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	MCL	PHG	AVERAGE	RANGE LOW-HIGH	TYPICAL SOURCE
Hardness, Total [as CaCO ₃] (ppm)	NA	NA	118	63–154	Naturally occurring in ground and surface water
Sodium (ppm)	NA	NA	19	16–21	Naturally occurring in ground and source water

Definitions

90th %ile: The levels reported for lead and copper represent the 90th percentile of the total number of sites tested. The 90th percentile is equal to or greater than 90% of our lead and copper detections.

AL (Regulatory Action Level): The concentration of a contaminant that, if exceeded, triggers treatment or other requirements that a water system must follow.

µS/cm (microsiemens per centimeter): A unit expressing the amount of electrical conductivity of a solution.

DBP: Disinfection By Product

LRAA (Locational Running Annual Average): The average of sample analytical results for samples taken at a particular monitoring location during the previous four calendar quarters. Amount Detected values for TTHMs and HAAs are reported as the highest LRAAs.

MCL (Maximum Contaminant Level): The highest level of a contaminant that is allowed in drinking water. Primary MCLs are set as close to the PHGs (or MCLGs) as is economically and technologically feasible. Secondary MCLs (SMCLs) are set to protect the odor, taste, and appearance of drinking water.

MCLG (Maximum Contaminant Level Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs are set by the U.S. EPA.

MRDL (Maximum Residual Disinfectant Level): The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

MRDLG (Maximum Residual Disinfectant Level Goal): The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.

NA: Not applicable

NS: No standard

NTU (Nephelometric Turbidity Units): Measurement of the clarity, or turbidity, of water. Turbidity in excess of 5 NTU is just noticeable to the average person.

PDWS (Primary Drinking Water Standard): MCLs and MRDLs for contaminants that affect health along with their monitoring and reporting requirements, and water treatment requirements.

PHG (Public Health Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. PHGs are set by the California EPA.

ppb (parts per billion): One part substance per billion parts water (or micrograms per liter).

ppm (parts per million): One part substance per million parts water (or milligrams per liter).

removal ratio: A ratio between the percentage of a substance actually removed to the percentage of the substance required to be removed.

TOC: Total Organic Carbon

TT (Treatment Technique): A required process intended to reduce the level of a contaminant in drinking water.

Review of cost versus scale: water and wastewater treatment and reuse processes

Tianjiao Guo, James Englehardt and Tingting Wu

ABSTRACT

The US National Research Council recently recommended direct potable water reuse (DPR), or potable water reuse without environmental buffer, for consideration to address US water demand. However, conveyance of wastewater and water to and from centralized treatment plants consumes on average four times the energy of treatment in the USA, and centralized DPR would further require upgradient distribution of treated water. Therefore, information on the cost of unit treatment processes potentially useful for DPR versus system capacity was reviewed, converted to constant 2012 US dollars, and synthesized in this work. A logarithmic variant of the Williams Law cost function was found applicable over orders of magnitude of system capacity, for the subject processes: activated sludge, membrane bioreactor, coagulation/flocculation, reverse osmosis, ultrafiltration, peroxone and granular activated carbon. Results are demonstrated versus 10 DPR case studies. Because economies of scale found for capital equipment are counterbalanced by distribution/collection network costs, further study of the optimal scale of distributed DPR systems is suggested.

Key words | distributed, optimization, reuse, scale, size, water

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INTRODUCTION

US water/wastewater infrastructure is now aging and in need of repair or replacement, offering an opportunity for careful reassessment of the entire municipal water management system. In that light, a recent report by the US [National Research Council \(2011, p. 3\)](#) found that ‘The use of reclaimed water to augment potable water supplies has significant potential for helping to meet future needs ...’ The report went on to note that, although de facto potable reuse, involving the use of source water largely composed of upstream wastewater effluent, is common in many US water systems, planned potable water reuse is not. Where practiced, potable water reuse has been termed either ‘indirect’ if treated wastewater is returned to the environment prior to reuse, or ‘direct’ if not. In fact globally there are currently no public water supplies utilizing more than 50% recycled wastewater. In that sense, all water reuse systems currently operating include an environmental buffer integral to the design. However, 100% direct potable water reuse (DPR), i.e. potable reuse without environmental buffer, was implemented successfully in Colorado from 1976 to 1982 ([Selby & Pure Cycle Corp. 1979](#)). Further, the National Research Council report found no evidence that an environmental buffer provides

generally higher dilution and attenuation relative to an engineered system, and recommended that potable reuse with or without environmental buffer be considered as a water management alternative.

When considering DPR, distributed DPR systems may further be considered, given that centralized potable reuse systems with gravity collection would require upgradient distribution of treated water. In fact, even in centralized systems, the energy consumed for conveyance may be significantly greater than is used in the treatment process. According to [Cohen *et al.* \(2004\)](#) and [Wolff *et al.* \(2004\)](#), the energy cost per unit water supplied in California is approximately 20 times higher for conveyance than for treatment, and the number approaches 39.5 in San Diego. These numbers may derive in part from the 3% of total electric power used in delivering water from the San Francisco Bay-Delta to Southern California ([Cohen *et al.* 2004](#)). As another less extreme example, in Iowa, energy consumed in conveyance of water/wastewater represents 30% of that consumed in treatment ([Sauer & Kimber 2002](#)). In fact, a study supported by the Electric Power Research Institute concluded that roughly 4% of US electricity is used for

treatment and conveyance of water/wastewater, of which 80% is used for conveyance (ICF Consulting 2002; Cohen et al. 2004). In addition, Cohen's analysis indicated that at least 6% of the water is lost in centralized distribution systems, resulting in higher demands for both water and energy.

In addition to saving energy, distributed plants may be more resilient to willful attack, and amenable to technological evolution, allowing incremental technological changes to be implemented and tested when required by local conditions. Modern communications technologies also make it conceivable that many water/wastewater monitoring, operation, and maintenance functions can be decentralized, supporting savings in conveyance energy and water. In fact, small-scale treatment of black water in semi-public buildings has been predicted as a trend in the future based on projected savings in energy and water (Timmeren 2007).

In considering distributed DPR, the question arises as to the optimal scale of the individual treatment plants. In many cases this question would be addressed by attempting to minimize total cost, which might also tend to minimize life-cycle energy demand. However, information on the costs of water reuse processes as a function of process scale is inadequate, existing primarily in gray literature sources, limited by the current lack of potable water reuse design experience and the specificity of cost information to site characteristics, technological developments, and temporal and political variability in monetary values.

