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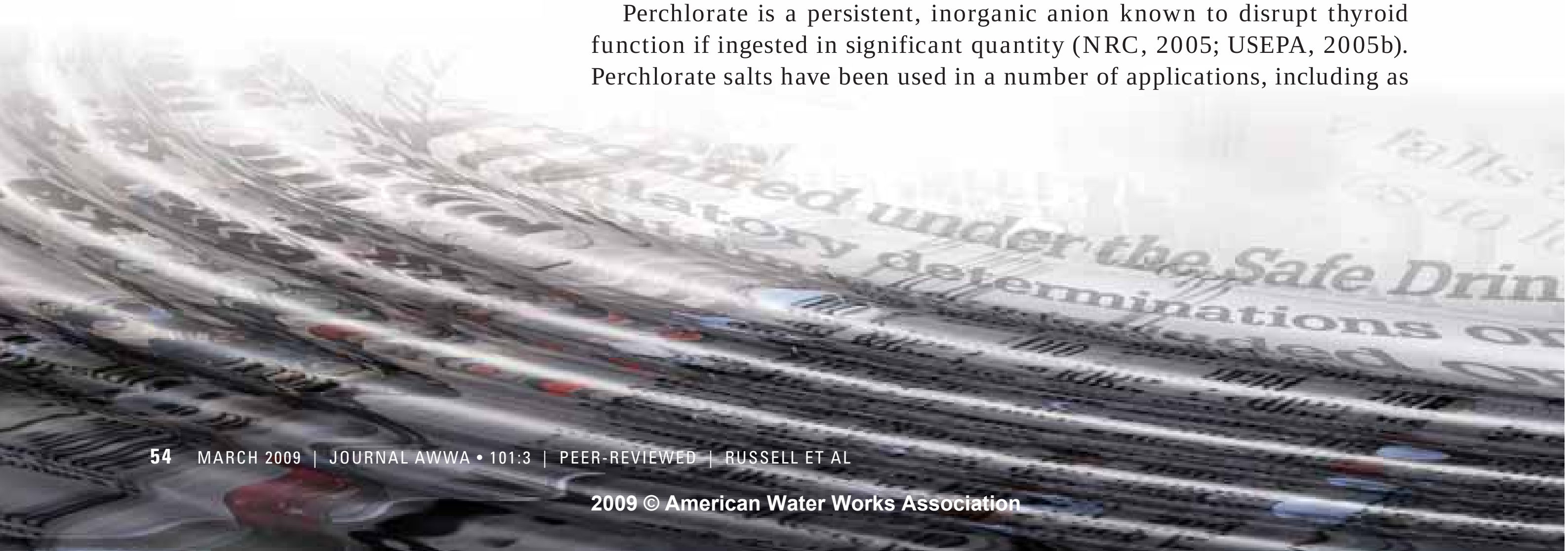
National cost implications of a perchlorate regulation

A LACK OF INFORMATION ON PROJECTED NATIONAL COSTS ASSOCIATED WITH PERCHLORATE TREATMENT PROMPTED A STUDY TO ESTIMATE THE NATIONAL COST IMPLICATIONS OF SETTING A FEDERAL MAXIMUM CONTAMINANT LEVEL FOR THIS CHEMICAL.

The treatment cost required to meet a national primary drinking water regulation (NPDWR) is one of several factors (including health effects from contaminant exposure, number of people affected, and degree of occurrence) that the US Environmental Protection Agency (USEPA) takes into account when establishing a new drinking water regulation. Recognizing a lack of available information on projected national costs associated with perchlorate treatment, the authors conducted a study to estimate the national cost implications of setting a federal maximum contaminant level (MCL) for perchlorate at levels between 4 and 24 µg/L. At the most stringent potential MCL evaluated (4 µg/L), the national compliance cost was estimated to be between $76 million and $140 million/year at a 3% discount rate, compared with an estimated $280 million/year (in 2008 dollars) for the Arsenic Rule at 10 µg/L (USEPA, 2001a). The relatively low national compliance cost for perchlorate reflects the small number of public water systems (PWSs) expected to be affected (3.4% at a perchlorate MCL of 4 µg/L). However, the cost impact for an individual system installing perchlorate treatment would likely be substantial.

PERCHLORATE REGULATORY BACKGROUND

Perchlorate is a persistent, inorganic anion known to disrupt thyroid function if ingested in significant quantity (NRC, 2005; USEPA, 2005b). Perchlorate salts have been used in a number of applications, including as



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an oxidizer in solid rocket fuel and as a component in fireworks and other explosives. The USEPA has identified more than 100 potential perchlorate releases from governmental and nongovernmental sites in 26 states, mostly associated with its use in solid rocket fuel (USEPA, 2003). Application of Chilean fertilizers (containing up to 0.18% perchlorate) in US agricultural areas has also been identified as a significant contributor to perchlorate contamination in the United States (Dasgupta et al, 2006). Some nonanthropogenic sources of perchlorate in the environment have also recently been proposed (Rao et al, 2007; Rajagopalan et al, 2006).

Because of the known presence of perchlorate in the environment and public health concerns associated with consumption of water contaminated with perchlorate, USEPA added perchlorate to the first Contaminant Candidate List (CCL1) in 1998 (USEPA, 1998). Perchlorate was retained on CCL2 (USEPA, 2005a) and on the recently published draft CCL3 (USEPA, 2008a). Perchlorate was also included in the list of contaminants to be monitored under the first Unregulated Contaminants Monitoring Rule (UCMR1; USEPA, 2001b). USEPA is required under the Safe Drinking Water Act (SDWA) to make regulatory determinations on a five-year cycle for contaminants included on the CCL.

In 2005, USEPA established a reference dose (RfD) of 0.007 mg/kg/d for perchlorate, corresponding to a Drinking Water Equivalent Level (DWEL) of 24.5 µg/L (USEPA, 2005b). DWELs are not enforceable standards. In May 2007, USEPA determined that insufficient information was available to make a decision about whether to regulate perchlorate, primarily because of the lack of complete information on perchlorate in food as opposed to water (USEPA, 2007). Since then, data from the Food and Drug Administration's (FDA's) Total Diet Study has been published (Murray et al, 2008). On Oct. 10, 2008, USEPA published its preliminary determination to not regulate perchlorate. However, USEPA recently stated (Jan. 8, 2009) that it would seek further advice from the National Academies of Science prior to making a final determination about whether to set a national standard for perchlorate.

