A Review of the California Department of Public Health's Cost-Benefit Analysis in Support of a Proposed Primary Drinking Water Standard for Hexavalent Chromium [Cr(VI)]: Addendum with Third-Party Cost Estimates[1]

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I. Executive Summary

In a review dated October 9, 2013, it was shown that the cost-benefit analysis (CBA) prepared by the California Department of Public Health (2013) (CDPH) implies that Maximum Contaminant Levels (MCL) for hexavalent chromium [Cr(VI)] ranging from 1 µg/L to 30 µg/L are economically infeasible for households served by small water systems relying on groundwater. The CDPH analysis also showed that standards below 15 µg/L were economically infeasible for large water systems.

A standard was judged to be potentially cost-effective if the engineering cost per theoretical cancer case prevented was less than or equal to the default value used by the U.S. Environmental Protection Agency (USEPA) for approximating the value of preventing a random premature mortality.

Belzer (2013) also identified several material defects in the benefit assessment component of the CDPH analysis. Each error systematically understated cost or overstated benefit. When only the most rudimentary of these defects was corrected, all MCLs were shown to be economically infeasible regardless of water system size. For large water systems, correcting these errors increased the engineering cost-effectiveness ratio for a 10 µg/L MCL from $12 million to $60 million per theoretical cancer case prevented. For small water systems, correcting errors increased the cost-effectiveness ratio for a 10 µg/L MCL from $122 million to $600 million per theoretical cancer case prevented.

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[1] This independent work was sponsored by the American Chemistry Council. The analyses presented belong to the author alone.

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Expert engineering comments have been submitted to the administrative record by Najm (2013) on behalf of Water Quality & Treatment Solutions, Inc. (WQTS). These comments indicate that CDPH substantially underestimated engineering costs. In this Addendum, calculations in Belzer (2013) are updated to account for the higher WQTS cost estimates. In addition, this Addendum utilizes the four illustrative case studies in Najm (2013) to calculate theoretical benefits, theoretical net benefits, benefit/cost ratios, and cost-effectiveness ratios.

This revised analyses leads to the following seven major conclusions in addition to those reported in Belzer (2013) and not repeated here.

1. **When examined in the aggregate using the cost estimation methods applied by CDPH, no MCL in the range of 5 to 20 μg/L is economically feasible.**
2. **When the CDPH model is corrected, statewide theoretical net benefit is three to six times worse than when calculated as CDPH did.**
3. **As expected, correcting errors in the CDPH cost analysis reduces benefit/cost ratios and increases cost-effectiveness ratios across the board.**
4. **Estimates of household-level impacts are crucial for fully understanding the effects of a primary drinking water standard for Cr(VI), but such estimates cannot be developed based on the WQTS analysis.**
5. **For each of the WQTS case studies, annualized net benefit is substantially negative at all MCLs.**
6. **For each of the WQTS case studies, a treatment mandate would cause reductions in household net worth ranging from substantial to devastatingly large.**
7. **Permanently high cost for Cr(VI) treatment could make a community unsustainable.**

Each of these conclusions is explained below.

1. **When examined in the aggregate using the cost estimation methods applied by CDPH, no MCL in the range of 5 to 20 μg/L is economically feasible.**

Aggregation is often used as a device for disguising significant population variability. To its credit, the CDPH did not attempt this. But its analysis left unclear whether aggregating small and large water systems in a single analysis could produce a statewide theoretical net benefit.

In fact, aggregation is not sufficient to produce a statewide net benefit for any MCL in the 5 μg/L to 20 μg/L range, inclusive. In annualized terms reported with two significant figures, statewide net benefit ranges from –$430 million (at 5 μg/L) to –$26 million (at 20 μg/L). These losses would be borne every year for 100 years. In present value terms, these annualized losses range from –$6,500 million to –$400 million. They are equivalent to one-time reductions in wealth.

2. **When the CDPH model is corrected, statewide theoretical net benefit is three to six times worse than when calculated as CDPH did.**

The purpose of the WQTS analysis was to ascertain statewide cost after correcting for certain technical errors in the CDPH cost analysis. These corrections are significant, as shown in Figure ES-1 below.

Some corrections to the cost analysis result in more water systems being required to install treatment, so benefit also must increase. It is not a simple matter to discern how much benefit would increase, however. As an approximation that probably overstates the true amount by which benefit increases, in this Addendum it is assumed that statewide benefit rises proportional to the portion of cost increase attributable to increases in the number of sources and systems estimated to be required to install treatment. Even under this generous assumption, cost rises more than benefit because some of the corrections made by WQTS result in higher costs for the same sources and systems.

In annualized terms reported with two significant figures, statewide net benefit declines to a range from –$1,300 million (at 5 μg/L) to –$140 million (at 20 μg/L). At the proposed 10 μg/L MCL, annualized net benefit is –$570 million. These losses would be borne every year for 100 years. In present value terms, annualized net benefit now ranges from –$20,000 million to –$2,000 million.

These results are presented graphically in Figure ES-1 (annualized cost), Figure ES-2 (annualized theoretical net benefit), and Figure ES-3 (present value theoretical net benefit).

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Figure ES-1: Uncorrected and Corrected Statewide Annualized Cost Derived from the WQTS Analysis

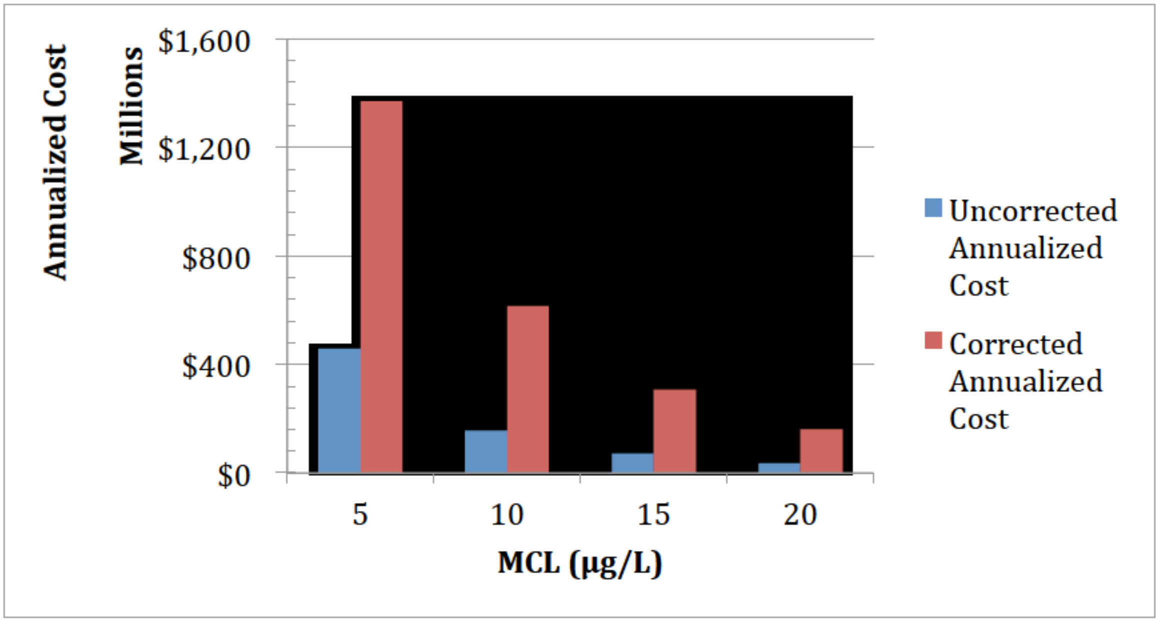

Figure ES-2: Uncorrected and Corrected Annualized Theoretical Net Benefit Derived from the WQTS Analysis

