Costs and Benefits of a Hexavalent Chromium Drinking Water Standard in Willows and Dixon, California[1]

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I. Executive Summary

This analysis was commissioned by the California Water Service Company to independently estimate the net benefit in Willows and Dixon, California, of a binding and enforceable primary drinking water standard for hexavalent chromium [Cr(VI)]. The company provided engineering cost estimates, so the task consisted of comparing cost with the theoretical value of benefit resulting from reduced Cr(VI) exposure via drinking water ingestion.

Costs, theoretical benefits, and net theoretical benefits are calculated for three alternative Maximum Contaminant Levels (MCLs)—5, 10 and 20 μg/L.[3] Calculations are made separately for Willows and Dixon, and at both the system and household levels. Cost-effectiveness ratios are derived by dividing annualized (or present value) cost by the annualized (or present value) number of theoretical cancer cases prevented. Benefit/cost ratios are obtained by dividing annualized (or present value) benefit by annualized (or present value) cost.

At the household level, annualized cost exceeds annualized theoretical benefit in both water systems for each alternative MCLs examined. Annualized net theoretical benefit per Willows household is negative: –$270 per year for both 5 μg/L and 10 μg/L; households escape this net income loss at the 20 μg/L MCL because drinking water would not be treated. Annualized net theoretical benefit per

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[1] This independent work was sponsored by the California Water Service Company, which supplies drinking water to 21 cities in California, including Willows and Dixon. Cost estimates were provided by the California Water Service Company; other input data are referenced. The analyses presented belong to the author alone.

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[3] In this report, cancer reduction benefits are described as *theoretical* consistent with the terminology used by California Department of Public Health (2013b), which describes estimated risk reductions calculated using the unit cancer risk factor derived in California Environmental Protection Agency Office of Environmental Health Hazard Assessment (2011).

household in Dixon also is negative, ranging from –$170 per year (at 5 μg/L) to –$210 per year (at 20 μg/L). Net benefits would be substantially more negative if not all cancer cases were assumed to be fatal; the 5-year survival rate for the relevant cancer is 65%.

For both Willows and Dixon, drinking water treatment to reduce cancer risk from Cr(VI) ingestion is a poor investment in protection from cancer. In Willows, Cr(VI) treatment costs $68 million (5 μg/L) to $100 million (10 μg/L) per theoretical cancer case prevented. In Dixon, cost-effectiveness ranges from $36 million (5 μg/L) to $240 million (20 μg/L) per theoretical cancer case prevented. All C-E ratios exceed by far the $7.9 million threshold implied by USEPA's default value for the prevention of a random premature mortality. C-E ratios would rise dramatically if biological cessation lags or less-than-certain causation were taken into account.

Consistent with an economics-based interpretation of *economic feasibility*, all binding MCLs examined are economically infeasible for both Willows and Dixon. This conclusion is insensitive to the most important variable about which there is population heterogeneity: households' preferences for immediate versus delayed cancer risk reduction. The CDPH cost-benefit analysis implicitly assumes that households are indifferent between cancer reductions today and decades hence (i.e., it assumes a 0% discount rate on future benefits). This assumption is the lower bound of what is possible and almost certain to be invalid. If future benefits are discounted at any plausible positive discount rate, all binding MCLs become more economically infeasible.

For each scenario, there are minimum Cr(VI) source concentrations necessary for treatment to become cost-effective. For Willows, these minimum concentrations range from 105 μg/L (MCL = 5 μg/L) to 109 μg/L (MCL = 10 μg/L). For Dixon, they range from 69 μg/L (MCL = 5 μg/L) to 81 μg/L (MCL = 20 μg/L). (Actual break-even concentrations are higher because concentrations this high and higher would be more costly to treat.)

Finally, the OEHHA risk model, which the CDPH cost-benefit analysis assumes is accurate, can be tested for plausibility by comparing its predictions to the actual number of relevant cancers reported by the California Cancer Registry. If OEHHA's model is correct, then Cr(VI) ingestion via drinking water alone is responsible for 59% and 90% of the relevant cancers in Willows and Dixon, respectively.

These fractions seem unlikely to be valid, however, and they are difficult to reconcile with cancer registry data from other counties. For example, if the average source water concentration in Dixon were just 11% higher, more than 100% of all cancers of the small intestine would be attributed to Cr(VI) ingestion via drinking water; no other causes would be even feasible. Similarly incongruous is the fact that, compared with Dixon. the relevant cancer rate is higher in San Francisco County and lower in Yolo County, but there is no Cr(VI) in San Francisco's drinking water and Cr(VI) source water concentrations in Yolo are about the same as in Dixon. For the OEHHA model to be correct, Cr(VI) ingestion via drinking water would have to be responsible for an implausible 97% of the relevant cancers in Yolo County but none of the relevant cancers in San Francisco. That would mean that San Franciscans would have to be exposed to a powerful but unidentified carcinogen that specifically targets the small intestine.

II. Methods

Three alternative enforceable Maximum Contaminant Levels (MCLs) for hexavalent chromium [Cr(VI)] are examined in this analysis: 5, 10, and 20 µg/L. The analysis follows the approach used in the review of the CDPH cost-benefit analysis by Belzer (2013).

Section A provides relevant background information about Willows and Dixon. Section B summarizes engineering cost estimates provided by the water utility. Section C derives estimates of theoretical benefits based on the cost-benefit analysis performed by the California Department of Public Health (CDPH) (2013b) after correction for certain methodological errors. Sections E and F describe the effects of additional corrections that ought to be made for a complete analysis. These corrections are not essential, however, because they do not materially affect the results.

A. Background

1. Willows

The City of Willows is located along Interstate 5 in Glenn County, California, roughly equidistant from Sacramento and Redding, the northernmost city in the Sacramento Valley. Drinking water is provided to 2,744 households from wells with an average Cr(VI) concentration of 15.8 µg/L from natural sources. Median household income for the service area is $42,787. These data are summarized in Table 1.[4]

[4] All statistics, including population, are assumed to remain constant over 100 years. This assumption is necessary to be able to assume a constant scale for the treatment train in years 21, 41, 61, and 81. A more complete analysis could account for alternative population projections.

2. Dixon

The City of Dixon is located along Interstate 80 in the northeastern corner of Solano County, approximately equidistant between Sacramento and Fairfield, the county seat, and about 65 miles northeast of San Francisco. Dixon is largely rural, though in recent years it has become a bedroom suburb of Davis, where a campus of the University of California is located. Reflecting these suburban characteristics, median household income is $66,270 for the service area. Drinking water is provided to 3,275 households from wells with have an average Cr(VI) concentration of 18.1 μg/L from natural sources. These data are summarized in Table 2.

B. Engineering costs

Table 3 and Table 4 summarize engineering cost calculations for Willows and Dixon, respectively. The assumed capital lifetime is 20 years. Because benefits are estimated over 100 years, capital is assumed to be replaced in years 21, 41, 61, and 81. Consistent with standard practice among water utilities, treatment is assumed to be undertaken if the source water concentration exceeds 80% of the MCL, and not undertaken if it is less than this threshold.

C. Theoretical benefits

Despite being described as a *cost-benefit analysis*, the CDPH report lacks a benefit assessment. Moreover, the cost-effectiveness calculations contained therein have several important methodological errors. These errors include (1) calculating cancer cases prevented in a manner inconsistent with the risk model used by the Office of Environmental Health Hazard Assessment (OEHHA) to estimate cancer risk;[5] (2) discounting future costs but not future benefits; (3) using a shorter time horizon for counting accumulated costs than accumulated benefits; (4) failing to account for cessation lags; and (5) failing to account for less-than-certain causation in dose-response. These errors systematically and substantially overstated the benefit of Cr(VI) treatment at every MCL examined; they are discussed and substantially corrected in Belzer (2013).