USEPA takes into account a number of factors when making a determination about whether to regulate a drinking water contaminant, including the health effects from exposure to the contaminant, the number of people affected, the degree of contaminant occurrence, and whether a national drinking water regulation would provide an opportunity for significant risk reduction as required by the SDWA. Although a number of studies have evaluated perchlorate occurrence and health effects (Brandhuber et al, 2008; Kimbrough & Parekh, 2007; NRC, 2005; Gullick et al, 2001), information on projected national costs associated with a NPDWR for perchlorate is lacking. On the basis of this recognized data gap, an AWWA-funded study was conducted to estimate the national cost implications of setting a federal MCL for perchlorate at levels between 4 and 24 µg/L. This article presents the results from this study.

APPROACH TO ESTABLISHING NATIONAL COSTS

Five potential perchlorate MCLs were evaluated: 4, 6, 12, 18, and 24 µg/L. The lower end of the range is based on the 4 µg/L detection limit for reporting (DLR) associated with method 314 (USEPA, 2000) at the time that UCMR1 samples were analyzed. Although many laboratories are now able to measure perchlorate to concentrations as low as 0.5 µg/L, the sensitivity of the analytical method at the time samples were collected for UCMR1 only allowed detection to a concentration of 4 µg/L or greater. The upper end of the range is based on the 24.5 µg/L concentration associated with the previously discussed, USEPA-adopted RfD of 0.007 mg/kg/d (USEPA, 2005b). Intermediate concentrations were selected to provide an even distribution of val-

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TABLE 1 Steps to identify the compliance costs for perchlorate regulatory levels

Step	Description
Step 1	Identify source waters and public water systems contaminated with perchlorate.
Step 2	Determine perchlorate concentration and flow rate for each contaminated source.
Step 3	Identify a likely treatment strategy for the contaminated sources.
Step 4	Assign capital costs associated with treating each contaminated source.
Step 5	Assign operations and maintenance (O&M) costs associated with treating each contaminated source.
Step 6	Tally capital and O&M costs to treat each contaminated source with a perchlorate concentration exceeding a given value (e.g., 4, 6, 12, 18, or 24 µg/L).

O&M—operations and maintenance

ues, from 6 µg/L (the MCL for the state of California) to 24 µg/L.

Table 1 shows the general approach used to estimate national costs associated with treating source waters containing perchlorate at concentrations exceeding each proposed MCL. The approach was developed based on the guidelines described in Raucher et al (1995) for estimating the cost of compliance with drinking water standards.

Occurrence data. As a first step, PWSs with detectable concentrations of perchlorate were identified using the UCMR1 database. Under UCMR1, all community water systems (CWSs) and nontransient–noncommunity water systems (NTNCWSs) serving water to more than 10,000 people (large systems) were required to sample all entry points to their distribution system for perchlorate. Four samples collected quarterly over one year were required for surface waters and two samples collected over the course of one year were required for groundwater sources. UCMR1 sampling of large systems was conducted between Jan. 1, 2001, and Dec. 31, 2003 (USEPA, 2001c). A randomly selected sample of 800 CWSs and NTNCWSs serving fewer than 10,000 people (small systems) was also assessed for perchlorate contamination (USEPA, 2001d). The small systems were required to monitor all entry points to their distribution system once during one year between Jan. 1, 2001, and Dec. 31, 2003.

The UCMR1 database was queried for all entry points with a detectable perchlorate concentration. As mentioned, multiple samples were collected from each large system entry point during a 12-month period. Perchlorate concentrations associated with each entry point (Table 1, step 2) were determined using two alternative approaches, median values and 90th percentile values. The median values were used to represent a less-conservative cost estimate, whereas the 90th percentile values were used to represent a more conservative cost estimate. In doing these calculations, nondetects were assigned zero values.

Next, design and average flow rates were assigned for each entry point based on the population size of the associated PWS. Recent population data for each PWS was retrieved from USEPA's Safe Drinking Water Information System database. The flow rates were then calculated for each PWS with a perchlorate detection by plugging the population data into the following regression equations developed by USEPA (2005c):

Surface waters:

$$\text{Design flow (mgd)} = 0.36971 \times \text{population}^{0.97757}/1{,}000$$

$$\text{Average daily flow (mgd)} = 0.10540 \times \text{population}^{1.02058}/1{,}000$$

Groundwaters:

$$\text{Design flow (mgd)} = 0.39639 \times \text{population}^{0.97708}/1{,}000$$

$$\text{Average daily flow (mgd)} = 0.06428 \times \text{population}^{1.07652}/1{,}000$$

The design and average daily flow rates for each entry point were then estimated by dividing the PWS flow rates by the total number of entry points in the PWS under consideration. The number of entry points for each PWS was tallied based on the total number of sampling points (i.e., unique sample points) included for that system during the UCMR1 sampling effort.

For the purpose of this study, each entry point was assumed to represent a different source water for a given PWS. Therefore, each entry point with a detectable perchlorate concentration was considered a "contaminated source". Because only a few perchlorate treatment systems had been installed at PWSs by the time of UCMR1 sampling (i.e., between 2001 and 2003; the first regenerable ion exchange treatment plant was installed in the United States for perchlorate removal in 2001; Russell et al, 2008), perchlorate levels in samples collected during that time from entry points to the distribution system are expected to be representative of source water concentrations.

Treatment strategy. In Table 1, step 3 in the cost estimation approach was to define probable treatment strategies for the contaminated sources. Perchlorate removal can be achieved using regenerable ion exchange, single-pass ion exchange, biological treatment through fixed or fluid-

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ized bed reactors, and reverse osmosis (Brown et al, 2005; Aldridge et al, 2004; Evans et al, 2004; Amy et al, 2002). Table 2 lists advantages and disadvantages associated with each treatment technology. Regenerable ion exchange is more expensive than single-pass ion exchange (Russell et al, 2008; Aldridge et al, 2004) because of the large quantity of salt required to desorb perchlorate from the resin. Regenerable ion exchange also produces a perchlorate-laden waste brine that requires disposal and may require treatment, depending on discharge requirements. Reverse osmosis also generates a waste brine stream and is relatively expensive to operate. The effectiveness of biological treatment has been demonstrated (Brown et al, 2005); however, because of potential public acceptance issues and additional posttreatment costs, no water utilities have adopted biological treatment for perchlorate removal in the United States as of October 2008. On the basis of the advantages and disadvantages mentioned previously and also on the basis of current trends in treatment selection by several Southern California utilities, single-pass ion exchange treatment was considered to be the preferred treatment technology for the purpose of this national cost evaluation. The advent of perchlorate-selective resins has made single-pass ion exchange an economically competitive treatment option for perchlorate removal (Russell et al, 2008; Aldridge et al, 2004).