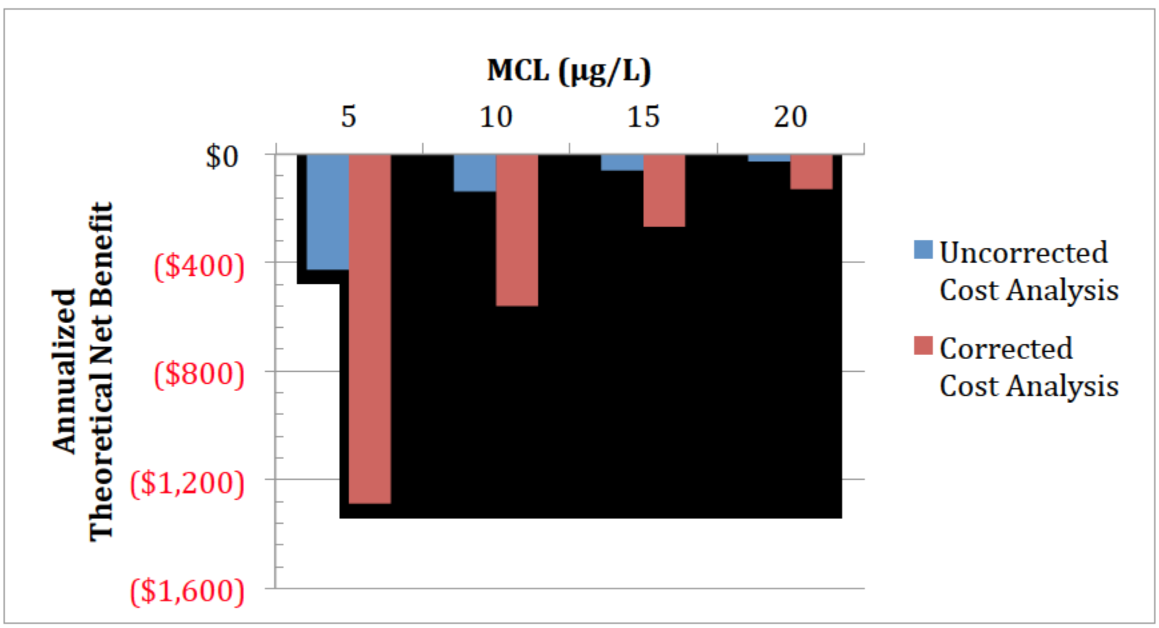

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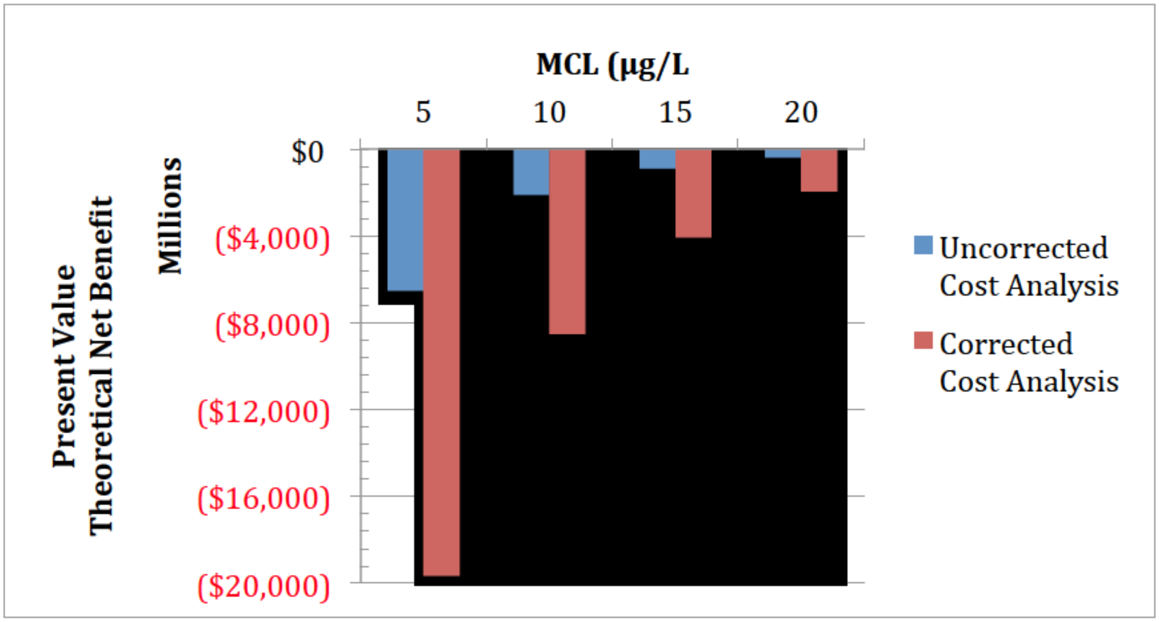
Figure ES-3: Uncorrected and Corrected Present Value Theoretical Net Benefit Derived from the WQTS Analysis



3. **As expected, correcting errors in the CDPH cost analysis reduces benefit/cost ratios and increases cost-effectiveness ratios across the board.**

For an investment or regulation to be economically feasible, the benefit/cost ratio must be greater than 1.0. Even before errors in the CDPH cost analysis are corrected, the benefit/cost ratio is far less than 1.0 for all MCLs, ranging from 0.067 (at 5 µg/L) to 0.26 (at 20 µg/L). Correcting errors in the cost methodology reduces the benefit/cost ratio to 0.061 (at 5 µg/L) to 0.15 (at 20 µg/L) even though benefits rise as well.

Economic feasibility also requires the cost-effectiveness ratio to be less than the value of preventing a random cancer case. Statewide, the cost-effectiveness ratio before correction ranges from $120 million (at 5 µg/L) to $30 million (at 20 µg/L) per theoretical cancer case prevented. Correcting errors in the cost methodology increases the cost-effectiveness ratio to $130 million (at 5 µg/L) to $51 million (at 20 µg/L) per theoretical cancer case prevented.

These results are presented graphically in Figures ES-4 and ES-5.

Figure ES-4: Uncorrected and Corrected Theoretical Benefit/Cost Ratios Derived from the WQTS Analysis

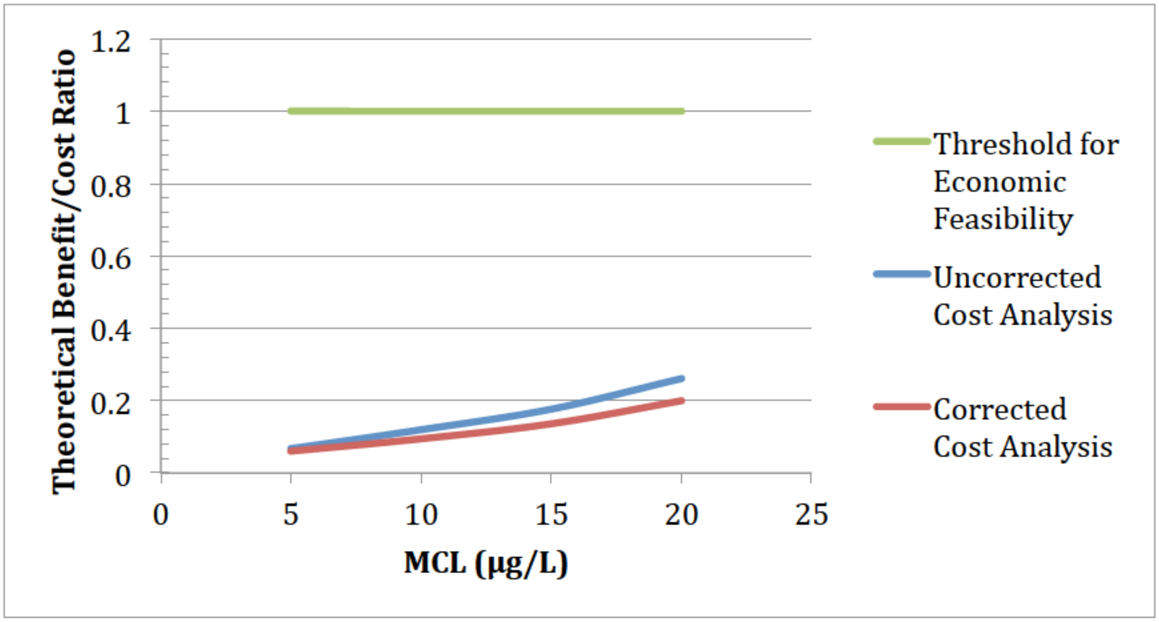
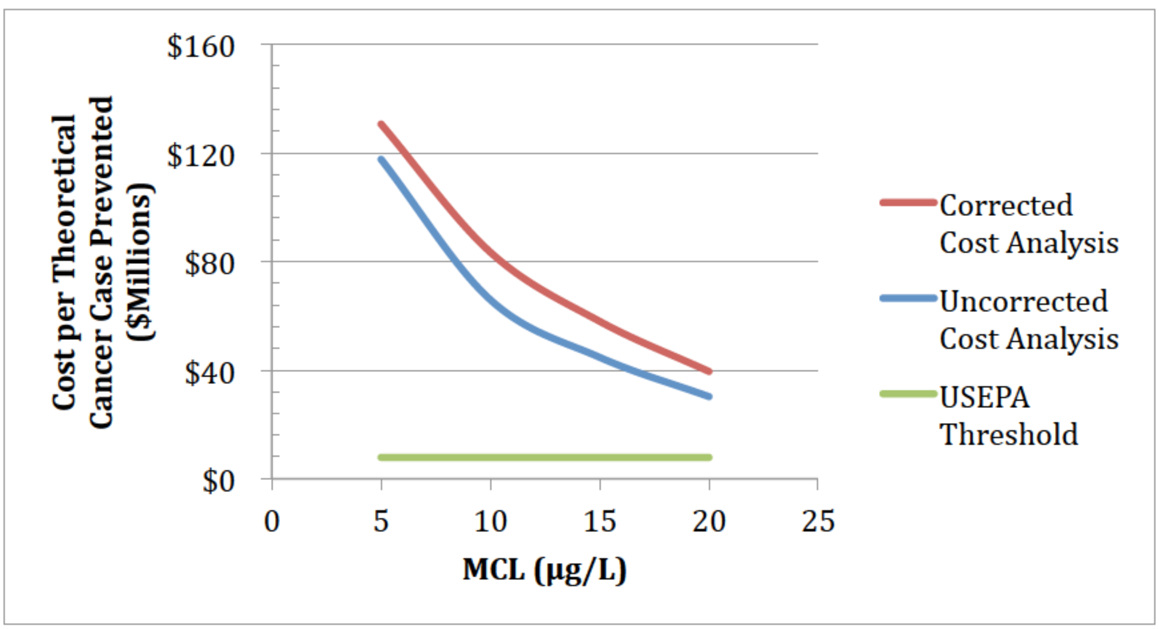


Figure ES-5: Uncorrected and Corrected Theoretical Cost-Effectiveness Ratios Derived from the WQTS Analysis



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4. Estimates of household-level impacts are crucial for fully understanding the effects of a primary drinking water standard for Cr(VI), but such estimates cannot be developed based on the WQTS analysis.

Aggregate cost and benefit estimates are very hard to put in useful context. For this reason, it is essential to calculate effects at the household level. This cannot be done based on the main WQTS analysis, however, because it does not include estimates of the number of households that would be covered under each MCL. Furthermore, CDPH's estimates also cannot be used because they do not include the higher number of households gaining cancer risk reduction benefits in the WQTS model. Dividing statewide cost or benefit estimates obtained from the WQTS model by the CDPH's number of households covered would grossly overstate cost and benefit per household, and do so in a highly nontransparent manner. For this reason, no estimates of household-level effects are provided based on the WQTS statewide analysis. Some insight can be gleaned from the WQTS case studies, however, though it is important not to draw inferences about the population from them.

Figure ES-6: Annualized Cost and Theoretical Benefit per Household for WQTS Case Studies

MCL Avg Δ Cr(VI)	Coachella Valley [2-21 μg/L]		Woodland [6-30 μg/L]		Oak Trail Mutual [17-19 μg/L]		Tierra Buena #1 [12 μg/L]	
	Benefit	Cost	Benefit	Cost	Benefit	Cost	Benefit	Cost
MCL=5 μg/L Δ –12 μg/L	$29.04	$1,207	$55.07	$1,539	$47.39	$14,692	$41.15	$13,300
MCL=10 μg/L Δ –8 μg/L	$19.36	$744	$36.71	$1,288	$31.59	$14,531	$27.43	$13,182
MCL=15 μg/L Δ –4 μg/L	$9.68	$286	$18.36	$1,190	$15.80	$14,467	$0	$0
MCL=20 μg/L Δ –2 μg/L	$4.84	$98	$9.18	$848	$7.90	$14,467	$0	$0

Population, households, and annualized cost: Najm (2013), Figures 14, 18, 22, and 26; reported source water concentrations are in [square brackets]. Benefits calculated by author based on methodology devised in Belzer (2013). Figures are reported as calculated, but readers are cautioned that they include excess precision.

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5. **For each of the WQTS case studies, annualized net benefit is substantially negative at all MCLs.**

The WQTS analysis includes four case studies that were intended to illustrate the severity of cost impacts. Two case studies involve small water systems; two others concern large water systems that, because of the geography of their infrastructure, would experience impacts as if they were small systems. Figure ES-6 reports annualized cost and theoretical benefit side by side for specified average concentration reductions associated with each MCL. Even at the most stringent MCL considered (5 μg/L), annualized theoretical benefit per household is in the lower tens of dollars per household. Meanwhile, annualized costs are in the thousands and tens of thousands per household.