Errors (1) through (3) are also corrected in this analysis; the implications of errors (4) and (5) are described illustratively because the biologically correct cessation lag is not known and the true probability of causation is a matter of

Alternatively, a decision to install treatment could be postponed until such time as population growth and technological change reduced the cost-effectiveness ratio to an appropriate level.

[5] California Environmental Protection Agency Office of Environmental Health Hazard Assessment (2011).

toxicology, not economics. In any event, correcting errors (4) and (5) is not how much 70-year lifetime exposure is reduced. In steady state, annual cancer risk reduction equals 1/70th of the risk reduction calculated over a 70-year lifetime.

Table 1: Statistics for the Willows, California Service Area

Population Served[1]	7,035
Households Served[1]	2,744
Average Household Size	2.56
Average Source Concentration (μg/L)[1]	15.8
Median Household Income (MHI) of Service Population[1]	$42,787
Percent below ~80% MHI[2,3]	43 %
Percent below ~60% MHI[2,4]	33 %

[1] Personal communication with Tarrah Henrie, Acting Director of Water Quality, California Water Services Company.
[2] U.S. Census Bureau (2013b). 2011 MHI for Willows City = $43,493 ± $3,635.
[3] 80% MHI = $34,230. Figure reported is percent below $35k. Willows meets the CDPH definition for a "disadvantaged community." See CDPH (2013b, PDF p. 82).
[4] 60% MHI = $25,672. Figure reported is percent below $25k.

Table 2: Statistics for the Dixon, California Service Area

Population Served[1]	9,624
Households Served[1]	3,275
Average Household Size	2.94
Average Source Concentration (μg/L)[1]	18.1
Median Household Income (MHI) of Service Population[1]	$66,270
Percent below ~80% MHI[2,3]	34 %
Percent below ~60% MHI[2,4]	20 %

[1] Personal communication with Tarrah Henrie, Acting Director of Water Quality, California Water Services Company.
[2] U.S. Census Bureau (2013b). 2011 MHI for Dixon City = $72,626 ± $4,722.
[3] 80% MHI = $53,106. Figure reported is percent below $50k.
[4] 60% MHI = $39,762. Figure reported is percent below $25k.

Table 3: Capital and O&M Costs for Achieving a 10 μg/L Cr(VI) MCL, Willows, California

Well	Design Capacity (gpm)	Capital Cost	O&M Costs [1]
Station 7	525	$1,583,100	$250,000
Station 8	1,400	$3,125,100	
Station 9	650	$1,836,850	
Total	2,575	$6,545,050	$250,000

[1] Based on treating 1,800 gpm across three treatment plants to achieve 80% of the MCL. Average source water concentration: 15.8 μg/L. Population: 7,035. Households: 2,744. Capital life: 20 years. Source: Tarrah Henrie, Acting Director of Water Quality, California Water Service Company.

Table 4: Capital and O&M Costs for Achieving a 10 μg/L Cr(VI) MCL, Dixon, California

Well	Design Capacity (gpm)	Capital Cost	O&M Costs [2]
Station 7	1,400	$3,039,550	$150,000
Station 8	2,000	$3,608,850	
Total	3,400	$6,648,400	$150,000

[2] Based on treating 1,700 gpm maximum at two treatment plants to achieve 80% of the MCL Average source water concentration: 18.1 μg/L. Population: 9,624. Households: 3,275. Capital life: 20 years. Source: Tarrah Henrie, Acting Director of Water Quality, California Water Service Company.

necessary to demonstrate the economic infeasibility of Cr(VI) drinking water standards between 5 μg/L and 20 μg/L, inclusive.

1. Cancer cases prevented must be calculated in a manner consistent with the OEHHA risk model.

The OEHHA risk model is a linear no-threshold extrapolation from high doses in laboratory animals to low doses in humans. Among other things, the model assumes that every microgram of Cr(VI) ingested poses the same cancer risk per unit of body weight, regardless of when it occurs and the baseline dose to which it is an increment. This means that risk reduction is assumed to proceed in proportion to

However, this annual risk reduction is not realized until the 70th year after the MCL is achieved. During each of the first 70 years of MCL compliance, consumers gain *n*/70^{ths} of the annual cancer risk reduction, where *n* equals the cumulative number of years of exposure reduction that have been achieved through MCL compliance. The annual risk reduction that CDPH assumed would begin immediately cannot be realized until year 70 and beyond.

A cost-benefit analysis must count risk reduction benefits in a manner that is consistent with the underlying risk model upon which the presumptive existence of benefit depends. This does not mean that cost-benefit analysts must assume that the underlying risk model is correct. Indeed, a cost-benefit analysis of the proposed Cr(VI) standard should include separate benefit estimates for a reasonable range of plausible biological risk models. For each such model, benefits must be estimated in a manner consistent with that model.

2. Future cancer cases prevented must be discounted.

Benefit-cost analysis requires that future benefits and costs be discounted using appropriate interest rates. The correct discount rate for cost is the before-tax cost of capital, which CDPH assumes is 7%.[6] In the analysis presented here, 7% is used in the main analysis and a sensitivity analysis is conducted to determine the effects of a lower discount rate (5.6%) suggested by the California Water Service Company.

Like health protection generally, reducing cancer risk is a normal good that people prefer to have today than in the future. Individuals generally discount future risks at rates similar to the rates they use to discount future consumption. The correct discount rate for future benefits is the rate of time preference of water system customers with respect to their tradeoff between reducing cancer risk now or later.[7] It is reasonably expected that all water system customers would prefer to reduce cancer risk now than later. However, the rate at which they would voluntarily exchange current for future risk reductions is likely to vary for a host of reasons, including age, income, wealth, health status, and intrinsic risk aversion; it also may vary over time for the same customer.[8]

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[6] California Department of Public Health (2013b), PDF p. 40.

[7] U.S. Environmental Protection Agency (2010) recommends using a “social discount rate” that implicitly assumes benefits are widely dispersed in the population. Whatever its merits in that context, the case of drinking water is fundamentally different. Costs are borne by, and benefits are obtained by, water system customers, not the public at large. Therefore, it is the private discount rates of a water system’s customers that are dispositive.

[8] U.S. Environmental Protection Agency (2010), p. 7-11.

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Population heterogeneity argues for circumspection about using averages when the actual people involved may have widely varying discount rates. Therefore, this analysis uses the 7% rate that CDPH used to discount future costs in the main analysis, but also adds a sensitivity analysis to examine the effects of alternative discount rates. Three alternative rates are considered; one lower and two greater than 7%.

The lower discount rate (3%) would be most appropriate for households that routinely postpone current consumption, such as by dedicating substantial resources toward college and retirement funds, and rarely or never finance current consumption by borrowing at credit card rates. A 13% rate is used to approximate the 40% of U.S. households that use credit cards to finance some current consumption.[9] Finally, a 30% discount rate is used to represent households with poor credit that borrow heavily to finance current consumption. This rate is roughly the upper-bound interest rates for revolving credit card accounts, but it is much lower than the rates at which some households borrow, such as through pawn shops and payday or auto title lenders.[10]

The key feature of this sensitivity analysis is it takes as given the rates of interest at which different people borrow. It passes no moral judgment on these choices, and instead describes the effects of an enforceable Cr(VI) drinking water standard from their perspective.