Cost data. A range of probable costs associated with treating each contaminated source water was estimated following steps 4–6 of Table 1. Less conservative (low-end) treatment costs were estimated using the calculated median perchlorate concentrations and assuming that 10% of the contaminated sources would either be able to blend with alternate water supplies to meet the MCL or would just switch to alternate supplies, abandoning the contaminated source entirely. The assumption that 10% of systems would blend/abandon contaminated sources was based on observed trends for systems with perchlorate contamination and best engineering judgment. More conservative (high-end) costs were estimated using the calculated 90th percentile concentrations and assuming that each source would be treated; blending and source abandonment were not considered as potential contamination abatement options for the high-end cost estimates. The use of a 90th percentile value was based on commonly accepted engineering practice for water treatment plant design (e.g., turbidity and ultraviolet absorbance values).

The calculated perchlorate concentration for a given source (i.e., median or 90th percentile value) was critical in identifying the systems requiring treatment (and the resulting compliance costs) at each MCL evaluated in this study. However, capital and operations and maintenance (O&M) costs were assumed to be independent of the influent perchlorate concentration based on experience that system size and operation are primarily dictated by plant capacity and concentrations of competing anions. Additionally, the costs were calculated based on the assumption that systems installing treatment would treat to nondetection because all but one of the queried utilities with single-pass ion exchange systems for perchlorate removal treat to nondetection.

Capital costs. Capital costs to install single-pass ion exchange systems were obtained from seven water utilities in southern California. The *Engineering News Record* Cost Indexes for Los Angeles were used to adjust capital costs to 2008 dollars for systems installed in previous years (ENR, 2008). Los Angeles Cost Indexes were used

TABLE 2 Disadvantages and advantages of available perchlorate treatment technologies

Treatment Technology	Advantages	Disadvantages
Regenerable ion exchange	Demonstrated technology	Produces a perchlorate-laden waste brine
	Also effective for nitrate removal	High salt costs
Single-pass ion exchange	Relatively low cost	Ineffective as a nitrate treatment technology
	Simple	Resin costs affected by petroleum market
	Demonstrated technology	
Biological treatment	CDPH approved technology	Posttreatment to meet SWTR may be required
	Negligible waste stream	Public acceptance issues
	Also effective for nitrate removal	
Reverse osmosis	Also effective for nitrate removal	High costs Produces a perchlorate-laden waste brine

CDPH—California Department of Public Health, SWTR—Surface Water Treatment Rule

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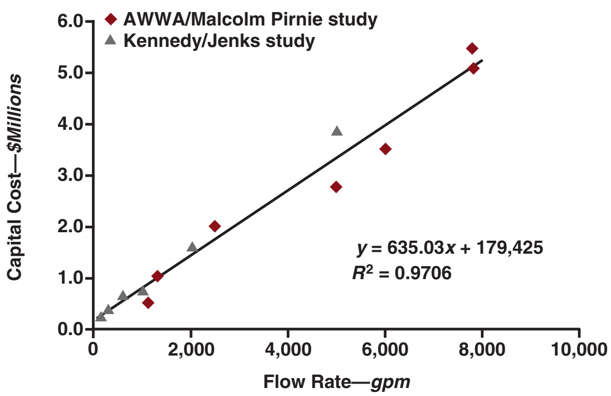
FIGURE 1 Baseline capital costs as a function of system flow rate



because more of the affected utilities are in California than any other individual state and because the baseline cost data were obtained from California utilities that have already installed perchlorate treatment. Use of Los Angeles Cost Indexes (and baseline cost data) is considered a conservative approach based on the generally higher construction costs in southern California relative to other parts of the nation.

Baseline capital costs for each of the participating utilities are shown in Figure 1 and include the first fill of resin, ion exchange vessels, foundation and site work, installation of the vessels and resin, electrical work, process controls, and engineering services. Cost data from a perchlorate cost study conducted by Kennedy/ Jenks Consultants (2004) are also included in the graph.

As indicated by the R^2 value (Figure 1), the linear regression line provides a relatively good fit of the data. The linear regression equation was therefore used to assign baseline capital costs for all identified source waters/entry points from the UCMR1 database with a perchlorate detection. The minimum and maximum flow rates for the contaminated source waters identified in the UCMR1 database—3 and 9,320 gpm, respectively—generally fall within the range of full-scale data obtained for this study.

Some water systems are expected to incur additional costs for installation of perchlorate treatment. For example, additional land may be required to accommodate the single-pass ion exchange vessels. Several recent perchlorate treatment installations have included prefiltration to protect the resin from clogging with suspended solids in the source water. Acid addition may also be added to the process to protect against scaling. Additionally, walls or buildings may be required for aesthetic purposes at some facilities, buildings for process controls may be required for sites that currently do not have any treatment installed, and piping may be required for systems that are one mile or more from the well because of space limitations.

The following approach was used to assign these additional costs to a portion of the identified contaminated source waters:

- Costs for land acquisition and site preparation were added to 35% of the contaminated sources. This percentage (35%) was selected on the basis of trends observed in southern California (e.g., one of three utilities in the San Gabriel Valley installing single-pass ion exchange required additional land purchase). A 7,800-gpm or larger system was assumed to require three 0.2-acre parcels of land; a 2,500–5,000-gpm system was assumed to require two 0.2-acre parcels of land; and a 2,500-gpm or smaller system was assumed to require one 0.2-acre parcel of land. The median price for a 0.2-acre parcel of land was assumed to be $220,000 based on the National Association of Realtors' nationwide median home prices between 2005 and 2008. Site preparation costs were assumed to be $50,000 per lot. No attempt was made to adjust this price downward given the recent loss of property values in many parts of the United States.
- Pretreatment costs were added to 40% of the contaminated sources at 20% of the baseline capital costs.
- Wall/building/piping costs were added to 50% of the contaminated sources at 15% of the baseline capital costs.