Traditionally, cost functions of the Williams Law form, $C = \beta \cdot Q^\alpha$, in which C is cost, Q is system scale (size), and β and α are positive constants (Williams 1947), have been found applicable for capital, operation and maintenance costs. The exponent α is less than one when economies of scale obtain, and values ranging from 0.2 to 1.5 have been reported for many processes (Hinomoto 1974; Tyteca 1976; Gillot et al. 2007). Although economy of scale has generally been assumed for overall capital cost, diseconomy of scale has been reported for water treatment plant capital cost (Hinomoto 1974). Further, if energy costs for water/wastewater plants are assumed to follow Williams Law, and conveyance energy were constant at 80% of total energy as mentioned above, then total energy would be approximately $C = 5 \cdot \beta \cdot Q^\alpha$. More realistically, the multiplier accounting for conveyance energy can be assumed a similar function of system size, equal to unity for a system serving a single building, so that $C = N^\gamma \cdot \beta \cdot Q^\alpha$, in which N is the number of buildings served and γ is a constant. Then, the ratio, R , of the cost of a single system serving N buildings to the cost of N systems serving N buildings is: $R = N^\gamma \cdot \beta \cdot Q^\alpha / N \cdot \beta \cdot (Q/N)^\alpha$. At the break-even point for decentralization, this ratio is equal to

unity. In that case, $N^{\gamma+\alpha-1} = 1$, or in general $\gamma + \alpha = 1$. That is, for the centralized system to show advantage, the sum of the exponents must not exceed unity, even though the fraction of energy dedicated to conveyance may increase with system size (i.e. show diseconomy of scale, $\gamma > 1$). Hence, diseconomy of scale may be more common than has been realized.

The purpose of this study is to review and synthesize available information on the costs of individual unit processes applicable for distributed DPR, as a function of process scale, and to verify this information as possible versus previous limited experience with DPR system implementation. In particular, a review is presented of cost information for unit processes useful for water reuse including activated sludge, membrane bioreactor (MBR), coagulation/flocculation, reverse osmosis (RO), ultrafiltration, peroxone, and granular activated carbon (GAC), and continuous cost functions are developed. Review of costs for rainwater harvesting, which are highly site-specific, and other existing and emerging processes useful for reuse is beyond the scope of this study. Costs of previously reported reuse treatment systems are then estimated based on the cost functions presented, and compared to information available on actual system costs. Discussion and conclusions regarding DPR system costs are offered.

COST FUNCTIONS FOR WATER REUSE UNIT PROCESSES

In this section, cost information for several water/wastewater treatment and reuse unit processes is reviewed. To synthesize results for general applicability, reported results are first converted to constant 2012 US dollars in proportion to the increase in the GDP deflator (US Bureau of Economic Analysis 2013). Then, capital equipment and operation and maintenance (O & M) costs were fitted to functions of system scale including the form suggested by Williams (1947) using the Levenberg–Marquardt algorithm (Marquardt 1963) and SigmaPlot® version 12.0 software. The only function found to fit available cost data adequately over several orders of magnitude of system scale (including onsite systems) was a logarithmic variant of Williams' power law, as follows:

$$\log(y) = a[\log(x)]^b + c \quad (1)$$

The R^2 values found for Equation (1) by non-linear regression are reported for each technology.

Activated sludge

The activated sludge process may be a useful DPR component for removal of organic and nitrogen constituents. Per capita capital cost was reported by Butts & Evans (1970) as a function of population served, with costs for factory-built package plants (750 to 5,000 people) and plants fabricated onsite (10,000 to 50,000 people) reported separately. In addition, costs obtained in current research, development, and construction of an onsite DPR system (Englehardt *et al.* 2013) indicate capital costs of \$49,600 (2009) and \$36,334 (2011) for 5.68 m³/d (1,500 US gallons per day (GPD)) and 1.89 m³/d (500 GPD) attached-growth biological treatment systems, respectively. In Figure 1, Equation (1) is fitted to the onsite data points and the capital costs obtained from the functions of Butts & Evans (1970) for package and site-built plants of selected capacities of 283.9, 733.0, 1,892.5, 3,785.0, 8,463.5, and 18,925 m³/d, assuming an average flow per capita as 0.378 m³/d (100 GPD) at capacities of 750, $\sqrt{750 \times 5,000}$, 5,000, 10,000, $\sqrt{10,000 \times 50,000}$, 50,000 people, with R^2 value of 0.999. Also shown is a line corresponding to a linear relationship between cost and capacity, i.e. neither economy nor diseconomy of scale, passing through the data point for the smallest plant. Economy of scale is indicated in this case, by a flatter empirical slope relative to the dashed line.

Membrane bioreactor

The MBR process is a relatively new modification of the activated sludge process which may provide higher quality effluent, appropriate for DPR. Costs vary greatly with local

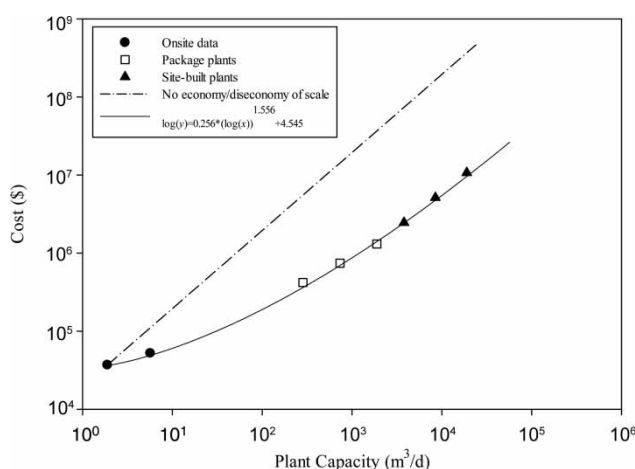


Figure 1 | Capital cost of activated sludge plants (Butts & Evans 1970; Englehardt *et al.* 2013). Conditions: costs converted to constant 2012 US dollars based on the GDP deflator (US Bureau of Economic Analysis 2013).