3. The same time horizon must be used for both benefits and costs.

The CDPH cost-benefit analysis uses a 20-year time horizon for counting treatment costs. This appears to be a reasonable approximation of the service life of the treatment train. Nonetheless, it significantly understates the true cost of treatment because it ignores all costs accruing after the 20th year. At the 7% discount rate used by the CDPH, every $1 million in cost borne in year 21 is equivalent to $242,000 today.

The CDPH does not explicitly define a time horizon for counting benefits. In practice, however, the CDPH credits an MCL with delivering benefits within the 20-

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[9] 13.11% was the average interest rate charged on credit cards with balances in August 2013. See Board of Governors of the Federal Reserve System (2013), "Terms of Credit". Actual rates often are higher, however. See, e.g., CreditCards.com (2013), showing national average rates exceeding 15% and rates for instant approval averaging 28%.

[10] According to the Federal Trade Commision (2008), interest rates on payday loans greatly exceed 100%. Auto title loans have similar interest rates. These options for people with poor credit tend to be marketed as short term loans, which would make them inappropriate here, but in practice they often become long term loans due to rollover provisions.

year time horizon for cost that do not even begin until the 70th year. That is 855% more undiscounted cancer risk reduction than the OEHHA risk model allows.

This analysis uses a 100-year time horizon for both costs and benefits. A 100-year time horizon is sufficient because both costs and benefits accruing after the 100th year are trivial. At 7%, every $1 million in effects accruing in year 101 is worth about one tenth of one cent today.

D. *Benefits assessment should account for biological cessation lags.*

Every biologically plausible dose-response model for carcinogens recognizes that there is a lag between the reduction of exposure and the reduction of risk. It is therefore methodologically inappropriate to assume that no lag exists.

A benefit assessment should take account of the empirical evidence for alternative lags in the scientific literature,[11] and it is conventional practice to do so at USEPA.[12] Where the literature is insufficient to inform the choice of lag, the proper methodological approach consists of performing a sensitivity analysis of several alternative biologically plausible lags.

Belzer (2013) examined three lags of 5, 10, and 20 years using the CDPH's preferred 7% discount rate. This sensitivity analysis showed that the cost-effectiveness ratio for Cr(VI) treatment increased by about 50% for a 5-year lag, about 100% for a 10-year lag, and about 300% for a 20-year lag. Higher percentage increases would be expected with higher discount rates.

E. *Benefit assessment should account for less-than-certain causality in risk assessment.*

The extrapolation of risk from high to low doses and from rodents to humans is fraught with uncertainty. Normally, this uncertainty cannot be resolved by epidemiological hypothesis testing because the number of cancer cases predicted at environmentally relevant doses is a very small fraction of background. In this case, however, that is not strictly true. The OEHHA risk model predicts that a very high proportion of the observed incidence of cancer of the small intestine is attributable to Cr(VI) ingestion, but these cancers are not correspondingly rare in jurisdictions where Cr(VI) is absent.[13]

More generally, conventional cancer risk assessment methods were never intended to provide objective estimates. Rather, they were designed to be very

[11] Chen and Gibb (2003).

[12] See, e.g., U.S. Environmental Protection Agency (2005).

[13] This is discussed in Section IV.C below.

unlikely to understate the true (but unknown) risk while accepting the near certainty of substantially overestimating risk.[14] However, cost-benefit analysis requires *unbiased* risk estimates—i.e., estimates that are equally likely to under- or overstate the true (but unknown) value. That means the OEHHA unit cancer risk estimate is inherently incompatible with cost-benefit analysis. By relying upon the OEHHA value instead of an unbiased estimate, CDPH overstated both the baseline cancer risk posed by Cr(VI) ingestion and the benefit of treatment that would reduce Cr(VI) exposure.

Biologists may disagree about the true human dose-response relationship at drinking water concentrations, and it is the responsibility of the cost-benefit analyst to capture a reasonable range of biological opinion through sensitivity analysis. It is not appropriate to simply assume that a precautionary risk estimate is unbiased, as the CDPH did in its cost-benefit analysis. By using only the OEHHA unit risk estimate, and not even identifying it as precautionary by design, CDPH implicitly ignores the virtual certainty that OEHHA risk model is not correct. For this reason, the CDPH cost-benefit analysis is inherently misleading, and it understates the true cost-effectiveness of each MCL examined.

In a sensitivity analysis, Belzer (2013, pp. 45-47) derived cost-effectiveness ratios for all probabilities of causation ranging from zero to one. For each of three alternative MCLs (1, 10, and 30 μg/L), readers were able to see that the CDPH assumption yielded the best (i.e., lowest) cost-effectiveness ratio possible. Readers also could determine the approximate cost-effectiveness ratio for any probability of causation of interest. For example, at the proposed 10 μg/L MCL, the C-E ratio for large water systems rose from $60 million to more than $100 million per cancer case if the probability of causation was assumed to be 50%. For small water systems, the cost-effectiveness ratio rose from $600 million to more than $1 billion per cancer case.

F. Value of preventing a random cancer case

To confidently derive benefit estimates, the cost-benefit analyst needs credible, objective empirical evidence concerning the monetary value of preventing a very small risk of the type presumed to be caused by Cr(VI) ingestion via drinking water. When aggregated across a population, this can be converted into a willingness-to-pay for preventing a random cancer case.

[14] See U.S. Environmental Protection Agency Office of the Science Advisor (2004), p. 13. OEHHA describes its PHG as a "health-protective concentration" based on unusually high exposures (i.e., the 95th percentile of drinking water intake). See California Environmental Protection Agency Office of Environmental Health Hazard Assessment (2011), pp. 102-103.

There are numerous factors that go into individuals' willingness-to-pay for risk reduction, such as age, income or wealth, and education. The theoretically appropriate valuation would be obtained from residents of Willows and Dixon served by the public water system, taking account of these communities' population characteristics.

When no community-specific empirical evidence is available, it is reasonable and appropriate to calculate benefits using a credible assumption—or, preferably, a range of credible assumptions if the choice has a material effect on the analysis. In this analysis, the value of preventing a random cancer case is assumed to be reasonably approximated by USEPA's recommended estimate of an individual's willingness-to-pay to prevent a very low probability of premature mortality ($7.9 million), which has an empirical foundation.[15] This is likely to materially overstate the true value because only a fraction of cancer cases is fatal, and thus make net benefits appear larger than they really are. In fact, the 5-year survival rate in California for cancers of the small intestine is 65%,[16] so a more accurate default cost-effectiveness threshold is $2.8 million.

III. Costs, Theoretical Benefits, and Theoretical Net Benefits of Alternative Cr(V) Drinking Water Standards in Willows and Dixon, California

A. Background.

This section summarizes the results of the cost-benefit analysis for Willows and Dixon. Though the two cities differ, household-level costs, theoretical benefits, and theoretical net benefits are quite similar. The subsections below explain the contents of each component of the analysis. Results are reported in Table 5 for Willows and Table 6 for Dixon.