For each additional cost category, the spreadsheet program[1] random-number generator function was used to randomly assign the additional costs for land/demolition, pretreatment, and wall/building/piping to the designated percentages of sources. Total capital costs for each contaminated source were then calculated by summing the baseline capital costs and any additional costs associated with land requirements, pretreatment, and other activities.

Several PWSs in southern California have already installed (or are currently installing) single-pass ion exchange systems to treat their contaminated source waters in compliance with the state's recently promulgated MCL. Capital and O&M costs for these systems (approximately six out of 387 sample points with perchlorate detections) were included in the national compliance cost estimates.

O&M costs. O&M costs were obtained from five PWSs that currently operate (or previously oper-

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ated) single-pass ion exchange systems for perchlorate removal. Table 3 shows the O&M costs (as cost per 1,000 gal of water treated) for the full-scale single-pass ion exchange systems by system flow rate. O&M costs that were estimated in a previous study (Malcolm Pirnie, 2008a) for one 2,500-gpm single-pass ion exchange treatment system and two 7,800-gpm systems are also included. O&M costs include expenses related to resin disposal; these disposal costs are typically included as part of the total fee for the purchase and installation of the new resin.

A best-fit polynomial was calculated to correlate known operating costs to system flow rate. (The O&M cost curve and best-fit polynomial were based on design flows for the systems listed in Table 3; a comparison to the best-fit polynomial using available average flows revealed equivalent results because the design and average flow rates for the listed groundwater systems were similar.) The polynomial equation was then used to estimate O&M costs from the calculated average flow rate for each contaminated source water/ entry point identified in the UCMR1 database. Based on observed trends in the data, a lower bound cost of $0.33/1,000 gal water treated was established to provide the best empirical equation given limitations in the number of data points available. This assumption is reasonable given that economies of scale do not completely apply to larger flow rates as more vessels are simply added to increase the treatment capacity. The polynomial and lower bound equations were applicable within the range of average flow rates calculated for the contaminated sources—3 to 9,306 gpm.

Total costs. After assigning capital and O&M costs for each contaminated source water, the costs were tallied to identify total national costs for perchlorate treatment to meet a given MCL. The following steps were used to tally the total costs.

(1) Contaminated source waters for small PWSs (< 10,000 people served) were separated from the data set. The capital and O&M costs estimated for these contaminated source waters needed to be scaled up because only 800 out of tens of thousands of small PWSs nation-wide were sampled during the UCMR1 sampling effort.

(2) The identified source waters requiring treatment were tabulated for each potential MCL and for each size category (i.e., large [≥ 10,000 people served] and small). For example, all contaminated sources for large PWSs with perchlorate concentrations of 6 µg/L or higher were tabulated to determine costs associated with a perchlorate MCL of 6 µg/L. Similar data assessments were conducted for the small PWS data set.

(3) The nationwide costs associated with treating small PWSs for each potential perchlorate MCL were estimated by multiplying the costs associated with treatment for the 800 PWS sample set by a factor of 83.8 (i.e., 66,826 small CWS and NTNCWSs nation-wide [USEPA, 2008b], divided by 797 small PWS respondents for the UCMR1 sampling effort).

(4) The total nationwide capital and O&M costs for each potential perchlorate MCL were then calculated by summing the costs for the large systems and the factored costs for the small systems. Amortized capital costs and net present value O&M costs were calculated assuming 20 years of operation and both a 3 and 7% interest rate.

TABLE 3 Reported O&M costs for single-pass ion exchange systems in Southern California*

Public Water System	Capacity *gpm*	Water Quality: Perchlorate *µg/L*	Water Quality: Nitrate *mg/L NO_3-N*	Costs per 1,000 gal: Resin Costs *$*†	Costs per 1,000 gal: Total O&M Costs *$*‡
City of Morgan Hill	400	4–6	6.1	0.37	0.63
California Water Service Company, East Los Angeles system	750	NA	NA	NA	0.77
Valencia Water Company	1,100	NA	NA	0.15‡	0.37
East Valley Water District	1,300	NA	NA	NA	0.44
La Puente Valley County Water District*	2,500	40	5.6	0.15	0.50
California Domestic Water Company	5,000	9	6.9	0.15	0.28
San Gabriel Valley Water Company, B6 Plant*	7,800	23	7.3	0.16	0.31
Valley County Water District*	7,800	12	13.0	0.22	0.40

NA—not available, O&M—operations and maintenance

*Resin and total O&M costs listed for La Puente, San Gabriel B6, and Valley County are based on screening level cost estimates prepared in a previous study (Malcolm Pirnie, 2008a).
†Resin costs were assumed based on average costs for similar systems.
‡Full-scale O&M costs are based on design flows. Design and average flows for these groundwater plants are similar.

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Cost verification. Verification of several parameters was conducted for quality assurance/control. Specifically, the following parameters were checked for a subset of the contaminated water sources and PWSs to verify the data: number of sources for a given PWS, population size for a given PWS, estimated design and average flow rate for a given contaminated source water, and estimated perchlorate concentration for all contaminated sources with design flow rates > 10,000 gpm.

For most of the listed parameters, the values were checked for PWSs that the authors were familiar with through previous work. However in some cases, the PWSs were contacted directly to verify the estimated values. For example, estimated perchlorate concentrations for all contaminated sources with design flow rates > 10,000 gpm were verified by contacting the PWS to inquire about the validity of the UCMR1 data.

ESTIMATED OCCURRENCE AND COMPLIANCE COSTS

Perchlorate occurrence. An initial evaluation of the UCMR1 database confirmed previously reported statistical trends in perchlorate occurrence (Brandhuber et al, 2008). Specifically, perchlorate was detected in 647 (1.9%) of 34,728 samples collected under the UCMR1 sampling effort. A total of 387 sample points (i.e., entry points/source waters) were identified in the UCMR1 database for which at least one sample exhibited a perchlorate concentration above the 4 µg/L DLR.

The 387 sample points with perchlorate detections correlate to a total of 160 PWSs contaminated with perchlorate because some PWSs had multiple entry points with detectable perchlorate concentrations. However, the number of PWSs with perchlorate detections is expected to be significantly higher (more than 900; Brandhuber et al, 2008) if all small PWSs are taken into account because the UCMR1 sampling effort only included 800 out of 66,826 CWSs and NTNCWSs serving < 10,000 people nationwide.