Figure ES-7 shows that annualized theoretical net benefit per household is negative for all four case studies at all four MCLs. The choice of MCL has some effect on the severity of negative theoretical net benefit for households served by the Coachella Valley Water District. This reflects significant variation in the number of wells that would require treatment depending on the MCL selected. It is important to keep in mind that these values are averages; that is, cost is assumed to be shared by all households served by Coachella Valley Water District, but only those households served by a well that is subject to a treatment requirement would actually gain any benefit. For the other three case studies, however, the only important question is whether the MCL selected forces the water system to install and operate treatment works.

Cost-effectiveness ratios are shown for all four case studies in Figure ES-8, with the implied USEPA threshold included for reference. Note that values are plotted on a log axis to ensure visibility. Coachella Valley and Woodland, both large water systems comprised of dozens of wells each of which may require the installation of treatment depending on the MCL, reside in the same cost-effectiveness "neighborhood"—between \$100 million and \$1 billion per theoretical cancer case prevented. Oak Trail Mutual and Tierra Buena #1 reside in a different neighborhood—between \$2 trillion and \$15 trillion per theoretical cancer case prevented.

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Figure ES-7: Annualized Theoretical Net Benefit per Household for WQTS Case Studies

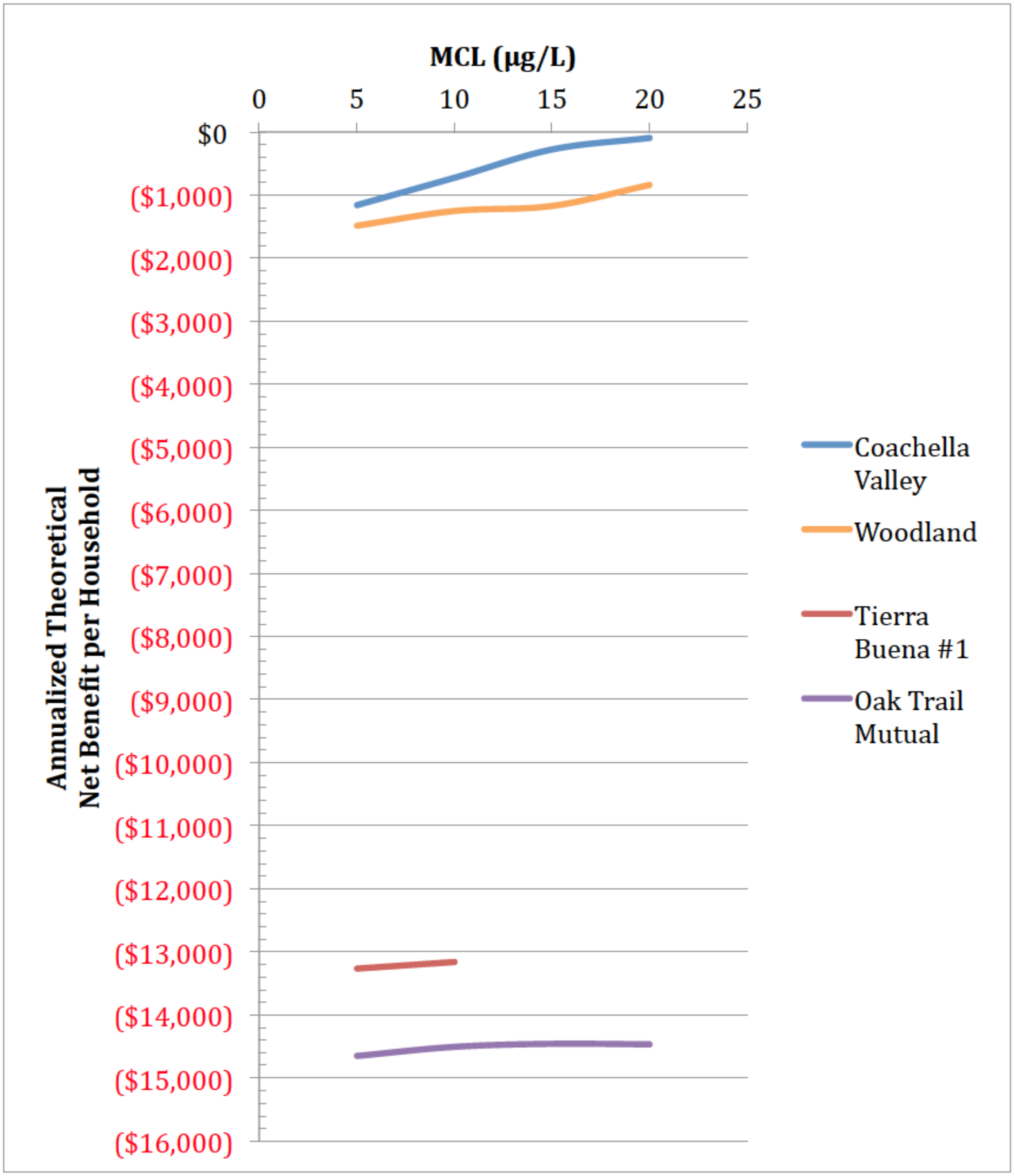

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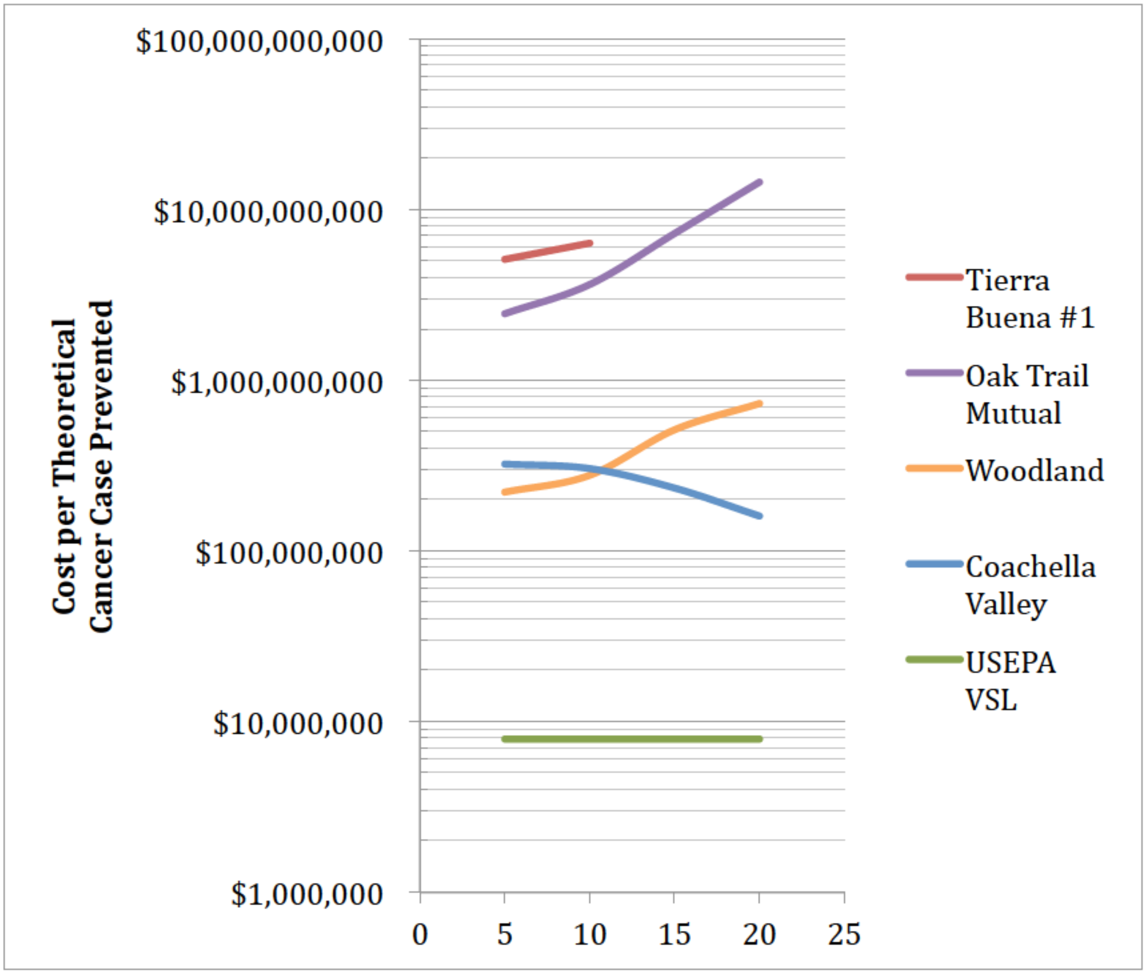
Figure ES-8: Cost-Effectiveness Ratio of Cr(VI) Treatment for WQTS Case Studies



6. **For each of the WQTS case studies, a treatment mandate would cause reductions in household net worth ranging from substantial to devastatingly large.**

Because present value theoretical net benefit is tied to service connections, it will be capitalized into the value of real properties for which there are no legally permissible or technically feasible alternatives besides connection to the public water system. Negative present values mean decreases in property values, and for households that are homeowners, this means reductions in household net worth.

Calculated reductions in household net worth are shown in Figure ES-9 for the four WQTS case studies; a log axis is used to ensure that all values are visible. For Oak Trail Mutual and Tierra Buena #1, net worth would decline $200,000 to

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$225,000 per household regardless of the MCL selected as long as it is binding. In Woodland, household net worth would decline $23,000 (at 5 μg/L) to $13,000 (at 20 μg/L). Reductions in net worth would vary the most for households served by the Coachella Valley Water District, ranging from $18,000 (at 5 μg/L) to $1,400 (at 20 μg/L). (As previously noted, for Coachella Valley it is assumed that cost, and hence losses in household net worth, can be spread across all households in the service area even though only households served by treated water actually gain any benefit.)