1. Number of theoretical cancer cases prevented.

The number of theoretical cancer cases prevented for each alternative MCL is presented in several different formats: (a) the number of cases per year from Cr(VI) ingestion via drinking water predicted by the OEHHA model; (b) the number of cases per year that the OEHHA model predicts would be eliminated in steady-state; (c) the expected number of actual cases per year derived from the California Cancer Registry, assuming constant countywide risk; and (d) the proportion of actual cases caused by Cr(VI) ingestion via drinking water assuming that the OEHHA risk model

[15] U.S. Environmental Protection Agency (2010), p. 7-16.

[16] National Institutes of Health (2013).

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is correct. Cancer cases are then reported three ways: (e) as present value equivalents, (f) as the number of years before a single case is expected to be prevented system-wide; and (g) as the number of households that must be served by the system for a single cancer case to be prevented in a year. Each statistic provides a different way to look at the same results.

2. Annualized theoretical benefit, cost, and theoretical net benefit.

Annualized cost is the fixed amount that each community must pay every year for 100 years to purchase, install, operate, and maintain the treatment train required to comply with the MCL over a 100-year period. Whereas the CDPH cost-benefit analysis caps these costs after 20 years, implying that they go away after that date, this analysis replaces the capital investment in years 21, 41,61, and 81, and sustains the O&M costs over all 100 years.

Annualized benefit is the fixed number of theoretical cancer cases prevented each year for 100 years that is equivalent to the unequal 70-year stream of rising cases followed by a 30-year stream of constant annual reductions, multiplied by the USEPA default value of preventing a random premature mortality. At the specified discount rate, residents served by the public water system are indifferent between receiving the annualized number of theoretical cases and the actual, uneven stream. Because it is counterfactually assumed that the OEHHA unit risk estimate is unbiased, benefit estimates are exaggerated.

Converting both theoretical benefit and cost into annualized values allows them to be compared consistently. Subtracting annualized cost from annualized theoretical benefit yields annualized net theoretical benefit. This is the fixed gain in welfare (or loss of welfare, if negative) that the community or household captures (or sacrifices) each year for 100 years that is equivalent to the actual but uneven 100-year streams of costs and theoretical benefits.

3. Present value theoretical benefit, cost, and theoretical net benefit.

Present value converts streams into fixed, one-time event equivalents. Present value cost is the fixed amount that each community or household would have to pay up front to fully fund 100 years of annual expenditures on treatment. Present value benefit is the fixed value of theoretical cancer reductions that each community would gain at the outset that is equivalent to the 100-year stream of uneven theoretical cancer case reductions.

Subtracting present value cost from present value theoretical benefit yields present value net theoretical benefit. A positive value implies a one-time increase in community or household wealth. Conversely, a negative value means a one-time

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decrease in wealth. These calculations will overstate true net benefit because benefit is theoretical rather than based on expected value.

4. Theoretical net benefit as a fraction of household income.

A common statistic is the percentage of household income that must be sacrificed to make compliance with an enforceable MCL "affordable." Drinking water regulators use varying percentages as guides. Typically, however, these income percentages include only cost; the value of benefits as not been subtracted. Presumably, this is because benefits could not be adequately quantified and monetized. If benefits have been subtracted, however, then "affordability" calculations have no common-sense meaning. No household would voluntarily spend any fraction of its budget on goods or services that yield nothing of value.

B. Willows

Table 5 provides cost, theoretical benefit, and theoretical net benefit for Willows at both the system and household levels for 5 μg/L and 10 μg/L. No treatment would be installed if the MCL were set at 20 μg/L. Cost and benefit are both discounted at 7%, the discount rate used by the CDPH in its cost-benefit analysis (but only for cost).[17] All calculations are reported with two significant figures to avoid excess precision.

1. Numbers of theoretical cancer cases prevented

Under steady-state conditions, the OEHHA model predicts that Willows experiences 0.076 cancer case per year due to Cr(VI) ingestion in drinking water.[18] Treatment is predicted to reduce that number by 0.037 case (at 5 μg/L) or 0.025 case (at 10 μg/L). The scale of these effects can be seen by noting that, under steady-state conditions, 16,000 to 24,000 households must be covered by the Willows treatment train before a single theoretical cancer case would be expected to be prevented in any one year. Alternatively, it would take 5.7 to 8.7 years of MCL compliance before a single theoretical cancer case would be expected to be prevented within the Willows service area. Based on the California Cancer Registry, Willows is expected to experience 0.13 case per year of cancer of the small intestine. The OEHHA model thus predicts that Cr(VI) ingestion via drinking water is responsible for 59% of these cancers.

The 100-year stream of cancer reductions is equivalent to a discounted present value of 0.17 cancer case for the Willows system, or 0.000014 case per

[17] California Department of Public Health (2013b).

[18] This is the number of cases that would be attributed by the CDPH model.

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household. That these numbers are small is made even more evident when they are monetized.

2. Annualized theoretical benefit, cost, and theoretical net benefit

System-wide annualized theoretical benefit is $97,000 at the 5 μg/L and $64,000 at 10 μg/L MCLs, or $35 and $23 per household, respectively. However, annualized cost is eight to 12 times greater—$830,000 system-wide, or $300 per household. Thus, system-wide annualized net theoretical benefit is –$730,000 for 5 μg/L and –$760,000 for 10 μg/L, or –$270 and –$280 per household.

3. Present value theoretical benefit, cost, and theoretical net benefit

Depending on the MCL, present value theoretical benefit is $1.4 million at 5 μg/L and $910,000 at 10 μg/L. Present value cost is $12 million under either MCL. Thus, present value net theoretical benefit ranges from –$10 million to –$11 million system-wide, or –$3,800 and –$4,000 per household.

4. Theoretical net benefit as a fraction of household income

Neither 5 μg/L nor 10 μg/L is an "affordable" primary drinking water standard in Willows because "affordability" has no common-sense meaning when net benefit is negative. Few, if any, households in Willows would agree that an expenditure of $300 per year to gain benefits valued at $23 to $35 is "affordable."

For the median income Willows household, having to comply with either MCL is equivalent to giving up about 0.6% of income every year. A Willows household meeting the CDPH definitions of "disadvantaged" (income ≤ $34,320) or "severely disadvantaged" (income ≤ $25,672) would have to give up 0.8% to 1.1% of income, respectively. Alternatively, they would have to be compensated by these percentage increases in income to be held harmless from the MCL's deleterious financial effects.

5. Cost-effectiveness and benefit/cost ratios

For both MCLs, the benefit/cost ratio is well below 1.0, the minimum ratio necessary to achieve economic feasibility. For 5 μg/L, this ratio is 0.12, meaning cost exceeds benefit by a factor of eight. For 10 μg/L, this ratio is 0.077, meaning that cost exceeds benefit by a factor of 13.

Cost-effectiveness ratios are $68 million per theoretical cancer case at 5 μg/L and $100 million at 10 μg/L. These ratios are well above the implied USEPA's $7.9 million threshold. As noted previously, this threshold applies to premature mortality, not cancer. If they were adjusted for the 65% relevant 5-year survival rate, the cost-effectiveness ratios would be $100 million and $150 million per theoretical cancer case.

C. Dixon

Table 6 provides cost, theoretical benefit, and theoretical net benefit for Dixon at both the system and household levels for 5, 10 and 20 μg/L MCLs. Costs and benefits are both discounted at 7%, the discount rate used by the CDPH in its cost-benefit analysis (but only for costs).[19] All calculations are reported with two significant figures to avoid excess precision.