construction and power rates, and cost functions are few. DeCarolis *et al.* (2007) estimated total capital and annual costs for 3,785.4 m³/d (1 million gallons per day (MGD)) MBR facilities of \$0.533–\$0.682/m³ water treated, in which total capital cost ranges from \$1,419,000 to \$2,330,000, and the corresponding annual O & M cost is \$218,000–\$302,000. Membrane replacement (28%) and energy costs (34%) were found to be the largest components of O & M expense, and continues with equipment repair/replacement (19%). Another report by DeCarolis *et al.* (2004) showed that the total capital and operating cost for 3,785.4 m³/d (1 MGD) MBR raw wastewater reclamation systems ranged from \$0.478 to \$0.592/m³, supporting their subsequent conclusion that the total cost of MBR facilities is relatively constant (DeCarolis *et al.* 2007). For a 1.89 m³/d (500 GPD) onsite MBR system, a capital cost of \$54,000 and annual O & M cost of \$600 are indicated based on prices obtained in current research, development, and construction of a DPR system (Englehardt *et al.* 2013). These data are shown in Figure 2, along with Equation (1) fitted to the same data ($R^2 = 0.996$ and 0.999 for capital and operating costs, respectively). The capital costs in Figure 2 include MBR, mechanical components, pump, chlorine dosing system, land, and engineering fee. Annual O & M costs include electrical power, equipment repairs, chemical cleaning, membrane replacement, and other labor. Economy of scale is seen for both capital and O & M costs.

Coagulation and flocculation

Coagulation and flocculation can effect colloid-scale removal at larger nominal filtration pore sizes, and aid in

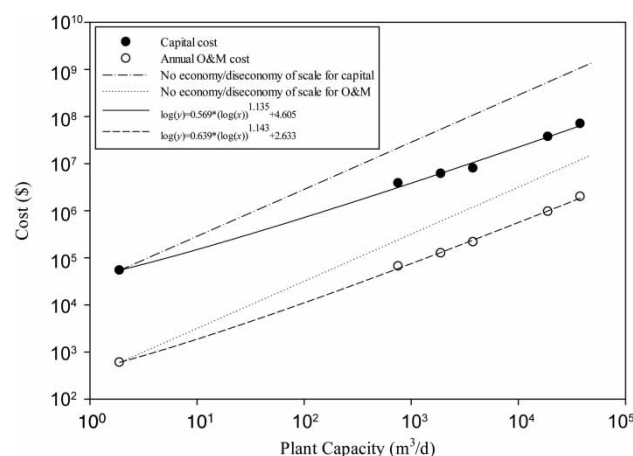


Figure 2 | Approximate cost of MBR treatment plants based on DeCarolis *et al.* (2004) and Englehardt *et al.* (2013). Conditions: constant 2012 US dollars proportional to the GDP deflator (US Bureau of Economic Analysis 2013).

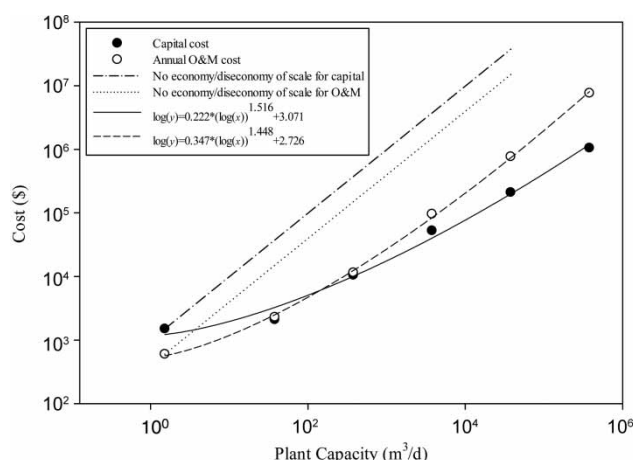


Figure 3 | Approximate costs of coagulation based on [Water Research Foundation \(2009\)](#), [US EPA \(2007\)](#), and [Englehardt *et al.* \(2013\)](#). Conditions: costs converted to constant 2012 US dollars proportional to the GDP deflator ([US Bureau of Economic Analysis 2013](#)).

removal of phosphorus, metals, organics, and other constituents. Estimated costs of coagulation at neutral pH, assuming 56.5 mg/L of coagulant dose (alum or ferric) and 2.5 mg/L of caustic dose, can be estimated using an online simulation tool developed by the [Water Research Foundation \(2009\)](#) and [US EPA \(2007\)](#), as shown in [Figure 3](#) for plant capacities 37.85, 378.5, 3,785, 37,850, 378,500 m³/d. Capital costs include upgrades to existing chemical feed systems, piping and valves, and instrumentation and controls. O & M costs include chemicals, power, replacement parts, and maintenance labor. Also, data obtained in current research and development ([Englehardt *et al.* 2013](#)) suggest a capital cost of \$1,500 and annual O & M cost of \$600 in 2012 for a 1.51 m³/d (400 GPD) coagulation system. Those data and the fitted Equation (1) are shown in [Figure 3](#) ($R^2 = 0.990$ and 0.999 for capital and O & M costs, respectively). Economy of scale is found for both capital and O & M costs.

Electrocoagulation represents an economical coagulation approach avoiding the introduction of soluble anions, e.g. sulfate or chloride. [Bayramoglu *et al.* \(2004\)](#) presented a simplified operating cost analysis for the treatment of a textile wastewater by electrocoagulation using iron and aluminum electrodes. While no identical/different cost function related to scale is reported, they suggested an operating cost function of the form $C = a \cdot C_{\text{energy}} + b \cdot C_{\text{electrode}}$, in which a is electrical energy price, b is electrode material price, C_{energy} and $C_{\text{electrode}}$ are consumption quantities per kilogram of chemical oxygen demand (COD) removed. Assuming an industrial electrical energy price, $a = \$0.06/\text{kWh}$, and electrode material price at \$1.80/kg for aluminum and \$0.30/kg for iron, they found an operating

cost of \$0.3–0.6/kg COD for aluminum electrodes and \$0.1–0.2/kg COD for iron. The latter represents ~\$14,000/year for a 5,000 m³/d plant removing 50 mg/L COD. The authors also noted that lower initial pH and higher conductivity result in lower energy consumption.