Figure ES-9: Present Value Theoretical Net Benefits/Reductions in Net Worth per Household for WQTS Case Studies

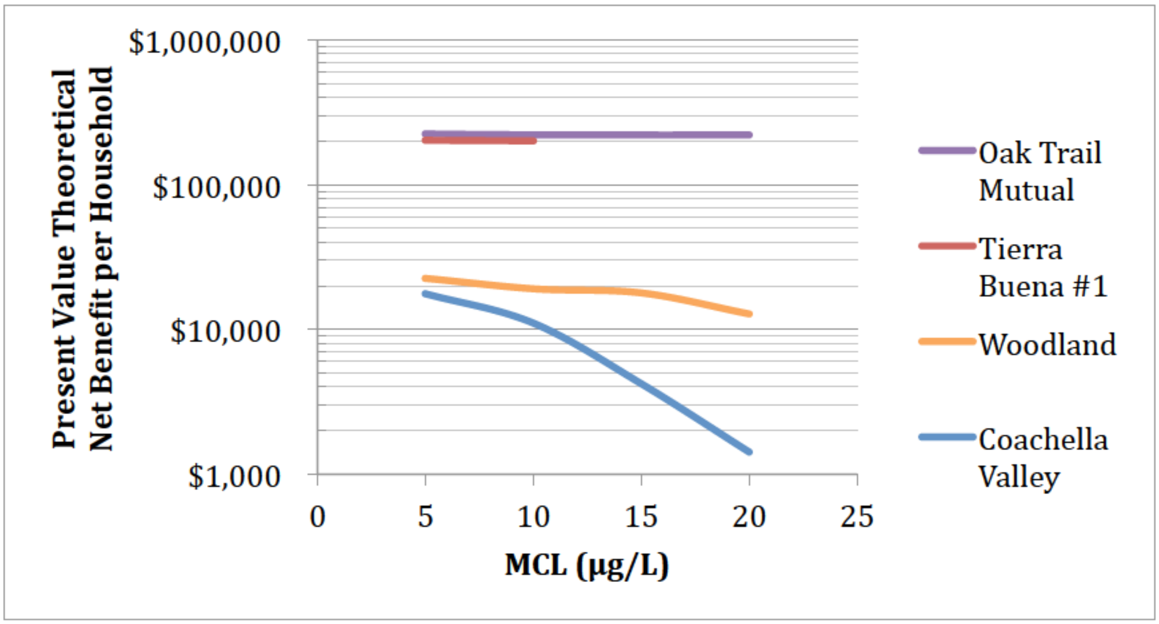
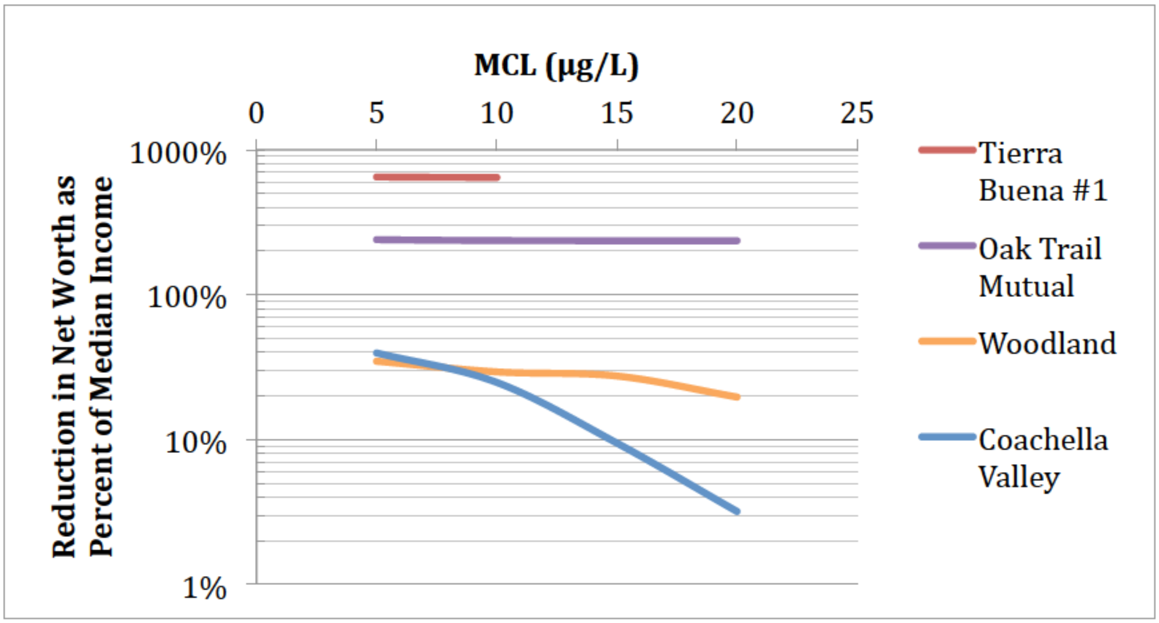


Figure ES-10 plots these reductions as percentages of each community's median income. Households served by Oak Trail Mutual and Tierra Buena #1 would experience potential reductions in net worth equal to 240% and 320% of one year's median household income, respectively, regardless of the MCL selected as long as it is binding. Few, if any, households could withstand such a loss. Some would strive to disconnect from the public water system in favor of untreated private wells.

In Woodland, reductions in net worth would range from 35% (at 5 μg/L) to 20% (at 20 μg/L) of one year's median household income. Households would have considerable difficulty absorbing the higher cost of public water, and securing alternative water supplies seems unlikely to be feasible. A stringent MCL would have especially troubling effects on homeowners with limited equity.

The widest variation in net worth losses among the case studies would be experienced by households served by the Coachella Valley Water District. The most stringent MCL (5 μg/L) would reduce household net worth by 40% of one year's median income; the least stringent (20 μg/L) would reduce household net worth by 3% of one' year's median income. Like in Woodland, a stringent MCL would have especially troubling effects on homeowners with limited equity.

Figure ES-10: Reductions in Net Worth as Percentages of Community Median Income for WQTS Case Studies



7. **Permanently high cost for Cr(VI) treatment could make a community unsustainable.**

Homeowners with substantial real estate equity would experience significant declines in net worth. For communities in which many households must endure such reductions, community sustainability would become problematic. This would be true irrespective of whether households could secure alternative water supplies. If no alternatives were feasible, the community would experience a general decline in property values, with concomitant adverse impacts on local public finances. To sustain a constant level of public services, the community would have to raise property tax rates to maintain the same revenue. Because rising property taxes, like rising water rates, are capitalized in property values, property values would decline further.

If a substantial percentage of customers eliminated their need for a connection to the public water system, the fixed cost of Cr(VI) treatment would have to be borne by an ever-shrinking customer base. Adverse effects on local public finances would be even greater than if no cost-effective drinking water alternatives were available.

II. Benefits and Costs of Alternative Cr(VI) Primary Drinking Water Standards Based on Revised Engineering Cost Estimates

Water Quality & Treatment Solutions, Inc. (WQTS) reviewed the CDPH cost analysis in three parts: (a) a replication of the CDPH report to produce statewide cost estimates; (b) a revision of (a) based on correcting certain errors in the assessment of engineering costs; and (c) cost calculations for four specific water systems to obtain estimates of costs per service connection (2013). WQTS estimated statewide engineering costs, however, and did not estimate costs separately for large and small systems. Therefore, comparisons between WQTS' results and those in CDPH (2013) and Belzer (2013), which are disaggregated by system size, must be made with caution.

A. The CDPH cost model, as replicated by WQTS, reveals that cost exceeds theoretical benefit for all four MCLs analyzed.

CDPH derived separate cost estimates for small and large public water systems. It did not aggregate these results into a statewide average, thereby leaving unclear whether aggregating small and large water systems in a single analysis could produce a statewide theoretical net benefit.

The WQTS re-analysis shows that aggregation is not sufficient to produce a statewide net benefit for any MCL in the 5 μg/L to 20 μg/L range, inclusive. Statewide annualized net benefit ranges from –$430 million (at 5 μg/L) to –$26 million (at 20 μg/L). These losses would be borne every year for 100 years. In present value terms, net benefit ranges from –$6,500 million to –$400 million.

B. WQTS' revised cost estimates are 3.0x to 4.6x higher than estimated by CDPH.

Najm (2013, p. 2) reports that WQTS was able to reconstruct the CDPH model and obtain very similar results, with differences generally less than 10% reported. However, four major errors in engineering cost estimation were discovered:

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1. Failure to include total chromium monitoring data in the calculation of the numbers of sources and systems that would be required to install treatment at each alternative MCL;
2. Use of incorrect values for water usage rates and peaking factors;
3. Failure to include land acquisition and treatment building costs; and
4. Failure to count sources with Cr(VI) levels within 80% of the MCL as covered by the standard.

These errors do not balance out; each systematically understates the likely cost of a primary dinking water standard.

Correcting these four errors results in substantially higher annualized cost estimates, as shown in Figure A. According to WQTS, CDPH underestimated statewide annualized engineering cost by amounts ranging from 200% (at 5 μg/L) to 357% (at 20 μg/L). At the proposed 10 μg/L MCL, corrected annualized engineering costs exceed $600 million—about three times CDPH's estimates. At the 5 μg/L MCL, annualized aggregate cost is 1.4% of the entire California state budget for FY 2013-14, 3.4% of total state K-12 education funding, or 52% of total State expenditures on environmental protection.[3]

C. Two of the four corrections WQTS made to the CDPH cost analysis imply greater Cr(VI) exposure reductions, approximated here as 2.7 to 3.5 times the exposure reductions calculated by CDPH.

Updating theoretical net benefit estimates requires updating theoretical benefit estimates as well as costs. The WQTS review does not address benefits, however, so the effects of WQTS' revised cost estimates on benefit estimates must be assessed indirectly.

Of the four major errors in engineering cost estimation for which WQTS offers revisions, the first and fourth have implications for benefit assessment because they mean more systems would require treatment than CDPH estimated. The second and third errors do not have benefit implications because they reflect higher costs for the same systems.

[3] State of California (2013), Figure SUM-01: General Fund Budget Summary and Figure SUM-02: 2013-2014 Total Expenditures by Agency.

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Figure A: WQTS' Aggregate Cost Estimates for Four Alternative MCLs

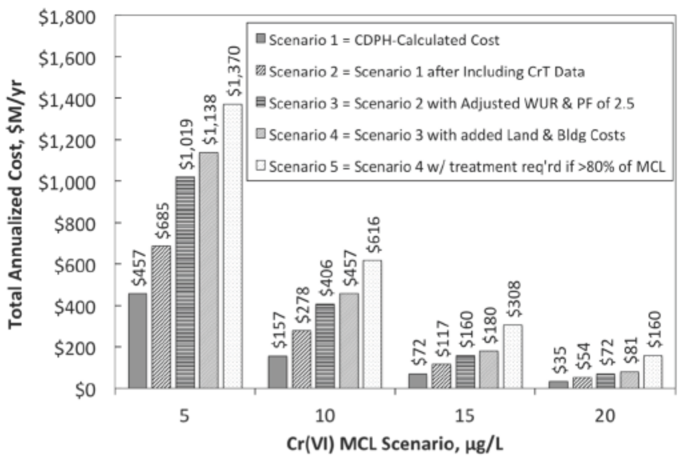

Figure 10 – Impact of Adding the Cost Adjustments on the Statewide Total Annualized Cost of Compliance with Four Cr(VI) MCL Values

Source: Najm (2013), p. 11.

1. Including sources based on total chromium monitoring data results in more systems requiring treatment and thus more Cr(VI) reductions.