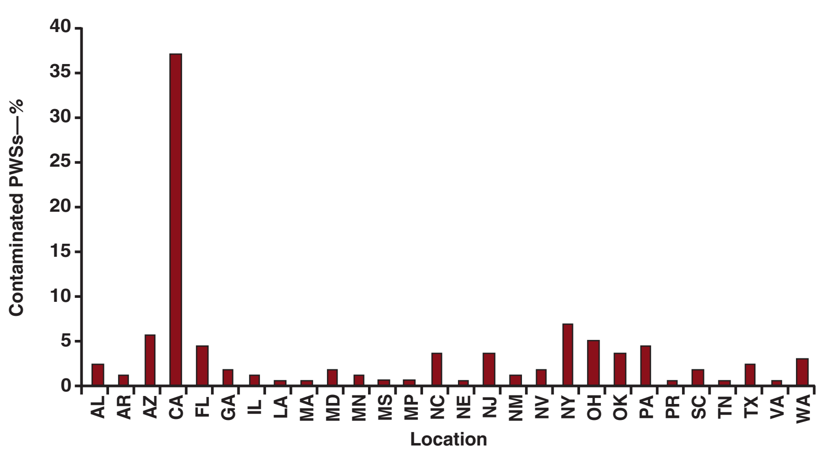
On the basis of UCMR1 data, a higher percentage of large PWSs are contaminated with perchlorate compared with smaller PWSs. Although a statistical approach was used to identify the set of small PWSs sampled under UCMR1, it is possible that a more complete sampling effort would reveal different trends in perchlorate occurrence in small PWSs because there is no guarantee that those 800 small PWSs were completely representative of the 66,826 small CWSs and NTNCWSs nationwide.

Figure 2 illustrates the geographic distribution of the 160 PWSs with perchlorate detections. As observed in previous assessments of the UCMR1 database (Brandhuber et al, 2008), 26 states were identified that had at least one PWS with a perchlorate detection. More than a third of the contaminated PWSs were in California.

The predominance of contaminated sources in the state of California relative to other parts of the country was first observed in a survey of surface and groundwater supplies for the American Water System (Gullick et al, 2001). Kimbrough and Parekh (2007) observed a higher percentage (15%) of source waters throughout California with perchlorate detections, compared with an estimated 2.6% of source water/entry points sampled nationwide exhibiting detectable perchlorate concentrations. However, the California data set analyzed in that study is biased toward source waters expected to be at high risk for perchlorate contamination. The majority of the remaining contaminated PWSs identified from the UCMR1 database are distributed across Nevada and Arizona, the south central United States (e.g., Texas, Louisiana), the southeast (e.g., Florida, Georgia, and North Carolina), and the northeast.

Figure 3 shows the percent of PWSs that would be affected by a given perchlorate MCL for the calculated 90th percentile and median perchlorate concentrations. At a potential MCL of 24 µg/L, only 0.3% of all PWSs would need to be treated for perchlorate removal as compared with 3.4% of all PWSs for a perchlorate MCL of 4 µg/L based on the 90th percentile perchlorate concentrations. Even at the

FIGURE 2 Percent of contaminated PWSs in a given state or territory



PR—Puerto Rico, PWSs—public water systems

Number of systems = 160

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most stringent MCL evaluated (i.e., 4 µg/L), the percent of PWSs expected to be affected is relatively low; only 2.2 to 3.4% are estimated to require perchlorate treatment based on the calculated median and 90th percentile perchlorate concentrations, respectively. These estimates suggest that the national costs for PWSs to comply with a potential perchlorate regulation may be relatively low.

The calculated percentages of PWSs affected by a given perchlorate MCL shown in Figure 3 differ slightly from values reported in Brandhuber et al (2008). The discrepancy is a result of slight differences in the approach used to analyze the UCMR1 data. Brandhuber et al (2008) assigned nondetects a value of 2 µg/L, whereas nondetects were assigned a zero value in this study. Further, Brandhuber et al (2008) averaged the perchlorate measurements at a given source; in contrast, the values shown in Figure 3 are based on either the median or 90th percentile values. Despite these variations in data interpretation, the trends shown in Figure 3 and reported in Brandhuber et al (2008) are similar.

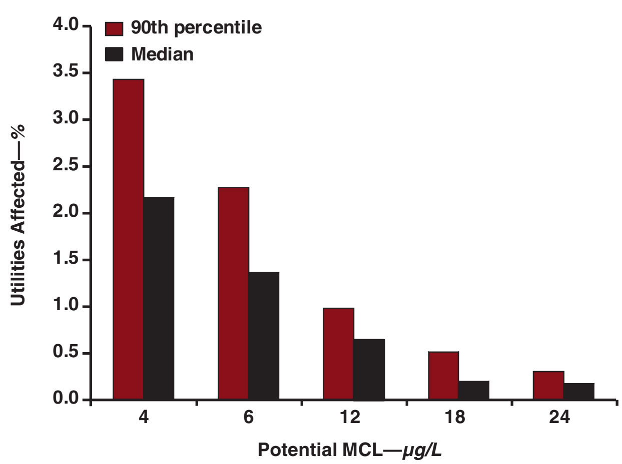
Compliance costs. *Capital costs.* Figure 4 shows estimated low- and high-end capital (part A) and O&M (part B) costs for each potential perchlorate MCL. Capital costs associated with a 4-µg/L MCL range from $470 million to $850 million, whereas, capital costs to comply with a 24-µg/L MCL are much lower at $10 million to $34 million. As expected, capital costs are higher if the 90th percentile perchlorate concentration is used and if blending/abandonment is not considered as a compliance option. Although a higher influent perchlorate concentration is not expected to affect capital costs to install a treatment system (based on observed trends that system size, e.g., number of vessels, volume of resin, is dictated primarily by the design capacity, concentrations of competing anions, and operational considerations), a greater number of contaminated sources are estimated for a given perchlorate MCL if the 90th percentile value is considered.

Generally, capital costs for perchlorate treatment are estimated to be low when compared with other regulations, even at the most stringent regulatory level evaluated. As a comparison, estimated capital costs to treat for arsenic, another inorganic anion known to contaminate some source waters, were estimated to be $4.5 billion in 2001 (USEPA, 2001a). The low estimated capital costs for perchlorate treatment reflect the small number of source waters expected to be affected nationwide (approximately 800) and the relatively low costs to install single-pass ion exchange systems. However, a small number of systems are carrying this cost burden, and the cost implications to an individual system installing perchlorate treatment would likely be significant, particularly when O&M costs are also taken into account.