Reverse osmosis

RO is employed in many reuse systems. Pretreatment comprising for example coagulation/flocculation, sedimentation, filtration, and/or disinfection is required in order to meet potable water standards ([Bixio *et al.* 2005](#)). [Côté & Liu \(2004\)](#) discussed two options for pretreatment in reuse applications: conventional activated sludge treatment followed by tertiary filtration, and integrated MBR treatment. [Côté *et al.* \(2005\)](#) estimated the capital cost at \$161/(m³·d) for infrastructure and pretreatment, and \$321/(m³·d) for the RO process, assuming membrane pretreatment, 75% recovery, 20 L/(m²·h) of flux, and 13.6 bar of pressure, not considering concentrate disposal costs. Total life-cycle costs were estimated at \$0.07/m³ capital cost plus \$0.21/m³ O & M, for a total \$0.28/m³ to produce potable water from secondary effluent.

Although [Akgul *et al.* \(2008\)](#) reported a similar cost for RO seawater desalination in Turkey, water desalination applications in general have been suggested to be doubly-expensive relative to water reuse and reclamation ([Côté *et al.* 2005](#)). Assuming only 30–40% recovery, a 3–5 year membrane life, 15 year system design life, and \$0.06/kWh of energy, unit capital cost is found as approximately \$0.375/m³ at a capacity of 250 m³/d, decreasing slowly up to 2,000 m³/d capacity at which point cost becomes constant at approximately \$0.175/m³, while the unit operating cost is reported almost stable at ~\$0.20/m³.

At the onsite system scale, data collected in current research and development ([Englehardt *et al.* 2013](#)) indicate a capital cost of \$5,750 in 2012 and an annual O & M cost of \$1,000 for a 2,200 GPD (8.33 m³/d) RO system without pretreatment. The online simulation tool from [Water Research Foundation \(2009\)](#) and [US EPA \(2007\)](#) also provides cost analysis of RO systems. Cost functions shown in [Figure 4](#) were found by fitting all available data. Capital cost in [Figure 4](#) includes membrane and infrastructure, including feed pumps, associated chemical feed equipment, and electrical and instrumentation, but not pretreatment, which is specific to source water quality. O & M costs are based on data reflecting 40% recovery and 14.2 L/(m²·h) for 250 and 2,000 m³/d capacities ([Akgul *et al.* 2008](#)), 75% recovery and 20.0 L/(m²·h) for 75,000 m³/d ([Côté *et al.*](#)

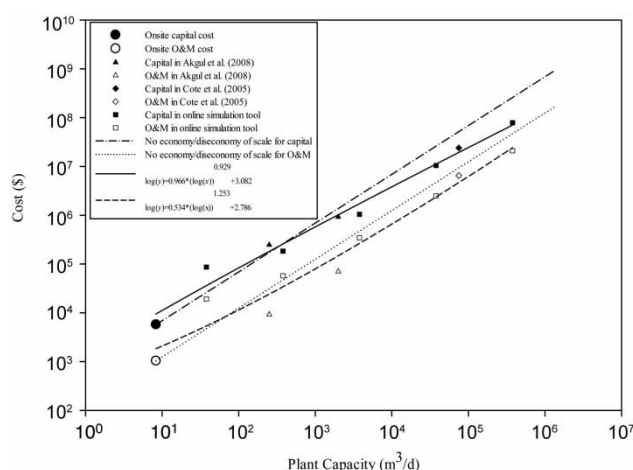


Figure 4 | Approximate cost of RO treatment plant capacity based on Côté *et al.* (2005), Akgul *et al.* (2008), Water Research Foundation (2009) and US EPA (2007), and Englehardt *et al.* (2013). Conditions: constant 2012 US dollars proportional to the GDP deflator (US Bureau of Economic Analysis 2013).

2005), and data for capacities of 37.85, 378.5, 3,785, 37,850, 378,500 m³/d from Water Research Foundation (2009) and US EPA (2007). O & M costs include power, replacement parts, membrane replacement, and maintenance labor. Also, cost data from Akgul *et al.* (2008) have been divided by a factor of 2.2, the reported ratio of the cost for desalination versus water reclamation applications (Côté *et al.* 2005). Non-linear regression R^2 values of 0.978 and 0.954 were found for capital and operating cost. However, in general, O & M cost can vary significantly due to variations in recovery rate, RO flux, membrane life, and pretreatment. Slight economy of scale is evident in both capital and O & M costs. In general, RO costs appeared to be most variable among the water reuse technologies reviewed, and the cost function presented here is intended only for preliminary analysis.

Ultrafiltration

Ultrafiltration is a relatively low-energy, high efficiency filtration process, successfully employed in water reuse applications. Pickering & Wiesner (1993) presented a model of low-pressure membrane filtration cost which indicates that ultrafiltration and other membrane filtration processes are typically less expensive than conventional filtration for plant capacity less than 48,000 m³/d. Also, a study of Drouiche *et al.* (2001) indicated that a 480 m³/d drinking water system employing ultrafiltration of surface water in the Kabylia region of Algeria incurred a total capital and operational cost of \$0.234/m³. Amortized capital cost over the 15 year period was considered the largest

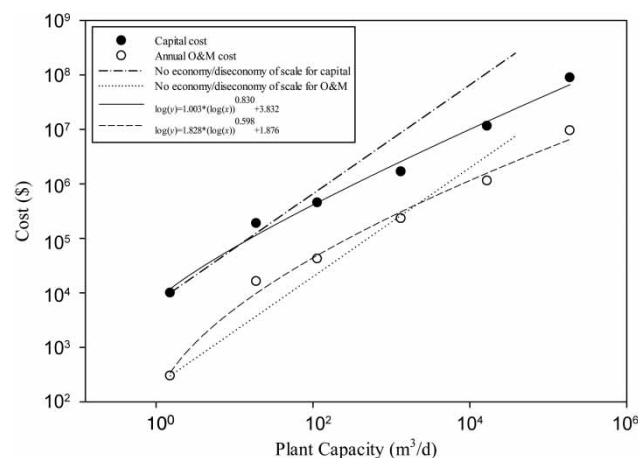


Figure 5 | Approximate cost of ultrafiltration and microfiltration based on Water Research Foundation (2009), US EPA (2007), and Englehardt *et al.* (2013). Conditions: constant 2012 US dollars proportional to the GDP deflator (US Bureau of Economic Analysis 2013).

expense, at \$0.117/m³, followed by interest on the invested capital at \$0.052/m³ (3% annually), maintenance at \$0.026/m³ (assumed as 1.5% per year), and membrane replacement at \$0.025/m³. Costs for other items including power, cleaning, and labor were relatively small. In addition, the online simulation tool developed by the Water Research Foundation (2009) and US EPA (2007) gives estimated costs for ultrafiltration and microfiltration as shown in Figure 5 for 37.85, 378.5, 3,785, 37,850, 378,500 m³/d plant capacities. Costs obtained in current research and development (Englehardt *et al.* 2013) indicate a capital cost of \$10,000 and annual O & M cost of \$300 in 2012 for a 1.51 m³/d (400 GPD) ultrafiltration system. Non-linear regression fitting of the simulation tool and onsite data to Equation (1) is shown in Figure 5 ($R^2 = 0.988$ and 0.990 for capital and operating costs, respectively). Capital costs do not include pretreatment and post-treatment. O & M costs include power, replacement parts, membrane replacement, chemicals, and maintenance-related labor. Economy of scale is evident for capital cost, but not O & M.

