



Identifying Meaningful Opportunities for Drinking Water Health Risk Reduction in the United States [Project #4310]

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The 1996 Amendments of the Safe Drinking Water Act (SDWA) requires that new drinking water regulations exhibit sufficient meaningful risk reduction. As called for in the SDWA Section 1412(b)(1)(A) General Authority, "...in the sole judgment of the Administrator, regulation of such contaminant presents a meaningful opportunity for health risk reduction for persons served by public water systems." To date, more than 90 individual contaminants have been regulated under the SDWA, and this regulatory approach has served drinking water consumers by protecting them from contaminants that can threaten water systems and pose risks to human health.

With improvements in analytical techniques, the list of contaminants detected in water has grown significantly. With this new information comes increased concern regarding the health impact of these contaminants, and how the nation should focus its resources to best serve the interests of public health. This project strives to provide a comparative health impact assessment tool for evaluating the relative health impact of contaminants in drinking water.

OBJECTIVES

The objective of Water Research Foundation project #4310 was to develop a tool that helps water utilities prioritize health risk reduction strategies for contaminants of concern and effectively communicate these relative health impacts to customers and policy makers. The final product is also intended to provide input to the national policy discussion on how to most effectively provide meaningful opportunities for health risk reduction in drinking water, drawing on national and historical estimates of drinking water health impacts generated with this tool. Finally, testing of the tool at utilities was included to determine applicability at the local level.

BACKGROUND

The role of drinking water treatment in protecting public health was dramatic in the 1900–1930 time period as the science of microbiology evolved. During this period, larger urban U.S. utilities incorporated filtration and disinfection processes into their facilities and witnessed a

dramatic reduction in typhoid fever and other microbial diseases. The benefits and costs of drinking water improvements were likewise dramatic, with an estimated 1,500 deaths averted annually at cost of \$500 (in 2003 dollars) per death averted and a benefit:cost ratio of 23:1 (Cutler & Miller, 2004). In contrast, recent regulations for arsenic are estimated to reduce the risk of arsenic-related deaths by a total of less than 60 per year at a cost of greater than \$4 million per death averted at a benefit:cost ratio of less than 1:1 (USEPA, 2000k). This illustrates the dramatic levels of drinking water-related risk reduction accomplished over the past 100 years, and the dramatically increased incremental cost of health risk reduction today.

As the health risks associated with drinking water have been reduced over the past 100 years, the benefits associated with additional improvements are much more difficult to observe compared to the benefits associated with microbial risk reduction in the past. The contribution of drinking water to the total burden of disease from all sources (food, air, human contact, recreational water, etc.) is very difficult to determine. Thus, the uncertainties associated with setting priorities for drinking water system improvements and national regulatory policies are significant and poorly characterized. In this uncertain environment, water utilities are faced with decisions regarding costly treatment plant upgrades to meet new and potential emerging health concerns, while also struggling to address other fiscally challenging issues such as the renewal of aging infrastructure.

Coincident with the need to prioritize facility improvements is the need to effectively communicate the health-related benefit:cost issues with customers and policy makers. In the absence of clearly defined health risks associated with the typically low level of contaminants associated with drinking water in the United States today, judgment is often required in setting priorities for resource allocation and regulation. This judgment is influenced by public concern regarding potential disease and adverse health impacts.

Noting that Americans are living longer, healthier lives and are much more likely to die of a chronic illness with lifetime exposure (such as cancer or heart disease) than from an acute disease such as AGI from microbial contaminants, it is understandable that concern over cancer-related death elevates the concern over the presence of any carcinogen detected in drinking water. What is often misunderstood, however, is that the risk of cancer-related disease being contracted through drinking water is typically very low and is largely unquantifiable by today's epidemiological studies. Thus, despite the relatively low level of contaminants detected in public water supplies, a prevailing concern with cancer-related contaminants often drives discussions with regards to regulation and treatment alternatives.

Against this background, this project seeks to provide a tool that allows all drinking water related health risks to be compared and prioritized. To accomplish this, the health impact of each contaminant-related disease needs to be assessed by a common metric. For this purpose, the "Disability Adjusted Life Year" (DALY) metric developed by the World Health Organization (WHO) was selected as the primary factor used to provide a common metric for relative health impacts. The DALY, along with exposure data and toxicity, formed the basis of the Relative Health Indicator (RHI) developed and used in this project as the metric for relative health impact comparison.

APPROACH

The research team evaluated various cumulative risk methodologies available today applicable for drinking water. The various methodologies were analyzed, considering limitations

posed by uncertainties in risk and exposure data. Both quantitative and semi-quantitative approaches were considered. Ultimately, a hybrid approach was established that allows the use of available information for exposure, toxicity, and disease severity in developing the Relative Health Indicator (RHI) metric within a spreadsheet-based model.