1. Numbers of theoretical cancer cases prevented

Under steady-state conditions, the OEHHA model predicts that Dixon experiences 0.12 cancer case per year due to Cr(VI) ingestion in drinking water.[20] Treatment is predicted to reduce that number by 0.061 case (at 5 μg/L) or 0.044 case (at 10 μg/L). The scale of these effects can be seen by noting that 11,000 to 16,000 households must be covered by the Dixon treatment train before a single theoretical cancer case would be expected to be prevented in any one year. Alternatively, it would take 3.5 to 24 years of compliance (depending on the MCL) before a single theoretical cancer case would be expected to be prevented within the Dixon service area.

Based on the California Cancer Registry, Dixon is expected to experience 0.13 case per year of cancer of the small intestine. The OEHHA model predicts that Cr(VI) ingestion via drinking water is responsible for 90% of these cancers. If the average source water concentration exceeded 20 μg/L (the reported average is 18.1 μg/L), the OEHHA risk model would attribute to Cr(VI) ingestion via drinking water more than 100% of the number of cancers of the small intestine expected to occur.

The 100-year stream of cancer reductions is equivalent to a discounted present value ranging from 0.29 case (at 5 μg/L) to 0.043 case (at 20 μg/L) for the Dixon system, or 0.000087 case (at 5 μg/L) to 0.000013 case (at 20 μg/L) per household.

2. Annualized theoretical benefit, cost, and theoretical net benefit

[19] California Department of Public Health (2013b).

[20] The number of cancer cases in Dixon predicted by OEHHA to have been caused by Cr(VI) is 90% of the number of cases in the California Cancer Registry. See Section IV.C for a discussion about the plausibility of this fraction.

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Annualized system-wide theoretical benefit ranges from $24,000 (at 20 μg/L) to $160,000 (at 5 μg/L). At the household level, these values range from $7.20 (at 20 μg/L) to $48 (at 5 μg/L). Annualized cost is fixed at $730,000 ($220 per household) for all MCLs. Annualized net theoretical benefit is thus negative in all cases, ranging from –$570,000 (at 5 μg/L) to –$700,000 (at 20 μg/L) system-wide, or –$170 to –$210 per household.

3. Present value theoretical benefit, cost, and theoretical net benefit

System-wide present value theoretical benefit ranges from $340,000 (at 20 μg/L) to $2.3 million (at 5 μg/L), or $100 to $690 per household. However, present value cost for all MCLs is $10 million system-wide, or $3,200 per household. Thus, theoretical net benefit is negative in all cases, ranging from –$8.1 million (at 5 μg/L) to –$10 million (at 20 μg/L) system-wide, or –$2,500 to –$3,100 per household.

4. Theoretical net benefit as a fraction of household income

None of the three MCLs examined is "affordable" because, as in Willows, "affordability" has no common-sense meaning when net benefit is negative. Households in Dixon are no more likely than households in Willows to voluntarily pay $220 per year to gain benefits valued at between $7 and $48 per year.

For the median income Dixon household, having to comply with these MCLs is equivalent to giving up 0.3% of income every year even after the value of benefits has been subtracted. A Dixon household meeting the CDPH definitions of "disadvantaged" (income ≤ $53,016) or "severely disadvantaged" (income ≤ $39,762) would have to give up 0.3% to 0.5% of income after the value of benefits has been subtracted. Alternatively, they would have to be compensated by these increases in income to be held harmless from the MCL's deleterious financial effects.

5. Cost-effectiveness and benefit/cost ratios

The benefit/cost ratio ranges from a low of 0.032 (at 20 μg/L) to a high of 0.22 (at 5 μg/L). Only ratios exceeding 1.0 are economically feasible investments in cancer prevention. The cost-effectiveness of treatment ranges from $36 million (at 5 μg/L) to $240 million (at 20 μg/L) per theoretical cancer case prevented.

These benefit/cost ratios are five to 30 times greater than the threshold used by USEPA ($7.9 million). As noted previously, this applies to premature mortality, not cancer. If the USEPA threshold were adjusted by the relevant 5-year survival probability, the range of cost-effectiveness ratios would be $100 million to $690 million per theoretical cancer case prevented.

Table 5: Costs, Theoretical Benefits, and Theoretical Net Benefits of Achieving Three Alternative Cr(VI) MCLs: Willows, California [a]

	System-Wide	Per Household	System-Wide	Per Household	System-Wide	Per Household
MCL [Concentration Reduction]	5.0 µg/L [11.8 µg/L]		10.0 µg/L [7.8 µg/L]		20.0 µg/L [0.0 µg/L]	
Cancer Cases/Year						
OEHHA Cases (Background)	0.076	0.000028	0.076	0.000028	0.076	0.000028
OEHHA Cases (Prevented)	0.037	0.000014	0.025	0.0000090	0.0	0.0
Cases in California Registry [c]	*0.13*		*0.13*		*0.13*	
OEHHA Background Cases as Percent of Registry Cases	*59%*		*59%*		*59%*	
Present Value Cancer Cases	0.17	0.000064	0.12	0.000054	0	0
System-Years & Households	5.7	16,000	8.7	24,000	—	
Annualized Benefits	$97,000	$35	$64,000	$23	$0	$0.00
Annualized Cost	$830,000	$300	$830,000	$300	$0	$0.00
Annualized Net Benefits [b]	-$730,000	-$270	-$760,000	-$280	$0	$0.00
Present Value Benefits	$1,400,000	$500	$910,000	$330	$0	$0.00
Present Value Costs	$12,000,000	$4,300	$12,000,000	$4,300	$0	$0.00
Present Value Net Benefits [b]	-$10,000,000	-$3,800	-$11,000,000	-$4,000	$0	$0.00
Net Benefit as Percent of Household Income						
Median HH	-0.6 %		-0.6 %		0.0%	
Disadvantaged HH	-0.8 %		-0.8 %		0.0%	
Severely Disadvantaged HH	-1.0 %		-1.1 %		0.0%	
Cost-Effectiveness Ratio	$68,000,000		$100,000,000		—	
Benefit/Cost Ratio	0.12		0.077		—	

[a] Discount rate = 7%. All results reported with two significant digits. [b] Differences may appear inaccurate due to rounding. [b] California Cancer Registry (2013); 48 cases in 1988-2010 for Colusa, Glenn, and Tehama Counties ÷ 23 years × age-adjusted rate/100,000 (1.83) × population.

Table 6: Costs, Theoretical Benefits, and Theoretical Net Benefits of Achieving Three Alternative Cr(VI) MCLs: Dixon, California [a]

	System-Wide	Per Household	System-Wide	Per Household	System-Wide	Per Household
MCL [Concentration Reduction]	5.0 μg/L [14.1 μg/L]		10.0 μg/L [10.1 μg/L]		20.0 μg/L [2.1 μg/L]	
Cancer Cases/Year						
OEHHA Cases (Background)	0.12	0.000036	0.12	0.000036	0.12	0.000036
OEHHA Cases (Prevented)	0.061	0.000019	0.044	0.000013	0.0091	0.0000028
Cases in California Registry [c]	*0.13*		*0.13*		*0.13*	
OEHHA Background Cases as Percent of Registry Cases	*90%*		*90%*		*90%*	
Present Value Cancer Cases	0.29	0.000087	0.20	0.000063	0.043	0.000013
System-Years & Households	3.5	11,000	4.9	16,000	24	77,000
Annualized Benefits	$160,000	$48	$110,000	$35	$24,000	$7.20
Annualized Cost	$730,000	$220	$730,000	$220	$730,000	$220
Annualized Net Benefits [b]	-$570,000	-$170	-$610,000	-$190	-$700,000	-$210
Present Value Benefits	$2,300,000	$690	$1,600,000	$500	$340,000	$100
Present Value Costs	$10,000,000	$3,200	$10,000,000	$3,200	$10,000,000	$3,200
Present Value Net Benefits [b]	-$8,100,000	-$2,500	-$8,800,000	-$2,700	-$10,000,000	-$3,100
Net Benefit as Percent of Household Income						
Median HH	-0.3 %		-0.3 %		-0.3 %	
Disadvantaged HH	-0.3 %		-0.4 %		-0.4 %	
Severely Disadvantaged HH	-0.4 %		-0.5 %		-0.5 %	
Cost-Effectiveness Ratio	$36,000,000		$51,000,000		$240,000,000	
Benefit/Cost Ratio	0.22		0.16		0.032	

[a] Discount rate = 7%. All results reported with two significant digits. [b] Differences may appear inaccurate due to rounding. [c] California Cancer Registry (2013); 99 cases in 1988-2010 for Solano County ÷ 23 years × age-adjusted rate/100,000 (1.37) × population.