O&M costs. Figure 4, part B shows the estimated range of nationwide costs to operate single-pass ion exchange treatment systems for perchlorate treatment for 20 years at a 3% discount rate. Comparing the O&M data (Figure 4, part B) with capital costs (Figure 4, part A) illustrates that O&M costs account for a larger portion of the total net present value (NPV) costs to treat for perchlorate than the capital costs. Similar to liquid-phase granular activated carbon (GAC) treatment for trace organic compounds, the cost to operate single-pass ion exchange is high relative to the capital costs because a significant component of the system must be replaced on a continual basis (i.e., the resin). O&M costs also continue in perpetuity or until the perchlorate contamination is removed from the groundwater.

An analysis of O&M costs for a single-pass ion exchange plant in southern California revealed that resin replacement costs are the most expensive line item at 58% of the annual operating costs, compared with 20% for power and 14% for labor. Although the development of perchlorate-selective resins with

FIGURE 3 Percent of utilities affected by various potential MCLs



Information presented in the figure is based on Unregulated Contaminant Monitoring Rule data and includes all system sizes.

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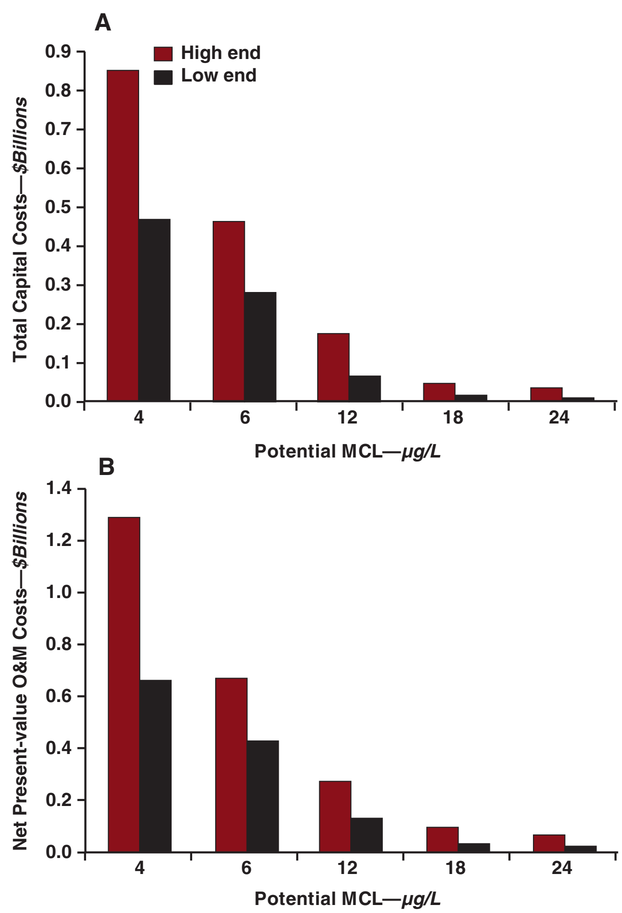
high capacities for perchlorate removal (e.g., 175,000–280,000 bed volumes depending on water quality; Russell et al, 2008) has made single-pass ion exchange systems economically competitive with other available perchlorate treatment technologies, resin replacement costs are still a major component of the total costs to operate single-pass ion exchange systems.

Table 3 lists total O&M costs for the eight queried PWSs. Several trends in the data warrant further discussion. The higher O&M costs per 1,000 gal of water treated for the smaller systems reflect economies of scale (e.g., a minimum level of staff hours are required despite system size). Additionally, several of the queried small water systems have entered into lease agreements with vendors of the single-pass ion exchange systems. O&M costs for these systems tend to be higher because of the type of contract and service fees paid to the vendors for oversight and maintenance of the systems.

The difference in estimated O&M costs for the two 7,800-gpm treatment systems reflects the differences in water quality between the two facilities. Nitrate concentrations in the source water for the Valley County (Calif.) Water District range between 11 and 13 mg/L as nitrogen (NO_3-N) compared with an average nitrate concentration of 7.3 mg/L NO_3-N for the San Gabriel Valley (Calif.) Water Company B6 plant. Despite higher selectivity of the perchlorate-selective resins for perchlorate removal, nitrate in the water can significantly reduce resin capacity because of orders of magnitude higher concentrations of nitrate than perchlorate (milligrams per litre of nitrate as opposed to micrograms per litre of perchlorate). The higher estimated operating cost ($0.40/1,000 gal) at Valley County (compared with $0.31/1,000 gal at San Gabriel's B6 plant) reflects the effect of nitrate co-occurrence on resin and total O&M costs. These factors known to influence O&M costs were inherently included in the nationwide compliance cost estimates since the O&M cost curve was developed using cost data for PWSs covering a range of different operations agreements (e.g., leasing versus operation by utility staff) and water quality.

Total costs. Figure 5 shows total compliance costs (capital plus NPV O&M) under the range of parameters investigated. The total cost of compliance for an MCL of 4 µg/L is estimated to be $2.1 billion ($0.85 billion in capital and $1.28 billion total NPV in operating costs) based on the high-end costs (90th percentile perchlorate concentrations, no blending/abandonment) and operation of the systems for 20 years at a 3% discount rate. In comparison, the estimated compliance cost for an MCL of 24 µg/L is much lower at approximately

FIGURE 4 Total estimated capital (A) and net present-value O&M costs (B) to treat for perchlorate at various potential MCLs



MCL—maximum contaminant level, O&M—operations and maintenance

Information in this figure is based on installation of single-pass–ion exchange treatment systems and on 20 years of operation at a 3% discount rate. High-end costs assume 90th percentile perchlorate concentrations and no blending; low-end costs assume median perchlorate concentrations and blending/abandonment for 10% of the contaminated sources.

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$0.1 billion or 4% of the cost at the most stringent MCL evaluated (4 µg/L). The significantly lower cost for the higher perchlorate concentration reflects the small number of PWSs that would be affected at that regulatory level (Figure 3).