Peroxone (hydrogen peroxide/ozone) for organics mineralization

Ozone is useful for disinfection without the introduction of chlorides, and the emerging hydrogen peroxide–ozone, or peroxone, process (Crittenden *et al.* 2012) is efficient for the advanced oxidation of organic constituents in secondary effluent (Englehardt *et al.* 2013). In this study it was desired to preliminarily assess the cost of the peroxone process if

used in the future for complete COD mineralization, to address potential issues with disinfection byproducts and endocrine disrupting constituents in recycled water. Information on process costs as a function of plant capacity is currently limited. However, The Metropolitan Water District of Southern California (MWDSC) & James M. Montgomery Consulting Engineers Inc. (1991) estimated that, for a new 378,500 m³/d (100 MGD) peroxone treatment plant, designed to disinfect and remove the taste/odor compounds geosmin and methylisoborneol at 2 mg/L ozone dose, peroxone system costs can be estimated at \$9.0 million capital and \$0.55 million annual O & M. Cost estimates in 1997 US dollars are also given for five scenario plants assuming an air-fed ozone generator capable of supplying a maximum ozone dose of 2.0 mg/L and an average dose of 1.5 mg/L, an air preparation system, buildings, a 25% uncertainty factor, 20% for engineering and administration, and another 25% for contingency. Because current research indicates that a dose of 130 mg/L may be required for effective mineralization of total COD (Wu 2013; Englehardt *et al.* 2013), assumed plant capacities for the MWDSC data were reduced by a factor of 65. In addition, current research and development (Englehardt *et al.* 2013) suggests a capital cost of \$35,000 and annual O & M cost of \$500 for a 1.51 m³/d (400 GPD) peroxone system, a capital cost of \$45,000 and annual O & M cost of \$1,000 for a 3.03 m³/d (800 GPD) system, and a capital cost of \$55,000 and annual O & M cost of \$2,000 for a 5.68 m³/d (1,500 GPD) system, all in 2012 US dollars. The cost functions developed by regression from all of these data are shown in Figure 6 (Equation (1), $R^2 = 0.999$ and 0.999), though

these preliminary curves should be used with caution. In general, economy of scale is indicated for capital cost. Costs for disinfection alone can be estimated by multiplying assumed plant capacity by 65. It should also be noted that costs for such systems may fall significantly with further development and increased population.

Granular activated carbon

GAC may represent a relatively low-energy process, when used for polishing and redundancy in water reuse systems so that required reactivation/recharge is minimal. Cost functions for concrete gravity contactors and pressure contactors for field-scale systems, and general capital cost function for various GAC systems, were presented by Clark (1987) and Clark & Lykins (1989). The multiple cost functions identified are in similar form to Williams Law, and can be used to generate detailed cost estimates for different aspects of particular GAC systems based on capacity parameters such as total GAC volume/mass, system flow rate, and contactor cross-sectional area.

For general cost estimation, Water Research Foundation (2009) and US EPA (2007) developed an online simulation tool which gives total cost as a function of system capacity, as shown in Figure 7 for plant capacities 37.85, 378.5, 3,785, 37,850, 378,500 m³/d. For onsite systems, current research and development (Englehardt *et al.* 2013) suggests a capital cost of \$3,500 and an annual O & M cost of \$1,000 in 2012 US dollars, for a 1.51 m³/d (400 GPD) GAC system. Capital costs include the addition of GAC contactors, initial carbon charge, associated piping and valves,

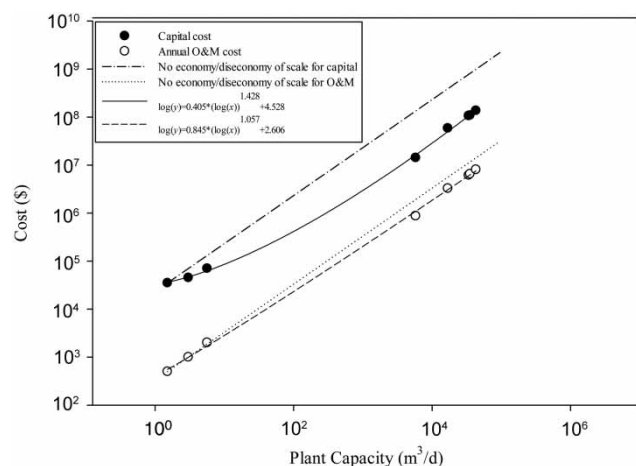


Figure 6 | Approximate cost for mineralization of COD by peroxone based on MWDSC & James M. Montgomery Consulting Engineers Inc. (1991) and Englehardt *et al.* (2013). Conditions: constant 2012 US dollars proportional to the GDP deflator (US Bureau of Economic Analysis 2013).