D. Accounting for cessation lag would substantially reduce net benefits.

An accurate portrayal of cancer risk reductions associated with reducing Cr(VI) ingestion via drinking water requires an honest attempt to estimate the biological cessation lag.[21] The CDPH cost-benefit analysis did not even acknowledge the existence of a cessation lag, however, much less include analysis sufficient to explain its significance. Instead, CDPH implicitly made the counterfactual assumption that no cessation lag exists.

Accounting for the alternative cessation lags, such as was done in Belzer (2013), would substantially reduce net theoretical benefit. Because net theoretical benefit is negative at all binding MCLs in both Willows and Dixon, accounting for cessation lag to make net benefits less theoretical would make them substantially more negative.

E. Accounting for less-than-certain causation would further reduce, and possibly eliminate, these benefits.

The CDPH cost-benefit analysis assumes that OEHHA's linear no-threshold model accurately predicts cancer risks in humans caused by ingestion of Cr(VI) at drinking water concentrations. This model may be correct, but there are biological reasons why it also might substantially overstate actual cancer risk. For example, OEHHA's model extrapolates from rodents exposed to as much as 180 mg/L.[22] This is 18,000 times greater than the proposed MCL, and it is reasonable to believe that the incremental biological effect of any dose depends on the baseline dose to which it is added. Further, the OEHHA model assumes that biological response in humans is the same as it is in rats. Section IV.C provides an empirical reason why the OEHHA model may substantially overestimate human cancer risk at environmentally relevant doses.

At a conceptual level, linear no-threshold extrapolation is intended to ensure that low-dose cancer risk in humans is not underestimated, so it has an inherent propensity to overestimate risk.[23] That is, linear no-threshold extrapolation is not intended to produce unbiased risk estimates—i.e., estimates equally likely to over- or understate the true but unknown risk. It is instead an implicit (and generally undisclosed) precautionary risk *managemen*t tool.

Cost-benefit analysis requires unbiased risk assessment to properly compare cancer reduction benefits to costs, however. Precautionary risk assessment methods

[21] U.S. Environmental Protection Agency (2010), p. 7-5.

[22] National Toxicology Program (2008).

[23] U.S. Environmental Protection Agency Office of the Science Advisor (2004), p. 13: "[USEPA's] policy is that risk assessments should not knowingly underestimate or grossly overestimate risks." OEHHA risk assessments use similar methods.

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cause cost-benefit analyses to substantially overstate both baseline risk and the benefit of reducing it. Subtracting *theoretical* benefit from *expected value* cost is especially pernicious because it systematically misleads decision-makers and the public by overstating net benefit, often by a substantial amount.

If less-than-certain causation were taken into account, such as was done in Belzer (2013), the cost-effectiveness ratio would increase in both Willows and Dixon. At the proposed 10 μg/L MCL, a 50% probability of causation would cause the C-E ratio to rise from $79 million to $160 million per cancer case in Willows, and from $40 million to $100 million per cancer case in Dixon.

IV. Other Sensitivity Analyses

Two other sensitivity analyses were performed. One concerns the choice of discount rate; the other seeks to identify the minimum Cr(VI) concentration necessary for net theoretical benefits to be positive.

A. Cost-effectiveness is worse at lower discount rates on future costs.

The California Water Service Company believes it may be able to finance Cr(VI) treatment at a slightly lower interest rate (5.6%) than the 7% rate CDPH assumed in its statewide cost-benefit analysis.[24] The ability to finance at a lower rate is helpful, but it also means that large future costs (such as capital replacements in years 61 and 81) are more expensive in present value terms.[25] If the discount rate on benefits is left unchanged, a lower discount rate used for cost makes net benefit is even more negative.

Table 7 presents alternative household-level costs and net theoretical benefits using a 5.6% discount rate on future costs. (Benefit estimates are, of course, unchanged.)

In Willows, annualized cost declines $20 per household, causing a commensurate $20 increase in annualized net theoretical benefit. Present value cost rises, however, because distant capital replacement costs (e.g.., system replacement in year 81) are higher in present value terms; a larger sum must be invested every year in order to produce the greater income needed to pay these future costs. Thus, present value net theoretical benefit is –$4,600 instead of –$3,900—a difference of –$700. The cost-effectiveness ratio rises from $79 million to $92 million per theoretical cancer case. This means Cr(VI) treatment, which in the main analysis is shown to be a poor investment in health protection, is worse at the lower cost

[24] Personal communication with Tarrah Henrie, Acting Director of Water Quality.

[25] Another way to understand this is a lower borrowing rate implies a smaller return on invested capital, which must be made up by higher annualized payments over the 100-year lifetime.

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discount rate. The proportion of household income lost also increases, but the change is small because net benefit is insensitive to the choice of discount rate on future cost.

In Dixon, annualized cost declines $10 per household; annualized net theoretical benefit increases $20, the difference due to rounding. Present value cost rises $500 because distant costs are more expensive. The cost-effectiveness ratio rises from $51 million to $58 million per theoretical cancer case prevented. As in Willows, Cr(VI) treatment is an even less attractive investment in health protection at the lower cost discount rate. The proportion of household income that is lost also increases, but the change is small because net benefit is insensitive to the choice of cost discount rate.

Table 7: The Effect of a Lower Discount Rate on Future Costs on Household-Level Effects for a 10 µg/L MCL [a]

	Willows		Dixon	
Cost Discount Rate	7%	5.6%	7%	5.6%
Annualized Benefits	$23	$30	$35	$35
Annualized Cost	$300	$280	$220	$210
Annualized Net Benefits	-$280	-$260	-$190	-$170
Present Value Benefits	$330	$430	$490	$490
Present Value Costs	$4,300	$5,000	$3,200	$3,700
Present Value Net Benefits	-$4,000	-$4,700	-$2,700	-$3,200
Net Benefit as Percent of Household Income				
Median HH	-0.6	-0.6%	-0.3%	-0.3%
Disadvantaged HH	-0.8	-0.7%	-0.4%	-0.3%
Severely Disadvantaged HH	-1.1%	-1.0%	-0.5%	-0.4%
C-E Ratio ($ Millions)	$68 m	$120 m	$51 m	$58 m
Benefit/Cost Ratio	0.12	0.07	0.16	0.14

[a] All results reported with two significant digits. Differences may appear inaccurate due to rounding.