Capital and O&M costs to remove perchlorate from contaminated sources for large PWSs account for a greater percent of the nationwide compliance costs associated with each potential perchlorate MCL (Figure 6). The higher portion of costs for large PWS compliance is attributed to several factors:

• the higher percentage of large PWSs with perchlorate contamination compared with small PWSs (Brandhuber et al, 2008),

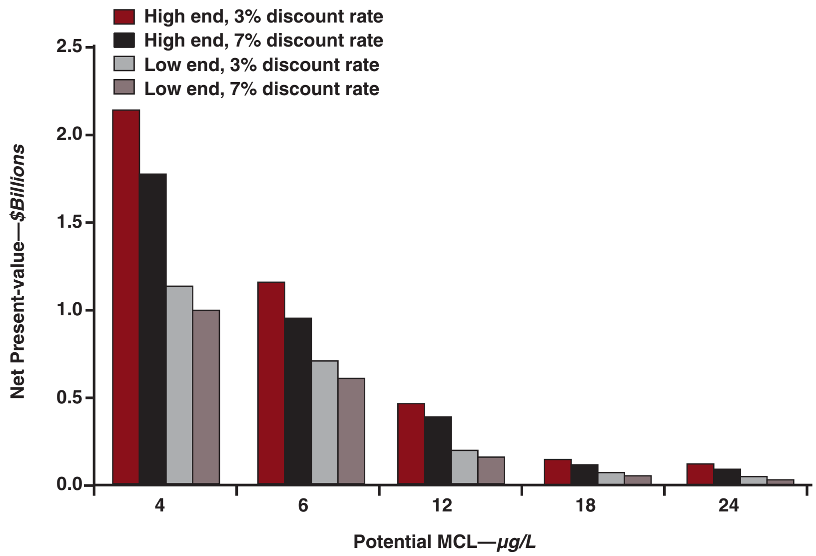
• the higher capital costs for a given system to meet the higher design flow, and,

• higher operating costs associated with the greater quantity of water requiring treatment for a given system.

None of the 800 small PWSs sampled under UCMR1 exhibited 90th percentile or median perchlorate concentrations above 18 or 24 µg/L in any of their source waters. Therefore, estimated compliance costs for small systems were negligible at the higher potential MCLs (18 and 24 µg/L). It is possible that several PWSs would be identified with perchlorate concentrations exceeding 18 µg/L in one of their source waters if all 66,826 small CWSs and NTNCWSs were sampled. However, based on the percent perchlorate occurrence in the small PWSs sampled under UCMR1 and the lower relative costs to treat the smaller systems, any additional costs attributed to small PWSs with perchlorate detections above 18 µg/L would not be expected to significantly affect the total nationwide costs of compliance.

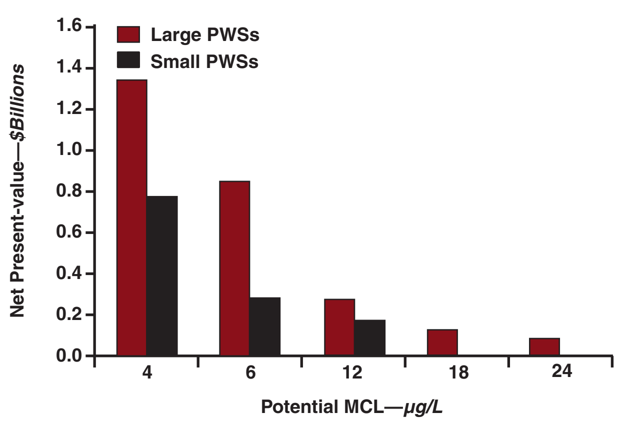
Table 4 lists estimated compliance costs (in 2008 dollars) associated with several significant NPDWRs. Projected annual costs for a perchlorate MCL of 4 µg/L are also listed.

FIGURE 5 Total estimated compliance costs for various parameters



Information in this figure is based on installation of single-pass ion exchange treatment systems and on 20 years of operation at a 3% discount rate. High-end costs assume 90th percentile perchlorate concentrations and no blending; low-end costs assume median perchlorate concentrations and blending/abandonment for 10% of the contaminated sources.

FIGURE 6 Total estimated compliance costs for large and small PWSs



Information in this figure is based on 90th percentile perchlorate concentrations, installation of single-pass ion exchange treatment systems, and 20 years of operation at a 3% discount rate.

The data illustrate that national compliance costs for perchlorate treatment, even at the most stringent level evaluated, are expected to be significantly lower than costs associated with prior drinking water regulations. Costs associated with the Arsenic Rule provide perhaps the best comparison because that rule similarly regulates levels of a single contaminant found primarily in groundwater. Nevertheless, compliance costs associated with the Arsenic Rule are also higher than projected costs for perchlorate treatment to meet an MCL of 4 µg/L.

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TABLE 4 Comparison of projected costs for a 4-µg/L perchlorate MCL to costs associated with previous regulations*

National Primary Drinking Water Regulations	Estimated Annual Compliance Cost—***$ million***
Lead and Copper Rule	1,462
Stage 2 Disinfection and Disinfectants Byproducts Rule	812
Surface Water Treatment Rule	1,309
Arsenic Rule	280
Estimated perchlorate costs based on 4-µg/L MCL	76–140†

*Costs in 2008 dollars using a 5% discount rate

†Low-end cost ($76 million/year) based on median perchlorate concentrations with source water blending/abandonment at a 3% interest rate; high-end cost ($167 million/year) based on 90th percentile perchlorate concentrations with no source water blending/abandonment at a 3% interest rate.

DISCUSSION

On the basis of the information available, the calculated perchlorate compliance costs at the regulatory levels evaluated are expected to be accurate within an order of magnitude. The following paragraphs discuss the potential effect that data limitations and assumptions may have had on the cost estimates and results from an evaluation of parameters (e.g., number of sources for a given PWS) with significant importance to the estimated compliance costs. A greater level of accuracy in the cost estimates will require analysis at specific utility levels rather than the national aggregate level. Such an analysis was beyond the scope of this study.

Limitations in data sources. The UCMR1 sampling included a 4-µg/L analytical limit for perchlorate. At the regulatory levels evaluated for this study (i.e., 4 µg/L and above), this limitation in the data is not expected to have notably affected the calculated compliance cost. However, if USEPA sets the perchlorate MCL below 4 µg/L, the limitation would have a much more significant effect on calculated compliance costs because the number of identified sources exhibiting concentrations below 4 mg/L is severely limited by the detection limit used during UCMR1 sampling.

Only 2% of the small systems (CWSs and NTNCWSs serving < 10,000 people) were sampled during UCMR1. Therefore, a large scale-up factor was included in the national cost estimate that could result in some inaccuracies if the sampled systems do not accurately represent the entire set of systems in the nation.