The RHI estimates were developed as the sum of two components: non-cancer RHI and cancer RHI. Non-cancer RHIs were calculated based on contaminant toxicity values (calculated using oral reference doses and uncertainty factors), non-cancer severity scores, and exposure estimates. Cancer RHIs for carcinogenic contaminants were calculated based on cancer slope factors, cancer severity, and exposure estimates.

Contaminant exposure data were provided from utility data and national databases. For chemical contaminants, toxicity data (reference dose) from EPA's Integrated Risk Information System (IRIS) were used as the primary indicator of health impact related to exposure. For those contaminants where IRIS data were not available, estimates for the reference dose were developed based on available toxicity data.

For microbial risk, indicators were developed based on available utility data (Total Coliform Rule (TCR) data, sourcewater data, level of treatment provided, and operational data from the distribution system). These factors were calibrated against the national estimate for Acute Gastrointestinal Disease (AGI). Assumptions required for developing the final RHI model were detailed to allow for further future refinement of the model.

Based on this methodology, the following analyses were performed:

- **Describe the current national drinking water risk cup:** The cumulative risk from regulated and select unregulated chemical and microbiological drinking water contaminants across water systems in the United States was estimated in terms of RHI. Publically available data from a number of EPA and other national databases were used to develop the risk estimates. In addition to the national drinking water risk cup, analyses were also performed for select subcategories of public water systems including groundwater systems, surface water and groundwater under the influence of surface water systems, very large systems, small systems, etc.
- **Illustrate drinking water risk reduction achieved over time:** A historical relative risk index graphic was developed to describe the impact of various drinking water quality improvements over time, such that they can be put into historical perspective. Significant advances in the treatment of drinking water such as chlorination and filtration, and the advent of the Safe Drinking Water Act (SDWA) were correlated with the corresponding reduction or change in health risk impacts associated with drinking water.
- **Prepare and validate utility case studies applying the developed methodology:** Case studies were prepared such that the RHI spreadsheet model could be demonstrated across a wide range of utility data and conditions including geography, utility size, source water, and water quality.

RESULTS/CONCLUSIONS

The hybrid cumulative risk methodology developed was tailored specifically for use by water utilities. Using data commonly available at the utility level, utility personnel can determine the contaminants that pose the greatest relative health risk (based on the RHI metric) in their treated drinking water, and can determine the effectiveness of various treatment alternatives in reducing overall risks in water.

The current national drinking water risk cup — meaning the total risk associated with consuming drinking water expressed as RHI and developed based on the cumulative risk methodology — indicates that microbiological contaminants pose the greatest health risk in the nation's drinking waters. Microbiological risks are shown to be greater than RHI-based risks from individual inorganic or organic contaminants and disinfection byproducts (DBPs). Microbiological contaminants pose the greatest risk for water systems of all size categories and all source water types, regardless of whether the system is disinfected or not. For surface water systems, in general, DBPs are the highest risk contributors after microbes, whereas for groundwater systems, arsenic, nitrate, radionuclides, etc. can pose elevated risks at the local level, alongside microbes and DBPs.

Some preliminary calculations were also done to compare drinking water risks to other societal risks. Taking arsenic in drinking water at a level of 10 µg/L, DALY values were calculated and compared to RHI values. Non-cancer RHI from arsenic is 1.78 E-4, and corresponds to a DALY value of 4.5 days of life lost due to disability over a 70 year lifetime. Cancer RHI from arsenic is 1.24 E-4, and corresponds to a DALY value of 3.1 days of life lost due to disability over a 70 year lifetime. Further, these DALY values were then compared to the World Health Organization's published total DALY estimates from all disease sources for "high income Americas world region". Based on the project's analysis, DALY's from arsenic in drinking water (at 10 µg/L across the population) amounts to 0.2% of total DALYs. The details of the calculations are provided at the end of Chapter 2.

The historical risk reduction analysis demonstrated that in the last 100 years, microbial risk has been reduced by more than three orders of magnitude, attributed to water treatment advances such as disinfection and filtration. Relative risks from some inorganic contaminants, such as arsenic, nitrate, or chromium have remained more or less unchanged, increased marginally due to agricultural or other anthropogenic activities, or decreased due to treatment/removal as a result of regulations. For some contaminants such as DBPs, the historical risk was zero prior to the advent of disinfection, and then increased rapidly as chlorination became more prevalent. In recent years, DBP risks have decreased due to DBP regulations.

The utility case studies were used to demonstrate and refine the cumulative risk assessment methodology. Utility case study results were generally very low and compared well with each other, even though, with the exception of microbes, the highest RHI contributing contaminants were different for each utility and varied based on their source water qualities and treatment trains. The overall risks for all of the utilities' waters studied in this project were lower than corresponding national values. This was anticipated because most of the case study utilities were large water systems with advanced treatment processes at their facilities. Similar to national estimates, microbiological contaminants posed the highest risk in all the case study utilities' waters. DBPs and inorganic contaminants such as arsenic, nitrate, chromium, and radionuclides were the other risk contributors in these case studies, depending on whether the utility uses surface water, groundwater, or both.