B. Very high Cr(VI) concentrations are needed for treatment to yield positive net benefits.

For both water systems, every binding MCL yields negative net theoretical benefit. Compliance makes residents poorer, and thus worse off, even after the value of cancer risk reduction has been subtracted. Of course, if the source concentrations in these systems were higher, more Cr(VI) would be removed and thus more cancer

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risk reduction would be delivered. How high must be the Cr(VI) concentration for the benefit of this additional (theoretical) cancer risk reduction be sufficient to exceed treatment cost?

For simplicity, it is assumed that treatment cost would not increase if the Cr(VI) concentration in source water was higher. For small differences, this assumption is reasonable; in the main analysis, cost is the same for each system irrespective of the MCL, and different amounts of Cr(VI) would be removed. But this assumption certainly fails if the amount of Cr(VI) removed is much greater. For that reason, the results of this sensitivity analysis should be understood as a lower bound on the minimum concentration needed to obtain net benefits.[26]

These minimum source water concentrations are reported in Table 8. For both water systems, these minima rise with the MCL, and would rise more if higher O&M costs were accounted for. In Willows, the minimum source water concentration ranges from 105 to 117 μg/L. In Dixon, the minimum ranges from 69 to 81 μg/L. That these minima are so far above all of the MCLs ever considered (the highest value analyzed by the CDPH is 30 μg/L) underscores how broadly economically infeasible Cr(VI) treatment is as a method of reducing cancer risk.[27]

C. There are sound empirical reasons for believing that the OEHHA risk model substantially overstates cancer risk from Cr(VI) ingestion.

Table 8 also shows that if Cr(VI) source water concentrations were this high, then the OEHHA risk model would have to be incorrect. The reason is that the number of small intestine cancers that attributed by the OEHHA model to Cr(VI) ingestion via drinking water would substantially exceed the actual number of cases reported in the California Cancer Registry. Whereas it is implausible that Cr(VI) ingestion via drinking water is responsible for 59% and 90% of the relevant cancers in Willows and Dixon, respectively, it impossible for Cr(VI) to be responsible for 230% to 410% of the actual number of cases.

For reference, it is useful to know the number of relevant cancer cases that might be reduced by Cr(VI) treatment. This information is available from the California Cancer Registry (2013). From 1988-2010 inclusive, 48 cases of cancer of the small intestine were reported in Glenn, Colusa, and Tehama Counties combined, or on average, 2.1 cases per year. The age-adjusted rate for these counties was 1.83 cases per 100,000, so 0.129 case per year from all causes would be expected in Willows if it is representative of the three counties. Similarly, 99 cancer cases were reported over the same period for Solano County, or on average, 4.3 cases per year.

[26] Higher O&M costs increase the break-even Cr(VI) concentration required to yield positive net benefits.

[27] Cr(VI) concentrations this high would be irreconcilable with the OEHHA risk model

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The age-adjusted rate for Solano County was 1.37 per 100,000, so 0.132 case per year from all causes would be expected in the Dixon service area if it is representative of the county.

Based on the OEHHA risk model, Cr(VI) in drinking water is responsible for 59% and 90% of all small intestine cancers in Willows and Dixon, respectively. This implies that Cr(VI) ingestion is not just one cause of small intestine cancer; it is the predominant cause. That implication is problematic for several reasons.

First, Cr(VI) would have to be a relatively potent oral carcinogen such that small intestine cancers were notably associated with high (e.g., occupational) exposure to Cr(VI). But OEHHA could not find credible evidence of elevated cancer risk from ingestion through occupational exposure.[28] Neither USEPA (2013) nor the National Toxicology Program (2011) have been able to do so, either. If ingestion via drinking water is responsible for up to 90% of relevant cancers, then there cannot be any other significant source of exposure by the ingestion pathway and it is unclear why epidemiologists have not detected it.[29]

Second, cancer of the small intestine occurs with equal or greater frequency in jurisdictions where Cr(VI) ingestion via drinking water is negligible or nonexistent. For example, the rate per 100,000 in San Francisco is 1.40 (i.e., higher than Solano County) but Cr(VI) is not found in its drinking water. If Cr(VI) is responsible for 90% of small intestine cancers in Solano county, and residents of San Francisco experience a higher cancer rate but have no Cr(VI) exposure via drinking water, then it must be true that San Franciscans are exposed to some other carcinogen that is responsible for an even greater risk of cancer of the small intestine.

Third, some California counties with relatively low small intestine cancer rates have relatively high Cr(VI) concentrations in their drinking water. For example, the City of Woodland has a reported average Cr(VI) concentration of 18 μg/L,[30] but the California Cancer Registry (2013) reports that Yolo County (Woodland is its county seat) has the second lowest small intestine cancer rate of all California counties (1.27 per 100,000). But if the implied Solano County cancer rate from Cr(VI)—1.37 x 90% = 1.23 per 100,000)—is applied to Yolo County, then Cr(VI) is responsible for 97% of all cancers of the small intestine in Yolo County.

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[28] California Environmental Protection Agency Office of Environmental Health Hazard Assessment (2011), p. 104.

[29] OEHHA (2011), p. 101 assumes that 20% of Cr(VI) ingestion comes from sources other than drinking water. This assumption is inconsistent with drinking water being responsible for 90% of all relevant cancers.

[30] Najm (2013), p. 13.

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In short, the OEHHA risk model appears to significantly overstate the cancer risk posed by ingestion of Cr(VI) via drinking water. Indeed, the amount by which the OEHHA model appears to overstate cancer risk is so great that it is essentially refuted by routinely collected cancer incidence statistics.

Table 8: Minimum Cr(VI) Concentrations for Positive Net Benefits at Three Alternative MCLs (μg/L) and Implied Percent of Reported Small Intestine Cancers that Would Have to Be Caused by Cr(VI) Ingestion via Drinking Water

Water System	**Alternative MCL** *[% of Observed Cases Caused by Cr(VI) Ingestion via Drinking Water]*		
	5 μg/L	10 μg/L	20 μg/L
Willows	**105 μg/L** *[250%]*	**109 μg/L** *[240%]*	—
Dixon	**69 μg/L** *[230%]*	**73 μg/L** *[370%]*	**81 μg/L** *[410%]*

V. Summary and Conclusions

This analysis leads to a number of conclusions about the costs, benefits, and cost-effectiveness of enforceable drinking water standards for Cr(VI) in Willows and Dixon. These conclusions are consistent with the inference that standards within the range examined are economically infeasible for households in these cities that obtain their drinking water from the California Water Service Company.

A. In both Willows and Dixon, drinking water treatment to reduce cancer risk from Cr(V) ingestion is a poor investment in health protection.

Annualized cost exceeds annualized theoretical benefit for any of the alternative MCLs examined in both cities. In Willows, annualized net theoretical benefit ranges from –$270 (5 μg/L) to –$280 (10 μg/L) per household; Willows households escape this net income loss at the 20 μg/L MCL only because drinking water would not be treated. In Dixon, annualized net theoretical benefit ranges from –$170 (5 μg/L) to –$210 (20 μg/L).

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For the residents of both cities, drinking water treatment to reduce cancer risk from Cr(VI) ingestion is a poor investment in health protection. In Willows, it costs $68 million to $100 per theoretical cancer case prevented. In Dixon, the C-E ratio ranges from $36 million to $240 million. All C-E ratios far exceed the cost-effectiveness threshold implied by USEPA's default value for the prevention of a random premature mortality. Adjusting for the 65% 5-year survival rate for cancer of the small intestine, the C-E ratio in Willows ranges from $190 million to $290 million per theoretical cancer case. In Dixon, the adjusted C-E ratio ranges from $100 million to $690 million per theoretical cancer case prevented. These ratios would rise dramatically if cessation lags or less-than-certain causation were taken into account.