The data illustrate that national compliance costs for perchlorate treatment, even at the most stringent level evaluated, are expected to be significantly lower than costs associated with prior drinking water regulations.

Limitations in assumptions. Source water monitoring costs associated with a federal regulatory determination were not included in the cost evaluation and would be an additional factor to consider when a potential perchlorate regulation is evaluated. It could be assumed that each of the approximately 54,000 CWSs would have to conduct one year of quarterly monitoring before potentially dropping back to reduced monitoring. An assumption of $50/sample, or $200 for four samples, yields an initial monitoring cost of approximately $11 million. The contribution toward the first year of compliance is not insignificant at 8 to 14% of the estimated annual compliance cost (for a 4-µg/L MCL). However, compared with the total cost for 20 years of compliance ($2.1 billion), the estimated costs for initial monitoring of all PWSs and continued monitoring of contaminated sources are not large. As a comparison, the California Department of Public Health (CDPH) estimated monitoring costs associated with their determination to regulate perchlorate at a 6-µg/L MCL (CDPH, 2007). The estimated annual monitoring costs were 2% of the total annualized treatment costs (capital and O&M).

The presence of nitrate is known to substantially affect resin capacity. The effects of higher source water nitrate concentrations and anion loading on O&M costs were implicitly considered via the distribution of water qualities for the reference systems considered in the cost analysis. However, depending on the nationwide co-occurrence of nitrate with perchlorate, the operating costs for perchlorate treatment may be underestimated in this study. Kimbrough and Parekh (2007) observed a weak but statistically significant correlation between perchlorate and nitrate occurrence in California water sources. In future evaluations, the incremental cost because of nitrate interference can be specifically considered.

Cost verification. The validity of the cost assessment being accurate within an order of magnitude was verified by checking the accuracy of several parameters with significant importance to the determination of compliance costs, specifically: the

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number of sources for a given PWS, the population size for a given PWS, estimated design and average flow rate for a given contaminated source water, and estimated perchlorate concentration for all contaminated sources with design flow rates > 10,000 gpm. The verification exercise revealed that parameter values estimated as part of this cost assessment (i.e., number of sources, source flow rate) were within range of actual values for each individual PWS evaluated. Details of the evaluation are provided in the AWWA-funded study (Malcolm Pirnie, 2008b).

Comparison with other cost studies. The total annualized national compliance costs were compared with costs developed in two previous studies—Kennedy/Jenks (2004) and CDPH (2007). The two previous studies estimated total perchlorate treatment costs for utilities in California to respond to a state regulation. Based on the geographic occurrence trends (37% of detections occurring in California), the estimated national compliance costs should be approximately three times the calculated California costs as a rough approximation, assuming that all three studies produced fairly accurate cost information.

Kennedy/Jenks (2004) estimated a total annual cost of $75 million (in 2004 dollars) to meet a 4-µg/L California MCL. The costs developed in this study indicate approximately twice that value for total national treatment costs, which is within an order of magnitude of expected results. For a 6-µg/L California MCL, Kennedy/Jenks (2004) and CDPH (2007) estimated $50 million and $24 million, respectively, in total annualized costs to treat perchlorate. The estimated national treatment costs for this study—$76 million to $140 million per year—are approximately three times the CDPH and Kennedy/Jenks calculated costs for California treatment, respectively. Therefore, the national cost estimates developed for this study agreed with the findings from the previous two studies within the expected order of magnitude.

CONCLUSIONS

In this study, the perchlorate occurrence data were used to estimate national costs to treat contaminated water sources to meet five potential regulatory levels. The following conclusions can be made from the evaluation:

- Only 3.4% of PWSs would be affected by a perchlorate MCL of 4 µg/L; < 1% of PWSs would be required to treat their water at an MCL of 24 µg/L.

Several California public water systems have installed single-pass ion exchange systems, like the one installed at the California Domestic Water Company, to maintain compliance with the state's maximum contaminant level.

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• Although perchlorate contamination has been detected in source waters in 26 states, one third of the PWSs affected are in California. Most of the affected PWSs in California are already required to remove perchlorate to meet the state's 6-µg/L MCL.

• Most PWSs required to treat for perchlorate are expected to install single-pass ion exchange systems given the simplicity and relatively low costs and on the basis of current trends in Southern California. The advent of perchlorate-selective resins has made single-pass ion exchange an economically competitive treatment option for perchlorate removal.

• Capital costs for single-pass ion exchange are relatively low because of the simplicity of the treatment system. Capital costs to install single-pass ion exchange systems for all PWSs with perchlorate concentrations exceeding 4 µg/L are estimated to be $0.9 billion. Costs to operate the treatment systems for 20 years account for a larger percentage of the total costs at $1.3 billion (NPV). A significant portion (i.e., more than 50% based on O&M costs for a utility that installed single-pass ion exchange in 2002) of the O&M costs for single-pass ion exchange systems is the cost to periodically replace the spent resin.

• Costs to treat large PWSs account for the majority of the estimated nationwide compliance costs. This is the result of the higher percentage of such PWSs with perchlorate contamination and the higher capital and O&M costs necessary to treat the resulting larger quantity of water.

• The presence of nitrate is known to substantially affect resin capacity and thus O&M costs. The effect of nitrate co-occurrence on costs was implicitly included in the cost evaluation by basing the O&M cost equation on known full-scale operating costs for systems with a range of water quality characteristics (i.e., nitrate concentrations ranging from 5 to 13 mg/L as nitrogen). Nevertheless, it may be beneficial in subsequent studies to consider the distribution of nitrate co-occurrence with perchlorate in the United States and then make reasonable assumptions of treatment process selection for the affected utilities and the associated treatment costs.

• Compared with other drinking water regulatory determinations, the cost implications of a perchlorate MCL are relatively low because of the limited occurrence in source waters throughout the United States. At an MCL of 4 µg/L, total net present value compliance costs are estimated to be $2.1 billion (20 years, 3% discount rate). The estimated nationwide compliance cost drops to approximately $0.1 billion at an MCL of 24 µg/L because of the small number of PWSs contaminated with perchlorate at that level. However, a small number of systems are carrying this cost burden, and the cost implications to an individual system installing perchlorate treatment would likely be significant.

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FOOTNOTES

[1]Excel, Microsoft Corp., Redmond, Wash.

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