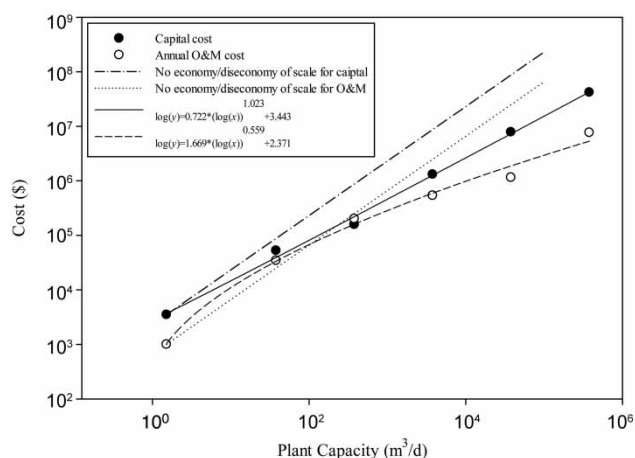


Figure 7 | Approximate cost of GAC based on Water Research Foundation (2009), US EPA (2007), and Englehardt *et al.* (2013). Conditions: constant 2012 US dollars proportional to the GDP deflator (US Bureau of Economic Analysis 2013).

and instrumentation and controls. O & M costs include spent GAC reactivation, power, replacement parts, and maintenance labor. Due to the recency and completeness of these data sources taken together, a general cost function was fitted to the output of the online simulation tool and the onsite data, as shown in Figure 7 ($R^2 = 0.996$ and 0.991).

Cost function summary

The cost functions for the technologies reviewed in this section are not universal. Local construction requirements vary widely, and combined systems may have different cost functions when applied in water and wastewater treatment regarding different influent quality and requirement of treated water. COWI Consulting (2005) suggests that for conventional treatment of surface water including pre-treatment, coagulation/flocculation, sedimentation, filtration and disinfection, a capital cost function would be $C = 18,200 \cdot Q^{0.51}$, in which C is the capital cost (€), and Q is the flowrate (m^3/d). O & M cost can be assumed at 8% of the capital cost. For a small $50\text{--}750 \text{ m}^3/\text{d}$ domestic wastewater treatment plant using an optimized combined sand filtration and ozone process, total capital and operational cost for 5 years was reportedly about $\$0.1\text{--}\$0.32/\text{m}^3$ (Ni et al. 2003). Overall, the cost functions reported here represent a basis for screening and scaling of water reuse treatment processes. A summary of cost functions for these water reuse unit processes is given in Table 1.

EXPERIENCE WITH WATER REUSE ECONOMICS VERSUS SYSTEM SCALE

Potable reuse systems have been implemented several times at differing scales in differing contexts. A review of the economics versus the scale of previous known implementations of potable reuse is given in this section.

Biosphere 2

In the Biosphere 2 closure experiment, eight researchers lived under a transparent $12,700 \text{ m}^2$ (3.14 acre) dome containing an artificial ecosystem from 1991 to 1993. An external energy system provided partial water supply to the crew inside (Dempster 1999). Both heating and cooling were provided by hot, cooled, and chilled water circulated from a closed piping system outside, through a heat exchanger in Biosphere 2. In the heat exchanger, 25 air handlers forced air circulation, each capable of an airflow up to $24 \text{ m}^3/\text{s}$. Thus while maintaining the temperature and humidity, the system also condensed $20\text{--}40 \text{ m}^3/\text{d}$ from the vapor in the atmosphere for potable uses. Water collected was used for drinking directly after UV sterilization. A separate water treatment system handled toilet, kitchen, and lab wastewater. Treatment consisted of anaerobic holding tanks and application to an agricultural system providing an environmental buffer (Nelson et al. 1999). An 870 m^3 storage tank equalized flow. Electrical power required by fans, pumps, and communications averaged about 700 kW, or more than $\$50,000/\text{month}$, provided by the external energy house. The annual cost of fuel in the compressive chiller and hot water boiler was approximately $\$1$ million (Dempster 1999). Thus the extreme energy demand of this system resulted in costs that would be prohibitive in most applications.

Windhoek, Namibia

The city of Windhoek, Namibia, population 240,000, built the Goreangab Water Reclamation Plant, a DPR facility, in the 1960s due to local water supply shortage and variability (Lahnsteiner & Lempert 2007). With an initial capacity of $3,287 \text{ m}^3/\text{d}$, and ultimately $7,500 \text{ m}^3/\text{d}$, the plant produced 12–18% of the total potable water supply for over 30 years. In 2002, a €12.5 million New Goreangab Water

Table 1 | Summary of cost functions of water reuse technologies (y is cost (\$), x is capacity (m^3/d))

Water reuse technologies	Capital cost	Annual O & M
Activated sludge	$\log(y) = 0.256 * (\log(x))^{1.556} + 4.545$	–
Membrane bioreactor	$\log(y) = 0.569 * (\log(x))^{1.135} + 4.605$	$\log(y) = 0.639 * (\log(x))^{1.143} + 2.633$
Coagulation and flocculation	$\log(y) = 0.222 * (\log(x))^{1.516} + 3.071$	$\log(y) = 0.347 * (\log(x))^{1.448} + 2.726$
Reverse osmosis	$\log(y) = 0.966 * (\log(x))^{0.929} + 3.082$	$\log(y) = 0.534 * (\log(x))^{1.253} + 2.786$
Ultrafiltration	$\log(y) = 1.003 * (\log(x))^{0.830} + 3.832$	$\log(y) = 1.828 * (\log(x))^{0.598} + 1.876$
Peroxone (mineralization)	$\log(y) = 0.405 * (\log(x))^{1.428} + 4.528$	$\log(y) = 0.845 * (\log(x))^{1.057} + 2.606$
Granular activated carbon	$\log(y) = 0.722 * (\log(x))^{1.023} + 3.443$	$\log(y) = 1.669 * (\log(x))^{0.559} + 2.371$

Reclamation Plant was built. Project influent was unchlorinated secondary effluent. The progressive city water price of \$0.72/m³ for 0–0.2 m³/d; \$1.18/m³ for 0.201–1.8 m³/d; and \$2.22/m³ for >1.8 m³/d in 2004 was reasonable in comparison with US prices of *ca* \$0.40/m³. Based on [Canizares *et al.* \(2009\)](#), the capital cost of ozonation cost can be estimated as $P = 2,359.85 \cdot (V/12)^{0.6143}$ after conversion to 2012 US dollars, where V is the flow rate (m³/d) and P is the capital cost (\$), assuming ozone dosage at 2 mg/L. Given a similar treatment train comprising enhanced coagulation and flocculation, ozonation, GAC filtration, and ultrafiltration, without chlorine disinfection or stabilization, and assuming the 21,000 m³/d capacity of the new plant, a capital cost of \$21.3 million (2012 US dollars) would be estimated using the equations in [Table 1](#).