In Section 2.2.1, Najm (2013) indicates that the number of water systems expected to be required to install treatment is considerably larger if total chromium (CrT) monitoring data are taken into account along with the limited Cr(VI) database. The argument for using CrT data is twofold. First, CrT and Cr(VI) concentrations in groundwater are essentially the same, so CrT concentrations above an MCL are highly likely to mean that Cr(VI) concentrations will as well. Second, the CrT database is substantially richer than the Cr(VI) database and thus is less uncertain.[4]

If more sources and systems must treat, we can expect that the aggregate amount of Cr(VI) exposure reduction also will be greater. However, Najm (2013) offers no way to precisely estimate how much more Cr(VI) exposure would be

[4] California Department of Public Health (2013) treats the absence of Cr(VI) monitoring data showing an exceedance as evidence of the absence of a prospective violation. This yields a lower-bound estimate of the number of sources and systems required to treat. CDPH did not include in its analysis the upper-bound assumption that the absence of a *nonviolative* Cr(VI) concentration is a presumptive violation.

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reduced.[5] As a first approximation, it could be assumed that the additional amount of Cr(VI) exposure reduction is proportional to the increase in aggregate cost. However, this would almost certainly overstate the amount of Cr(VI) exposure reduction. Whereas the OEHHA risk model assumes that risk reduction is a linear function of exposure reduction, engineering cost will rise more than linearly as the number of covered sources and systems increases.

2. Counting sources with Cr(VI) levels within 80% of the MCL as covered by the standard results in more systems requiring treatment and thus more Cr(VI) reductions.

In Section 2.2.4, the WQTS report shows that the number of water systems expected to be required to install treatment is considerably larger if sources with Cr(VI) (or CrT) concentrations exceeding 80% of the MCL are included. The argument for including these systems is that prudent water engineering practice calls for a margin of safety as protection from upside uncertainty about actual Cr(VI) concentrations in source waters.

The 80% heuristic is not something CDPH was unfamiliar with. Najm (2013, pp. 8-9) specifically mentions USEPA's use of it in two prior drinking water regulations. Thus it is unclear why CDPH did not account for the 80% rule in its analysis.

3. The additional Cr(VI) exposure reductions can only be approximated based on the WQTS analysis.

WQTS modeled four scenarios plus a baseline derived from its replication of the CDPH model. The way these scenarios were ordered makes it impossible to clearly distinguish between higher costs for the same systems (errors #2 and #3 in Section II.A) and higher costs due to more systems requiring treatment (errors #1 and #4 in Section II.A). The best we can do is approximately allocate the higher costs estimated by WQTS into these two categories, with only the latter category having implications for benefits assessment. This ensures that benefits are not extrapolated based on costs that are unrelated to benefits. Table 1 provides a series of cost ratios across relevant pairs of scenarios reported by WQTS. For example, Row 1 shows the incremental effect on statewide annualized cost of using CrT monitoring data. Depending on the MCL, this increases cost by a factor of 1.5 to 1.8. Row 2 takes the adjustment in Row 1 and also accounts for more accurate water use ratios and peaking factors; cost rises by an additional factor ranging from 1.3 to 1.5, depending on the MCL. Row 3 begins with the adjustments in Rows 1 and 2 and captures the

[5] To find out, the CDPH must re-run the benefits assessment in the CBA using the WQTS projections of sources requiring treatment and correct the errors identified in Belzer (2013).

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Table 1: Statewide Annualized Cost Ratios by Scenario Pair and Approximate Share of Higher Cost Accompanied by Greater Cr(VI) Exposure Reductions

Row	WQTS Scenario Cost Ratio	MCL (µg/L)			
		5	10	15	20
1	Scenario 2/Scenario 1	1.5	1.8	1.6	1.5
2	Scenario 3/Scenario 2	1.5	1.5	1.4	1.3
3	Scenario 4/Scenario 2	1.7	1.6	1.5	1.5
4	Scenario 5/Scenario 1	3.0	3.9	4.3	4.6
5	Scenario 5/Scenario 4	1.2	1.3	1.7	2.0
6	Approximate factor (% Share) of higher costs attributable to increased number of systems requiring treatment [a]	2.7 (90%)	3.1 (80%)	3.3 (77%)	3.5 (77%)

Source: Derived from Najm (2013, Figure 10).
[a] Sum of Rows 1 + 5. Percentage of Row 4 in parentheses.

additional cost of land acquisition and building costs, a factor ranging from 1.5 to 1.7. The composite factor for all three adjustments is provided in Row 4 and ranges from 3.0 to 4.6 times aggregate costs in WQTS's replication of the CDPH model.

Only after these adjustments have been made, two of which reflect higher costs for the same water systems, does WQTS expand the domain of covered systems to account for those relying on source waters with Cr (VI) or CrT concentrations expected to be 80-100% of the MCL. This domain adjustment results in cost ratios ranging from 1.2 to 2.0 on top of the previous three adjustments, which are shown in Row 5.

Of the 3.0x to 4.6x increase (depending on MCL) in estimated statewide annualized cost obtained by WQTS and reported in Figure 10, 1.5x to 1.7x (depending on MCL) is the result of higher costs for the same systems and 2.7x to 3.5x (depending on MCL) is attributable to more systems requiring treatment. Increases in cost due to increases in the number of systems requiring treatment are the predominant source of additional reductions in Cr(VI) exposure.

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This approximation probably overstates incremental aggregate benefits because it assumes they are proportional to incremental aggregate costs. The number of theoretical cancer cases prevented using the OEHHA risk model increases linearly with the quantity of Cr(VI) removed from drinking water. However, statewide annualized cost may well increase superlinearly, in which case the factors in Table 1 would overstate the number of theoretical cancer cases prevented in the Row 6 scenarios. With these caveats noted, upper-bound cancer risk reductions are approximately three times greater under the WQTS analysis because of the expanded domain of water systems expected to install treatment.

4. When the CDPH model is corrected, statewide theoretical net benefit is three to six times worse than when calculated as CDPH did.

How correcting the CDPH's errors in cost estimation change statewide annualized cost estimates is shown in Figure B and Table 2. The final row in the table shows the ratio of cost in the WQTS and CDPH analyses. Notice that the gap between the two estimates rises as the MCL becomes less stringent. The CDPH analysis underestimates cost more for higher MCLs because it is at higher MCLs that it most understated the number of sources and systems that would have to install treatment.

Table 2: Uncorrected and Corrected Statewide Annualized Cost Derived from the WQTS Analysis

	MCL (μg/L)			
	5	10	15	20
Statewide Annualized Costs ($ Millions)				
CDPH-R	$ 460	$ 160	$ 72	$ 35
WQTS	$1,400	$ 620	$ 310	$ 160
$\frac{WQTS}{CDPH-R}$	3.0	3.9	4.3	4.6
Derived from Najm (2013), Belzer (2013), and author's calculations. All figures reported with two significant digits.				

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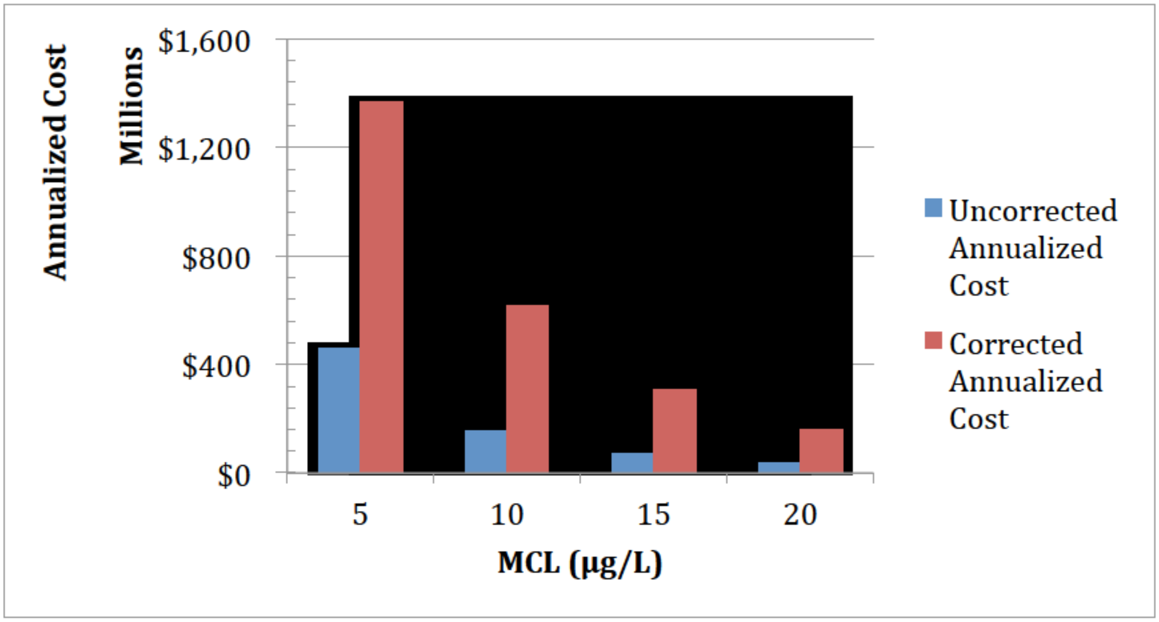
Figure B: Uncorrected and Corrected Statewide Annualized Cost Derived from the WQTS Analysis



D. Aggregate net benefits, cost-effectiveness ratio, and benefit-cost ratios based on WQTS' revised cost estimates are unambiguously worse than when derived from the CDPH cost model.

As expected based on the results, correcting errors in the CDPH cost analysis reduces benefit/cost ratios and increases cost-effectiveness ratios.

Table 3 summarizes annualized and present value theoretical benefits using the CDPH and WQTS cost analyses. The same information is shown graphically in Figure C and Figure D, respectively. Benefits are higher in the WQTS re-analysis because corrections to the cost model resulted in more sources and systems being subject to the treatment mandate, especially for the less stringent MCLs.

Table 4 summarizes annualized theoretical net benefits, cost-effectiveness ratios, and benefit/cost ratios. Net benefit is negative for both models and all four MCLs, and substantially more negative in the WQTS re-analysis. Annualized theoretical net benefit ranges from –$1,300 million (at 5 µg/L) to –$130 million (at 20 µg/L).