B. Promulgating a primary drinking water standard for Cr(VI) will make residents of Willows and Dixon poorer and adversely effect real estate values.

Negative net benefits mean that the promulgation of a binding and enforceable Cr(VI) drinking water standard in the range examined (or below) would make Willows and Dixon households unambiguously worse off. Annualized income losses may appear to be small, but they add up over time with predictably adverse consequences. For Willows, the present value of this stream of net income losses is about $3,900 per household. For Dixon, present value net income losses per household range from $2,500 (at 5 μg/L) to $3,100 (at 20 μg/L).

These income losses are tied to water system connections, so they will be manifest as reductions in the value of community real estate, including homes and apartments. The median value of owner-occupied homes in Willows and Dixon, respectively, is about $227,000 and $344,000.[31] The net cost of a binding Cr(VI) drinking water standard can be expected to be capitalized into real estate values. Median home values should decline by 1.7% in Willows and 0.7% to 0.9% in Dixon as buyers bid prices down to account for the higher cost of ownership.

C. Under any rational definition, a primary drinking water standard for Cr(VI) is economically infeasible in Willows and Dixon.

Using an economics-based definition, an alternative or a decision is *economically feasible* if and only if the benefits that accrue exceed the costs that must be borne to secure them. This is how economic feasibility is defined by reputable dictionaries[32] and California state agencies other than the CDPH.[33]

[31] U.S. Census Bureau (2013a).

[32] See, e.g., the Cambridge Business English Dictionary defines *economic feasibility* as "the degree to which the economic advantages of something to be made, done, or achieved are greater

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The net benefit and cost-effectiveness ratio calculations in Section IV unambiguously show that all of the alternative MCLs considered here are economically infeasible for Willows and Dixon. If properly informed, no resident of Willows or Dixon would voluntarily purchase treatment to obtain the reduction of theoretical cancer risk hypothesized by OEHHA to be associated with Cr(VI) ingestion. Refusal to pay would only intensify if cancer risk was characterized in unbiased rather than theoretical (i.e., speculative) terms.

A substitute for an economics-based definition economic feasibility that is popular among regulatory agencies is the notion of *affordability.* A regulatory standard is deemed to be *affordable* if it costs less than a designated *affordability threshold*, expressed as a percentage of median household income, less the share of income already expended in the baseline. Thus, *affordability* requires that expenditures for compliance with primary drinking water regulations not exceed a defined *expenditure margin*. The *affordability threshold* is typically set at 2.5%,[34] though there are important exceptions,[35] and no consideration is given to households whose income is substantially below the median.[36]

This definition of *affordability* is inherently circular. A standard is deemed *affordable* if it costs less than the *affordability margin,* which is arbitrarily defined. Indeed, there is no objective basis for choosing either the *affordability margin* or the *affordability threshold*. Both contain no economic content because they ignore the benefit that a presumably "affordable" expenditure would produce.

This lack of economic content appears to be historically tied to what are now decades-old judgments concerning the ratio of user fees to household income that investors would accept for underwriting revenue bonds to fund drinking water treatment. That is, neither the *affordability threshold* nor the *affordability margin*

than the economic costs." See http://dictionary.cambridge.org/us/dictionary/business-english/economic-feasibility.

33 California Department of Water Resources (2008), p. 5; De Souza, Medellín-Azuara, Burley, et al. (2011), p. 3-16.

34 U.S. Environmental Protection Agency (2012). In 2002, Congress directed USEPA to review its criteria and methodology. That review apparently is not yet complete.

35 Small California water systems may be allowed to install point-of-entry/point-of-use treatment systems if centralized treatment costs more than 1.5% of median household income, but only as a temporary emergency measure. *See* California Department of Public Health (2013a). Of course, the rule begs the question why *affordability* is used in lieu of *economic feasibility*, and why 1.5% (never mind 2.5%) is an appropriate threshold for *affordability*.

36 *See* U.S. Environmental Protection Agency Science Advisory Board (2002), which recommended that USEPA give attention to disadvantaged communities and households by considering measures other than median income, and percentages less than 2.5%.

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ever had anything to do with what constituted an *economically feasible* investment in health protection.[37]

These peculiar features make *affordability* an odd proxy for the statutory criterion of *economic feasibility* that CDPH must take into account. It is also counterintuitive. No household would rationally consider an expenditure *affordable* merely because it comprised a suitably small percentage of income without regard for the benefit expected to be gained. If benefit is large, households would happily commit much more than 2.5% of income. But it is unreasonable to expect a household to voluntarily pay anything at all above the monetized value of the benefit obtained. *Affordability* is not a synonym for *economic feasibility*; it is a politically determined substitute.

This returns us to the statutory criterion of *economic feasibility*. The only economically sensible definition of this criterion is that benefits must exceed costs, where both benefits and costs are objectively estimated (i.e., without bias). Under that definition, centralized Cr(VI) treatment is economically infeasible in Willows and Dixon under every plausible circumstance.

D. Conventional "affordability" calculations might be reasonable if benefits are abstract, but they make no sense in cases where benefits can be monetized and/or quantified.

One can imagine using affordability criteria in cases where benefits are difficult or impossible to quantify, or perhaps even grasp intuitively. This circumstance might arise, for example, if the benefit to be obtained was conceptually abstract, thus making quantification intuitively challenging or technically infeasible.

That scenario does not apply, however, to the establishment of a primary drinking water standard for a substance, such as Cr(VI), for which a dose-response relationship can be quantified and the health endpoint is easily understood. The presumed benefit to be obtained from Cr(VI)—cancer risk reduction—is easy to understand and readily susceptible to quantification and monetization. For this reason, the use of a conventional, cost-based affordability metric makes no sense in evaluating the merits of alternative Cr(VI) MCLs. Treatment to reduce Cr(VI) concentration yields either a net benefit or a net cost. If compliance with a Cr(VI) standard yields a net cost, then it is per se *unaffordable* and *economically infeasible* from the perspective of any rational decision-maker. This includes both households served by public water systems and regulators charged with acting in their best interests.

[37] Congressional Budget Office (2002), p. 53.

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E. The OEEHA risk model appears to substantially overstate cancer risk.

It has been shown that if the OEHHA risk model is correct, then Cr(VI) ingestion via drinking water is responsible for a very large fraction of cancers of the small intestine—90% of them, in the case of Dixon. This prediction is highly implausible given the absence of credible evidence from high exposure settings, such as historic occupational exposure. It stretches plausibility to or beyond the breaking point when it is noted that Cr(VI) concentrations in drinking water do not appear to predict small intestine cancer rates. Yolo County, which is geographically adjacent to Dixon, has similar Cr(VI) concentrations but the second lowest relevant cancer rate among California counties. San Francisco, which has no Cr(VI) in its drinking water, has a cancer rate higher than Solano County, where Dixon is located.

These facts about cancer incidence are very difficult to reconcile with OEHHA's risk model. If Cr(VI) concentrations in Willows and (especially) Dixon were just a little but higher, the OEHHA risk model would attribute more cancer cases to Cr(VI) ingestion via drinking water than are actually recorded. Under that scenario, it would be impossible to reconcile the OEHHA model with empirical evidence.

VI. References

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