APPLICATIONS/RECOMMENDATIONS/ FUTURE WORK

The [RHI Calculator Spreadsheet Model Tool](#) is anticipated to be useful to water utilities in multiple ways. Beyond compliance with MCLs, this tool allows utilities to identify contaminants in their treated drinking water that pose the highest remaining health risks in terms

of RHI. Utilities may also compare RHI values from various water sources, or the effectiveness of various potential treatment technologies using this tool.

This project is the first of its kind in attempting to develop a single health-based metric to reflect all drinking water contaminants and related adverse health end-points. As such, it can be useful for water utility managers and engineers needing context for where drinking water risks exist and how they may be prioritized. There are tremendous opportunities for future work resulting from this project. Future work includes refining the methodology and addressing some of the assumptions and simplifications made as part of the model development. Further refinement is particularly needed for the microbial RHI model (e.g., calibration, incorporation of microbial densities, etc.). Additionally, sensitivity analysis, development of an infrastructure improvement prioritization tool, and communication tools, are important next steps resulting from this project, as discussed in Chapter 7.

RESEARCH PARTNERS:

- American Water Works Association
- Drinking Water Inspectorate

Table ES.1 Strengths, weaknesses, and potential pit-falls of each of the Cr(VI) removal technologies evaluated in this study

	Strengths	Weaknesses	Potential Pit-Falls
SBA Treatment	<ul style="list-style-type: none"> • Mature technology, commonly used for groundwater treatment for the removal of nitrate, arsenic, and other inorganics. • No pH adjustment is required as is required with WBA treatment. • If brine treatment is not required, then no hazardous chemicals would have to be transported to, stored, and used at the site (other than chlorine). • SBA treatment is likely to be less costly than either WBA or RCF treatment. 	<ul style="list-style-type: none"> • Cr(VI) removal deteriorates with increasing sulfate and nitrate concentrations. • It generates a high-TDS waste brine solution that has very limited disposal options in most applications. • If Cr(VI) is removed from the waste brine before the brine can be disposed, then the water system will generate solid waste that is likely to be a non-RCRA California hazardous waste. 	<ul style="list-style-type: none"> • The entire treatment system operation depends on the ability to dispose of the waste brine without limitations. • Water agencies considering SBA treatment should carefully evaluate the viability and long term reliability of the waste brine disposal option being considered. • If the waste brine is to be hauled off site, the truck traffic required may become prohibitive.
RCF Treatment	<ul style="list-style-type: none"> • Requires no pH adjustment as is required with WBA treatment. • Does not generate a high-TDS salt brine with challenging disposal options as is the case with SBA treatment. • The treatment components are non-proprietary and are commonly used in groundwater treatment. • Waste backwash water could be discharged to a sanitary sewer under most conditions (assuming availability of sewer connection and hydraulic capacity). 	<ul style="list-style-type: none"> • Requires a larger footprint than either SBA or WBA treatment systems. • Multiple treatment chemicals are added, including ferrous iron, coagulant, and chlorine. • It generates a significantly larger volume of waste flow compared to SBA or WBA (likely between 2% and 5% of well production). • If sewer discharge is not available, the waste backwash water will require further treatment to separate the precipitated Cr into a solid waste, and recycle the recovered water back to the head of the plant. The solid waste will likely be classified as non-RCRA California hazardous waste. 	<ul style="list-style-type: none"> • No known pitfalls.
WBA Treatment	<ul style="list-style-type: none"> • Minimal liquid residuals to deal with (limited to backwash water during resin installation) • Requires the least operator attention compared to either SBA or RCF treatment. • No additional hazardous chemicals would have to be transported to, stored and used at the site (assuming CO₂ and air-stripping are used for pH adjustment) • Less “moving parts” than either SBA or RCF, and thus likely to have lower maintenance requirements. 	<ul style="list-style-type: none"> • Requires pH suppression to 6.0 for optimum process performance. The CO₂ dose required to achieve this pH is estimated at about 2 times the alkalinity of the water. • Air-stripping is required to raise the pH of the treated water to acceptable levels (7.5 to 8.0), which generates significant noise levels. • If uranium is present in the water, it will be removed by the resin. The presence of uranium on the spent resin will limit its disposal options, and increase its disposal cost. • Depending on the CO₂ usage rate and Cr(VI) level in the groundwater, WBA is likely to be a more costly treatment system than either SBA or RCF. 	<ul style="list-style-type: none"> • Depending on the alkalinity of the water, and the size of the treatment system, the frequency of CO₂ truck deliveries to the treatment site may become prohibitive, especially if the site is located within residential neighborhoods.