Denver potable water project

From 1979 to 1992, the Denver Potable Water Reuse Demonstration Project demonstrated the conversion of unchlorinated secondary effluent into water that could be directly piped into a drinking water distribution system. Product water from the 3,785.4 m³/d (1.0 MGD) plant was not used for drinking, but stored and shown as part of the project's public program ([Rogers & Lauer 1992](#)). The plant's construction cost was \$18.5 million, with \$6.0 million for scientific studies on health risks, and \$8.4 million O&M over the 13 years ([Lauer 1993](#)). For a similar system comprising flocculation, reverse osmoses, two stages of GAC, ozonation, and ultrafiltration, without lime treatment, recarbonation, air stripping, UV or chlorine dioxide disinfection, at a capacity of 3,785.4 m³/d, a capital cost of \$9.7 million would be estimated using the equations of [Table 1](#).

International Space System

As of November 2008, the International Space System developed by NASA included a Water Recovery System consisting of Water Processor Assembly and Urine Processor Assembly ([Carter 2009](#)). The system provided drinking water to a crew of six members, and was derived from a combination of condensate and urine. Flush water and urine were treated with a formula containing chromium trioxide and sulfuric acid. From there the water passed to a distillation assembly, consisting of a rotating centrifuge where the wastewater and urine stream were evaporated and condensed. The Urine Processor Assembly was designed for a load of 9 kg/d (19.8 lb/d) and could recover a minimum of 85% of the water content, essentially equivalent to the six-crew requirement. The

Water Recovery System reportedly averaged 743 W power consumption while in operation, and 297 W while in stand-by, or less than perhaps \$40/month, high for six people.

Village of Cloudcroft

Due to lack of sufficient water supply from local springs and wells, the village of Cloudcroft, New Mexico, USA, population 850 increasing to more than 2,000 during holidays, constructed a system to provide potable water from purified wastewater ([Livingston 2008](#)). Following treatment by MBR, disinfection, RO, and UV/hydrogen peroxide advanced oxidation, the treated municipal wastewater is blended with approximately 50% spring or well water. The blended water is detained for 2 weeks in a storage reservoir, after which it undergoes ultrafiltration, UV disinfection, and activated carbon adsorption. With a treatment capacity of 378.5 m³/d (100,000 GPD), capital cost of the project is roughly \$3,500,000, with operating costs of \$50,000/year and equipment maintenance costs of \$0.21/m³. Overall, the cost of operation and maintenance is \$0.63/m³, and the total cost of product water is \$2.38/m³. Given a similar system comprising MBR, RO, peroxone, ultrafiltration, and GAC at a capacity of 378.5 m³/d, a capital cost of \$3.5 million (without UV disinfection) would be estimated using the equations of [Table 1](#).

Chanute, KS

During a severe drought, the city of Chanute, Kansas, USA, population 12,000 at the time, implemented emergency wastewater reclamation and reuse for municipal water supply from October 1956 to March 1957 ([Mangan 1978](#); [Asano *et al.* 2007](#)). The Neosho River, previously used to supply the city water demand of 5,300 m³/d (1.4 MGD), was dammed upstream of the treatment plant, and sewage treatment plant effluent was returned to the river as source water. Treatment comprised standard 1950s physical–chemical technology, including alum flocculation, sedimentation, sand filtration and chlorine disinfection. Activated carbon and membrane filtration were not available. Assuming a similar treatment train consisting of activated sludge and flocculation, without sand filtration and chlorine disinfection in [Metzler *et al.* \(1958\)](#), at a capacity of 5,300 m³/d, a capital cost of \$3.4 million would be estimated using the equations of [Table 1](#).

Big Spring, TX

Due to a long-term drought in the Permian Basin of West Texas, the Colorado River Municipal Water District, which

supplies water to the cities of Odessa, Big Spring and Snyder, recently launched a wastewater reuse project. The plan is to treat 7,949.4 m³/d (2.1 MGD) of filtered secondary effluent with membrane filtration, RO, and UV/hydrogen peroxide oxidation; blend it with raw water in the transmission line; and pass the water to a potable water treatment process which includes flocculation, sedimentation, granular media filtration and disinfection, before release to the distribution network to comprise *ca* 5% of the finished water. In the preliminary design report (Sloan 2007), construction cost was estimated to be \$8.23 million, including \$3.45 million for treatment equipment, \$0.88 million for the pump station, and \$0.70 million for the pump line. Annual operating cost was estimated at \$667,000 for power, chemical, labor and equipment replacement. Produced water is projected to cost \$0.68/m³. Total energy consumption for operation of the membrane treatment, UV oxidation, and source water and product water pumping is projected at 1.41 kWh/m³. This is comparable to the current local operating cost of 1.33 kWh/m³, due principally to the long pumping distance and the 914.4 m (3,000 ft) elevation of Big Spring (Sloan *et al.* 2010). Assuming membrane filtration, RO, UV/hydrogen peroxide oxidation, coagulation, and granular media filtration at a capacity of 7,949 m³/d, a capital cost of \$14.6 million (without disinfection) can be estimated using the equations of Table 1.

Orange County Water District, CA

The Orange County Water District's Groundwater Replenishment System treats disinfected secondary effluent with microfiltration, RO, and UV/hydrogen peroxide oxidation, and product water is used to recharge existing groundwater basins. The augmented Orange County groundwater basin supplies water for roughly 2.5 million people, while receiving up to 265,000 m³/d of treated wastewater for recharge (Markus *et al.* 2008; Deshmukh 2009; Tchobanoglous *et al.* 2011). This \$481 million project had an annual budget of ~\$34 million (Woodside & Westropp 2009). Assuming an engineering process comprising microfiltration, three stages of RO, and UV/hydrogen peroxide oxidation at a capacity of 265,000 m³/d, a capital cost of \$253.8 million can be estimated using the equations of Table 1.

Pure Cycle Corporation

In the 1970s, the Pure Cycle Corporation developed a complete closed-loop DPR system for single homes. These units were installed primarily in mountain homes in Colorado

from 1976 to 1982 (M. Harding, Pure Cycle Corp., personal communication). The system consisted of a wastewater holding tank, a biological digester, an ultrafiltration unit, and a deionization unit (Selby & Pure Cycle Corp. 1979). A central control system communicated with company headquarters in Denver. After the company exited the business due to the expense of maintaining single systems scattered throughout the mountains, homeowners obtained permission from the State to operate the systems independently. While operating costs are not available for these systems, one could assume a cost of <\$1.32/m³ water treated for acid and base regenerant, assuming on the order of 100 mg/L ions removed, to be a dominant operating cost. The cost of brine evaporation or disposal is not known.