In both analyses, cost-effectiveness ratios greatly exceed the implied USEPA threshold, ranging from $130 million (5 µg/L) to $40 million (20 µg/L) per theoretical cancer case prevented. Benefit/cost ratios are close to zero, but they

Table 3: Statewide Annualized and Present Value of Reductions in Theoretical Cancer Cases Derived from WQTS Analysis

	MCL (µg/L)			
	5	10	15	20
Statewide Annualized Benefit ($ Millions)				
CDPH-R	$ 31	$ 19	$ 13	$ 9.1
WQTS	$ 83	$ 58	$ 42	$ 32
Statewide Present Value Benefit ($ Millions)				
CDPH-R	$ 470	$ 290	$ 190	$ 140
WQTS	$ 1,300	$ 890	$ 640	$ 490
Assumptions: (1) OEHHA LNT risk model is correct; (2) cancer case reductions are counted for 100 years; and (3) discounted at 7%.				

must exceed 1.0 for a Cr(VI) MCL to be an economically feasible method of reducing cancer risk. These results are illustrated in Figure E by the gap between the calculated C-E ratios and the maximum C-E ratio, and in Figure F by the gap between the calculated B/C ratios and the minimum B/C ratio, both of which are required for economic feasibility.

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Table 4: Statewide Annualized Net Benefits ($ Millions), Cost-Effectiveness ($ Millions/Theoretical Cancer Case Prevented, and Benefit/Cost Ratios

	MCL (µg/L)			
	5	10	15	20
Statewide Annualized Net Benefits ($ Millions)				
CDPH-R	–$ 430	–$ 140	–$ 59	–$ 26
WQTS	–$1,300	–$ 560	–$ 270	–$ 130
Statewide Cost-Effectiveness Ratios ($ Millions/Theoretical Cancer Case Prevented)				
CDPH-R	$ 120	$ 66	$ 45	$ 30
WQTS	$ 130	$ 83	$ 58	$ 40
$\frac{WQTS}{CDPH-R}$	1.1	1.3	1.3	1.3
Theoretical Benefit-Cost Ratios				
CDPH-R	0.067	0.12	0.18	0.26
WQTS	0.060	0.095	0.14	0.20
$\frac{WQTS}{CDPH-R}$	0.9	0.8	0.8	0.8
Derived from Najm (2013), Belzer (2013), and author's calculations. All figures reported with two significant digits.				

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Figure C: Uncorrected and Corrected Annualized Theoretical Net Benefit Derived from the WQTS Analysis

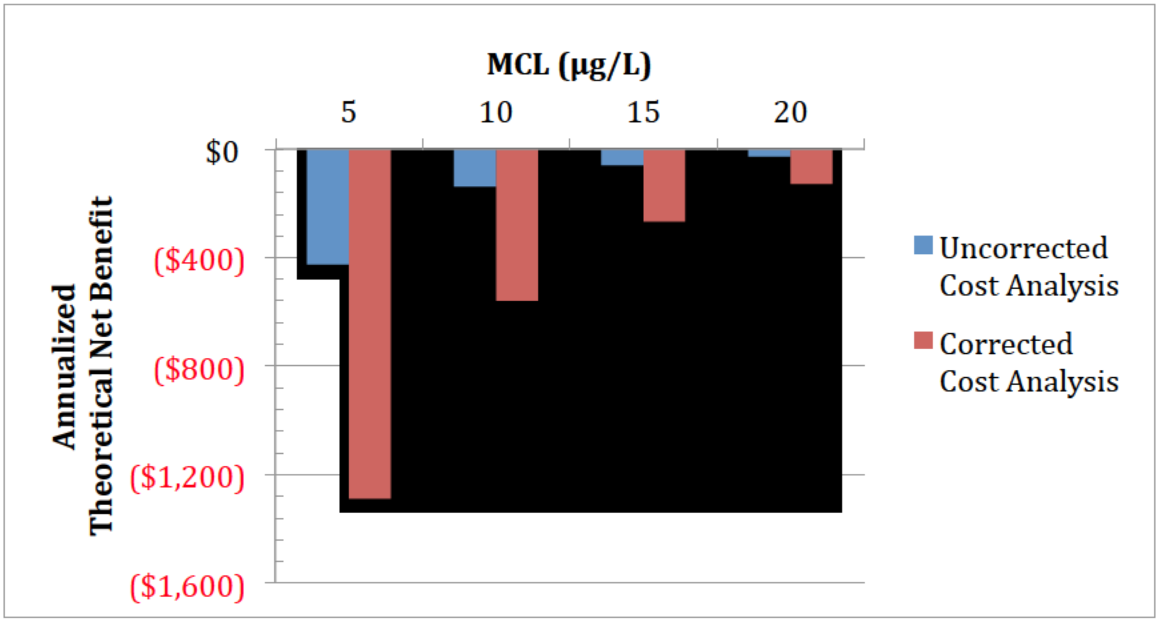

Figure D: Uncorrected and Corrected Present Value Theoretical Net Benefit Derived from the WQTS Analysis

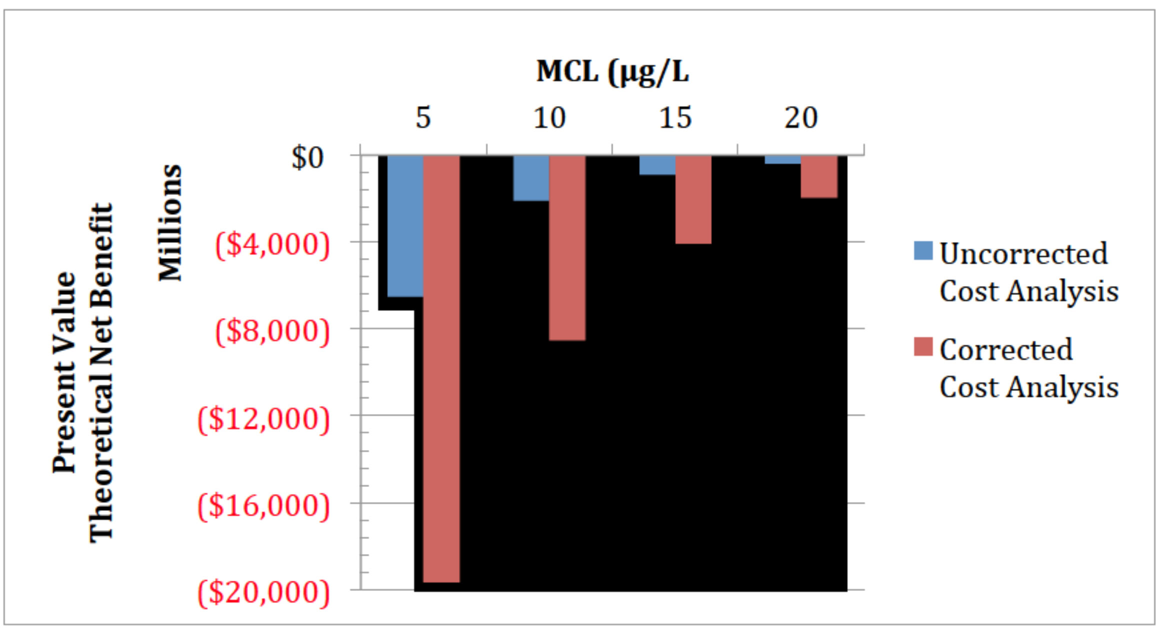

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Figure E: Uncorrected and Corrected Theoretical Cost-Effectiveness Ratios Derived from the WQTS Analysis

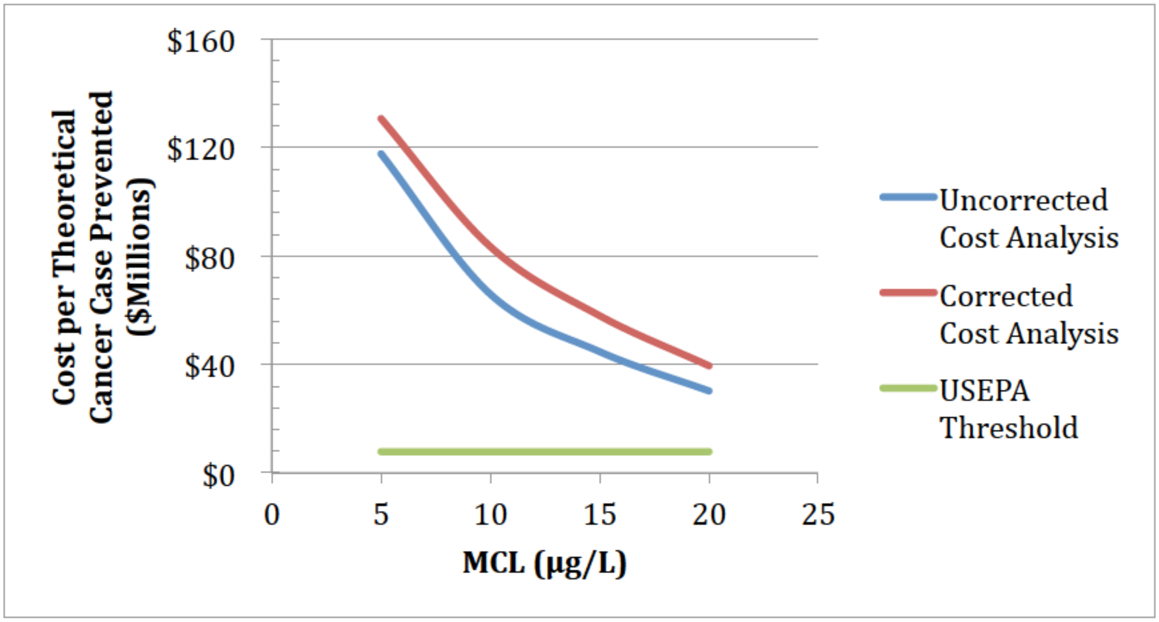
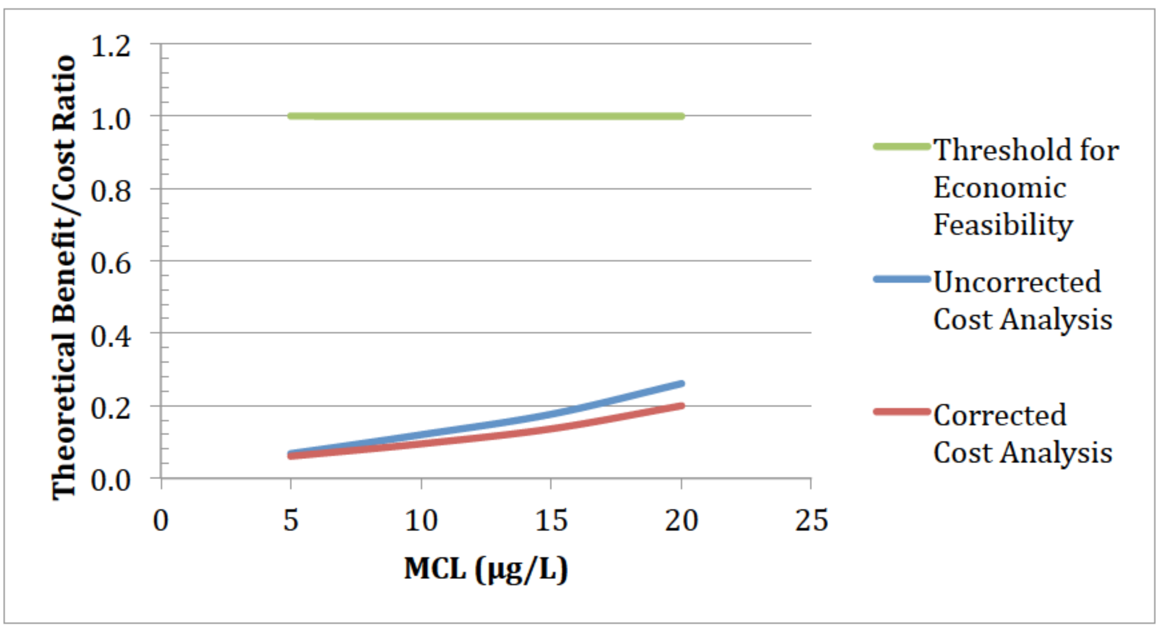


Figure F: Uncorrected and Corrected Theoretical Benefit/Cost Ratios Derived from the WQTS Analysis



E. Household-level effects are crucial but cannot be derived from the WQTS analysis.

To fully appreciate the costs and benefits of a Cr(VI) drinking water standard, they must be expressed at the household level. This is problematic, however. The number of households gaining cancer risk reduction benefits is greater under the WQTS model, but Najm (2013) does not provide estimates of how many households would benefit. Dividing statewide cost or benefit estimates obtained from the WQTS model by the CDPH's number of households covered would grossly overstate cost and benefit per household.

For this reason, no estimates of household-level effects are provided based on the WQTS statewide analysis. Some insight can be gleaned from the WQTS case studies, which is the subject of Section III.

III. Net Benefits and Cost-Effectiveness in the Four WQTS Case Studies

In addition to its statewide analysis, WQTS provides system-specific engineering cost estimates for four water systems that would be required to install treatment under some or all MCLs in the 5 μg/L to 20 μg/L range. These case studies appear to be strictly illustrative; the number of similarly situated water systems is not reported. Nonetheless, these case studies offer useful insights because net benefit and cost-effectiveness can be calculated at the household level based on actual populations, households, and source water Cr(VI) concentrations; there is nothing hypothetical about them.

Table 5 reports annualized benefit and cost per service connection for each MCL, using the corrected WQTS model and specific average reductions in Cr(VI) concentration.[6]

[6] Actual Cr(VI) reductions cannot be discerned from Najm (2013), which appears to adopt a strategy for minimizing compliance costs across multiple wells, so fixed amounts have been used that approximate what various MCLs would achieve given the reported source water concentrations. Note that benefits and costs are both reported with excess precision; at most, two figures in each calculation are significant.

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Table 5: Annualized Benefit and Cost per Household, WQTS Case Studies

MCL Avg Δ Cr(VI)	Coachella Valley [2-21 μg/L]		Woodland [6-30 μg/L]		Oak Trail Mutual [17-19 μg/L]		Tierra Buena #1 [12 μg/L]	
	Benefit	Cost	Benefit	Cost	Benefit	Cost	Benefit	Cost
MCL=5 μg/L Δ −12 μg/L	$29.04	$1,207	$55.07	$1,539	$47.39	$14,692	$41.15	$13,300
MCL=10 μg/L Δ −8 μg/L	$19.36	$744	$36.71	$1,288	$31.59	$14,531	$27.43	$13,182
MCL=15 μg/L Δ −4 μg/L	$9.68	$286	$18.36	$1,190	$15.80	$14,467	$0	$0
MCL=20 μg/L Δ −2 μg/L	$4.84	$98	$9.18	$848	$7.90	$14,467	$0	$0

Population, households, and annualized cost: Najm (2013), Figures 14, 18, 22, and 26; reported source water concentrations are in [square brackets]. Benefits calculated by author based on methodology devised in Belzer (2013). Figures are reported as calculated, but readers are cautioned that they include excess precision.

A. Benefits are in the tens of dollars per household per year.

Because risk is proportional to dose in the OEHHA risk model, benefits decline proportional to reductions in the amount of Cr(VI) removed at less stringent MCLs. Thus, if the average Cr(VI) concentration at 10 μg/L is 8 μg/L instead of 12 μg/L—a decline of 33%—the annualized benefit at 10 μg/L also declines by 33%. Table 5 is structured so that every stepwise increase in the MCL results in a 1/3rd reduction in benefit.

Still, even at the 5 μg/L MCL, the standard at which the benefits of treatment are the greatest, the value of cancer risk reduction across the four case studies ranges from $29 to $55 per year per household. This is equivalent to a line-item on the monthly water bill stating that treatment provides benefits of $2.40 to $4.60 per month.

Setting the MCL below 5 μg/L does not have a material effect on benefits, either. For example, setting the MCL at 0.02 μg/L would theoretically produce $88 in annualized benefit per household among Woodland customers, or $7.30 per month.

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B. *Costs are in the thousands and tens of thousands of dollars per household per year.*

At a 5 μg/L MCL, annualized costs range from $1,200 (Coachella Valley Water District) to $15,000 per household (Oak Trail Mutual).[7] These costs decline as the MCL is made less stringent, but costs do not necessarily decline as fast as benefits. For example, in Woodland choosing 10 μg/L instead of 5 μg/L as the MCL reduces annualized benefits by 33%. However, annualized cost declines only 16%. For the small systems, which are dependent one or two wells, raising the MCL has virtually no effect on cost unless it exempts the water system from having to install treatment.

Annualized cost calculations are illustrated graphically in Figure G. A linear vertical axis is used so that differences among the case studies are fully apparent.

C. *Cost-effectiveness ratios are stratospheric.*

Figure H presents results for the four cases studies in terms of cost-effectiveness ratios, with the implied USEPA threshold given as the horizontal green line. This time, curves must be plotted on a logarithmic vertical scale to ensure visibility, though readers may not fully appreciate the magnitude of differences displayed in logarithms. Options located above the USEPA threshold are economically infeasible.

[7] Tierra Buena #1 has neither cost nor benefit at the 15 μg/L and 20 μg/L MCLs because treatment would not be required.