Singapore NEWater Project

With a large urban population and limited land area, the Singapore city-state launched the NEWaterProject in 2002, to reuse clarified secondary effluent as a supplemental water supply (Singapore Water Reclamation Study 2002). Treatment comprises microfiltration, RO, and UV disinfection, followed by blending with reservoir water for potable use. Recycled water contributed only ~2% to the finished potable water as of 2010. Two 72,000 m³/d plants were commissioned in January 2003. A third 24,000 m³/d plant began supplying water in January 2004, and a fourth 148,000 m³/d plant was brought online January 2005 (Asano *et al.* 2007). Cost of the product water including production, transmission and distribution was about S\$1.30/m³ in 2003, decreasing to S\$1.00/m³ (US \$0.66/m³) by April 2007 (Zhang *et al.* 2009). Assuming microfiltration, and RO at a capacity of 316,000 m³/d, a capital cost of \$152.8 million (without disinfection) can be estimated using the equations of Table 1.

Case study summary

A summary of the scales and costs of previous potable reuse implementations is given in Table 2, based on the information in this section. Capital costs estimated as described for each case study in this section, using the cost functions developed in this work, are also shown in the table. Despite the site-specificity of many labor, construction, and other costs, predicted costs are generally within a factor of two relative to reported costs, except for the Denver research and demonstration project, which may have phases not reflected in estimated costs. Also, no obvious bias is apparent.

Table 2 | Summary of reported and projected reuse case study costs in constant 2012 US dollars proportional to the GDP deflator (US Bureau of Economic Analysis 2013)

Case name	Total scale	Capital cost	Capital cost per average home served ^a	Annual operation cost	Unit operating cost of water	Water reuse technologies	Estimated capital cost with cost functions available in Table 1	Reference
Biosphere 2	20–40 m ³ /d	–	–	\$2.13 million	\$145.89–291.78/m ^{3f}	Condensation	–	Dempster (1999)
Windhoek	21,000 m ³ /d	\$17.0 million (€12.5 million in 2007)	\$920	–	\$0.40/m ³ (€0.30 /m ³ in 2007)	Enhanced coagulation and flocculation, ozonation, GAC filtration, ultrafiltration, disinfection and stabilization	\$21.3 million ^e	Lahnsteiner & Lempert (2007)
Denver Potable Water Project	3,785.4 m ³ /d (1 MGD)	\$27.8 million	\$8,325	\$975,000	\$0.68/m ³	Filtration, UV irradiation, reverse osmoses, air stripping, ozonation, chloramination, and ultrafiltration	\$9.7 million ^e	Rogers & Lauer (1992)
International Space System	0.0078 m ³ /d ^b	–	–	\$504	\$177.03/m ^{3f}	Condensate and urine vacuum distillation	–	Carter (2009)
Village of Cloudcroft	378.5 m ³ /d (0.1 MGD)	\$3.71 million	\$11,130	\$53,000	\$0.67/m ³ (\$2.40/1,000 gallons)	Membrane bioreactor, disinfection, RO, and UV/hydrogen peroxide advanced oxidation	\$3.5 million	Livingston (2008)
Chanute, KS	5,300 m ³ /d (1.4 MGD)	–	–	–	<\$1.05/m ³ (\$4/1,000 gallons) ^c	Activated sludge, alum coagulation and flocculation, sedimentation, sand filtration, and chlorine disinfection	\$3.4 million	Metzler <i>et al.</i> (1958)
Big Spring, TX	7,949.4 m ³ /d (2.1 MGD)	\$8.89 million	\$1,067	\$720,000	\$0.73/m ³ (\$2.59/1,000 gallons in 2007)	Membrane filtration, RO, and UV/hydrogen peroxide oxidation, flocculation, sedimentation, granular media filtration and disinfection	\$14.6 million ^e	Sloan (2007)
Orange County Water District, CA	265,000 m ³ /d (70 MGD)	\$505 million	\$2,164	\$35.7 million	\$1.26/m ³ (\$4.55/1,000 gallons in 2009)	Microfiltration, 3 stages of RO, and UV/hydrogen peroxide oxidation	\$253.8 million ^e	Woodside & Westropp (2009)
Pure Cycle Corporation	–	–	–	–	<\$1.32/m ^{3d}	Biological digestion, ultrafiltration, and deionization	–	Selby & Pure Cycle Corp. (1979)
Singapore NEWater Project	316,000 m ³ /d	–	–	–	\$0.69/m ³	Microfiltration, RO and UV disinfection	\$152.8 million ^e	Zhang <i>et al.</i> (2009)

^aAssumes water usage of 1.14 m³/d (300 GPD) per home.^bCalculated based on 81% reported Urine Processor Assembly recovery of 180 kg urine in 6 weeks, and the ratio of the flow rate of Urine Processor Assembly to Water Processor Assembly (Carter 2009).^cThe city denied the decision of transport water at \$4/1,000 gallons for cost and physical limitation (Metzler *et al.* 1958).^dBased on estimated cost of acid and base regenerant, for removal of on the order of 100 mg/L ions.^ePrimary and secondary treatment not included.^fCalculation based on actual flow rate rather than design flow.

CONCLUSIONS

The applicability of distributed DPR systems will likely depend in part on local topographic, demographic, and hydrologic characteristics, on needs for reductions in energy consumption for water conveyance, and on projected increases in water demand. When substantial investment has previously been made in centralized water/wastewater treatment systems, the scaling of potable water reuse systems may be largely determined by existing infrastructure. However, much of the water/wastewater infrastructure in the USA today is in need of repair and/or replacement, and therefore information on the cost of current technologies versus system scale will be needed. In particular, the following conclusions were drawn based on the literature reviewed.

1. A logarithmic variant of the Williams Law cost function appears to apply satisfactorily to both capital and O & M cost of water reuse technologies, over orders of magnitude in system capacity.
2. The cost functions found in the literature and derived in this work were roughly demonstrated versus available data on DPR systems.
3. Results indicate that economies of scale apply for many unit processes. However, capital and operating costs for collection/distribution networks counterbalance these economies in centralized systems. Therefore, study of the optimal scale of distributed DPR systems is recommended, along with further study of the costs of emerging processes.

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