Figure G: Annualized Theoretical Net Benefit per Household for WQTS Case Studies

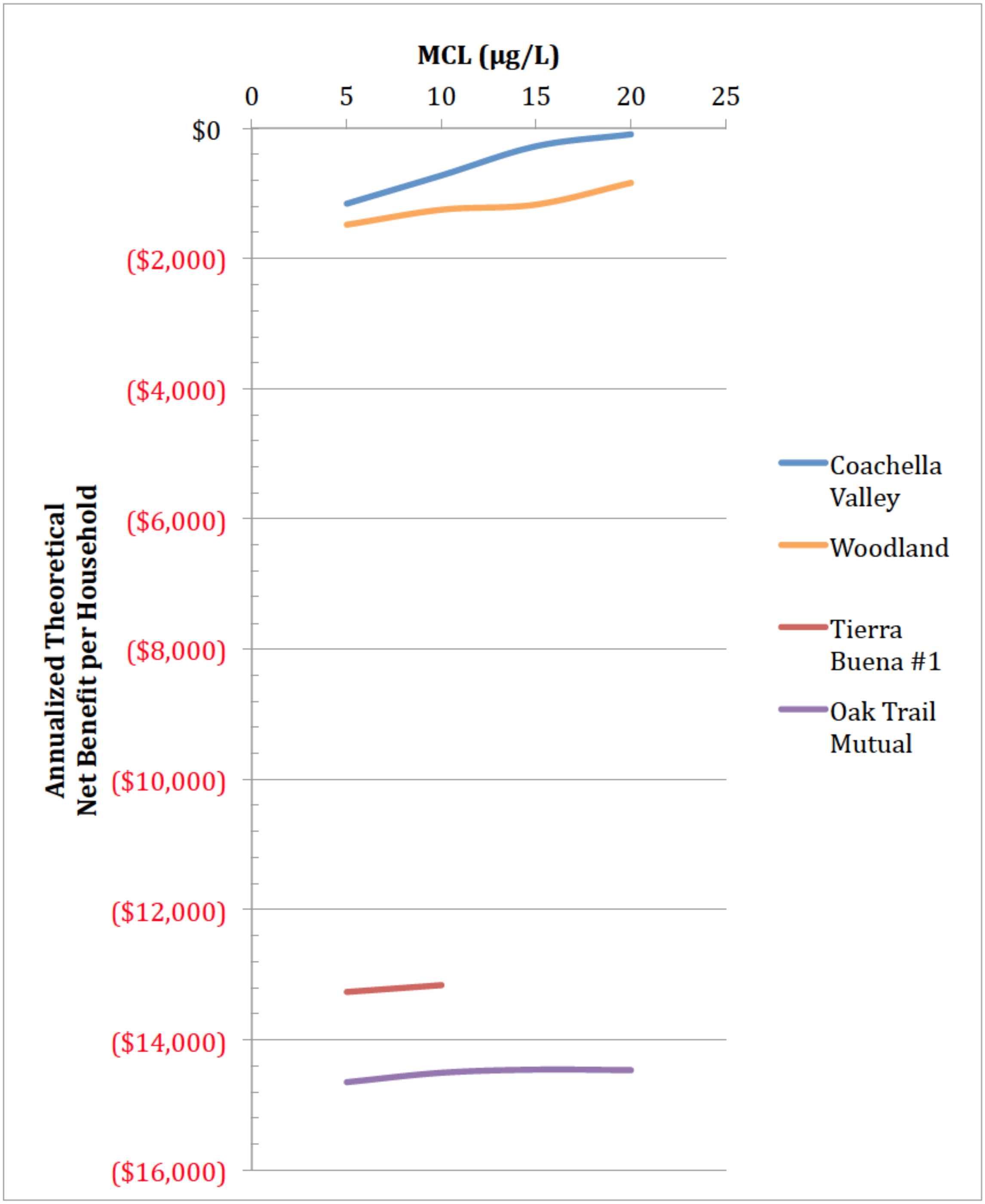

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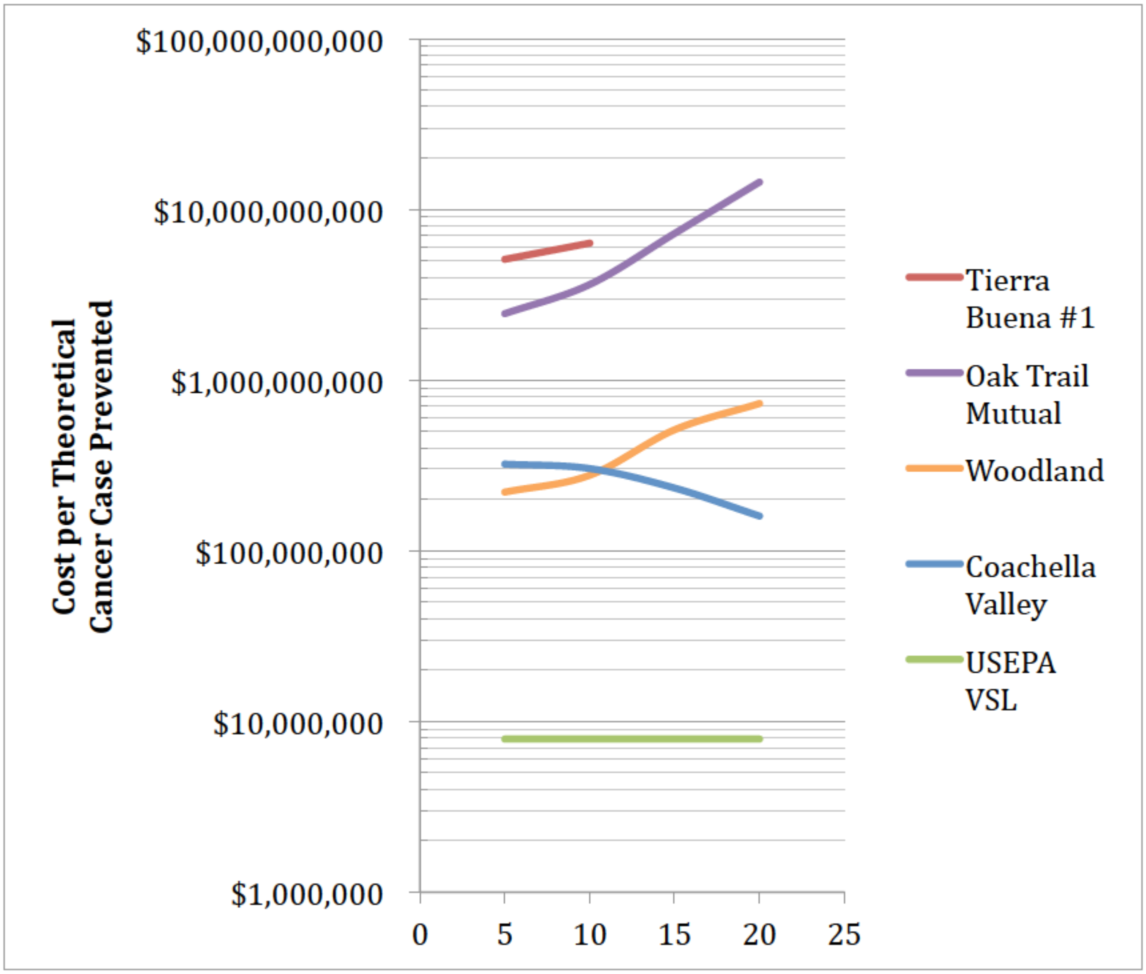
Figure H: Cost-Effectiveness Ratio of Cr(VI) Treatment for WQTS Case Studies



Coachella Valley and Woodland reside in a similar "neighborhood" in which the cost is between $100 million and $1 billion per theoretical cancer case prevented. Coachella Valley's cost-effectiveness ratios range from 20 to 41 times great than the implied USEPA cost-effectiveness threshold. Woodland's range from 28 to 92 times greater.

Oak Trail Mutual and Tierra Buena #1 belong to a different "neighborhood" altogether. Cost-effectiveness ratios range from $2.5 trillion to $14.5 trillion per theoretical cancer case prevented. These ratios are 300 to 1,800 times greater than the implied USEPA cost-effectiveness threshold.

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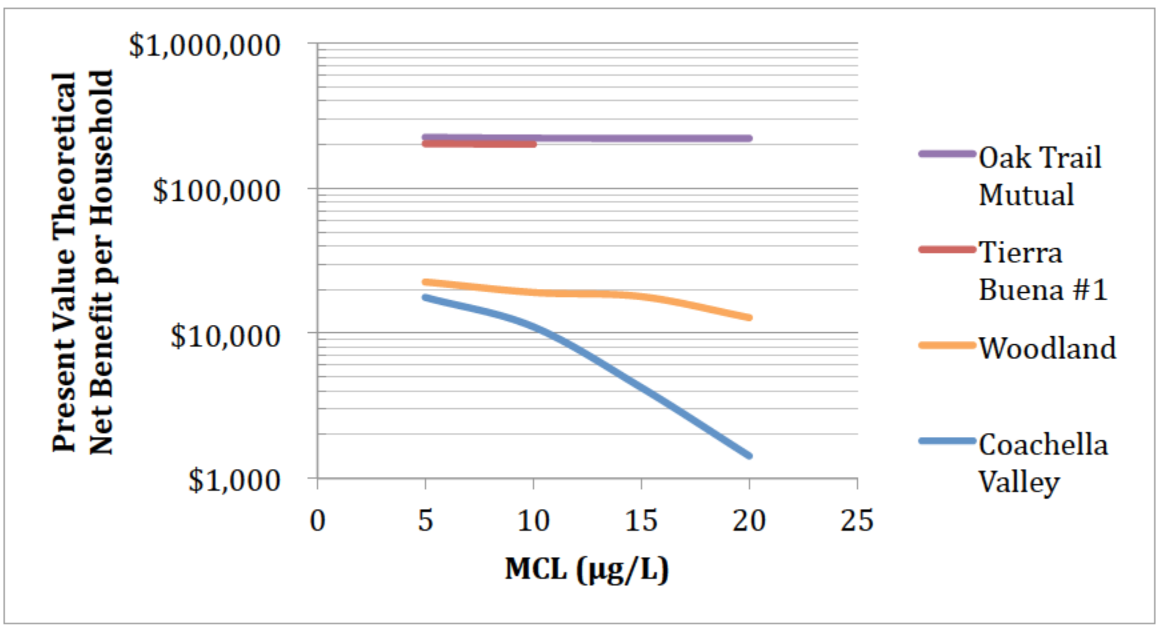
D. Negative net benefits translate into substantial reductions in household net worth.

Negative net benefits endured each and every year cause permanent financial harm. The magnitude of harm is calculated by converting annualized negative net benefits into present value equivalents. Present value is the one-time "stock" that is equivalent to the 100 years of annual "flows." Unless they have a legally permissible and technically feasible way to disconnect from the water system, homeowners can expect the value of their properties to decline by an amount roughly equal to the present value.

Present value theoretical net benefit per household is shown graphically in Figure I. The vertical axis is logarithmic to make the more than 100-fold difference across the four case studies visible. For homeowners served by Oak Trail Mutual or Tierra Buena #1, a binding Cr(VI) MCL would reduce the value of their properties by $200,000 to $225,000.

Figure I: Present Value Theoretical Net Benefits/Reductions in Net Worth per Household for WQTS Case Studies



Isolated net worth declines of this magnitude would be devastating for affected households but not necessarily endanger community sustainability. But community sustainability would become problematic if large net worth declines were systematic. Households would seek alternative water supplies to the extent they were able. This would increase the fraction of fixed cost borne by each household with a service connection. Moreover, every increase in this fraction incentivizes more existing customers to seek alternatives, causing fixed costs to be borne by an ever-shrinking customer base.

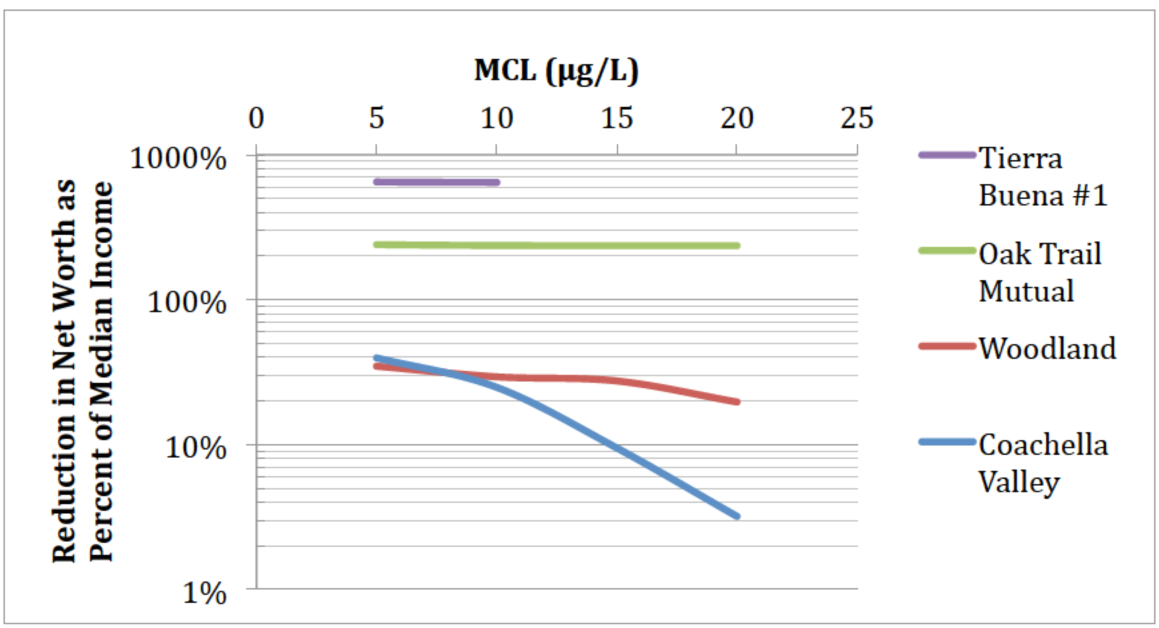
Systematic, large net worth losses in a community also would squeeze local public finances. Communities would have to raise tax rates to maintain the same level of services. Because rising property taxes also are capitalized in real estate values, this would compound the loss in net worth directly resulting from the drinking water standard.

E. Reductions in household net worth are substantial fractions of median household income.

For homeowners in the four case studies, reductions in net worth resulting from a treatment mandate range from serious to devastating. In Coachella Valley, lost net worth among homeowners ranges from 40% of one-year's median household income (at 5 μg/L) to 3% (at 20 μg/L). Among Woodland homeowners, the range is 35% (at 5 μg/L) to 20% (at 20 μg/L). But for Oak Trail Mutual and Tierra Buena #1 homeowners, lost net worth is simply devastating. These reductions range from 240% to 320% of median household income.

Figure J plots lost household net worth as a fraction of median household income for each community.

Figure J: Present Value Theoretical Net Benefits/Reductions in Net Worth per Household for WQTS Case Studies



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