# HealthStream

**Issue 101** June 2021

**Perspectives on 25 Years**
Seeking Better Management of Drinking Water Risk

**Disinfection By-Products**
A Health Risk Perspective

## WATER QUALITY INSIGHTS FOR TODAY'S PROFESSIONALS

**With special guest editor Steve E. Hrudey**


**Perspectives on 25 Years Seeking Better Management of Drinking Water Risk**


**Guest Commentary From the Field**
Dan Deere


**Disinfection By-Products A Health Risk Perspective**


**The Flint Water Crisis Politicians and Bureaucrats Take Heed**

42 News Items


Contents

## From the Literature


**Microbial Pathogens and Waterborne Outbreaks** 44

Spatial and temporal distributions of enteric viruses and indicators in a lake receiving municipal wastewater treatment plant discharge

Risk assessment of parasites in Norwegian drinking water: opportunities and challenges

Askøy, Norway, Campylobacter outbreak, June 2019

Waterborne outbreaks: a public health concern for rural municipalities with unchlorinated drinking water distribution systems

**Arsenic** 49

Valuing the cancer mortality risk reduction from lowering the arsenic maximum contaminant level in New Hampshire municipal water supplies

Effect of low- and high-level groundwater arsenic on peripheral blood and lung function of exposed rural women

Bayesian benchmark dose analysis for inorganic arsenic in drinking water associated with bladder and lung cancer using epidemiological data

**Lead** 51

A field survey on elution of lead and nickel from taps used in homes and analysis of product test results.

**Nitrates** 53

Prenatal Exposure to Nitrate from Drinking Water and Markers of Fetal Growth Restriction: A Population-Based Study of Nearly One Million Danish-Born Children

**Cyanobacteria** 53

Cyanobacteria and their secondary metabolites in three freshwater reservoirs in the United Kingdom

**Disinfection By-Products** 54

Reactivity-directed analysis – a novel approach for the identification of toxic organic electrophiles in drinking water

Mixture effects of drinking water disinfection byproducts: implications for risk assessment

New methods for identification of disinfection by-products of toxicological relevance: Progress and future directions

**Access to Improved Drinking Water** 57

Inequality in access to improved drinking water sources and childhood diarrhoea in low- and middle-income countries

**Sars-CoV-2 Surveillance in Wastewater** 57

Epidemiological evaluation of sewage surveillance as a tool to detect the presence of COVID-19 cases in a low case load setting






# LETTER FROM THE GUEST EDITOR

**Being invited to serve as Guest Editor and Associate Editor for the 101st edition of Health Stream is a great honour given the outstanding reputation that Martha Sinclair and Pam Hayes established for this publication over the past 25 years. We certainly appreciate not only the exceptional quality of Health Stream over that period but we recognise how much work goes into producing four issues a year.**

These 25 years have marked a period that has aligned remarkably well with my engagement with drinking water safety in Australia. Although I had previously visited Australia, my first trip with regards to drinking water came in 1991 having just assumed the Chair of the International Association on Water Quality (a forerunner of IWA) Specialty Group on Off-Flavours in Water. South Australia had been selected to host the 1994 Specialty Conference, so I visited Adelaide to discuss early plans for the Conference. I was fortunate to visit Adelaide again in March 1994 for an international workshop on cyanobacterial toxins as part of a research team for the American Water Works Research Foundation preparing a resource guide on the topic. This trip, followed shortly thereafter by the IAWQ Specialty Conference, provided my first opportunity to meet Don Bursill (inaugural CEO CRC WQT) who engaged me to serve as an international reviewer on the funding proposal for the CRC on Water Quality & Treatment. Thereafter, Don helped me organise a sabbatical leave at the CRC in 1998-99. These years of deep collaboration that followed have been the most rewarding of my professional career. The rest is history, as I will recount in our feature article with 17 invited expert commentaries about the past 25 years of advancing, achieving and ensuring safe drinking water in Australia and around the world.

On this journey, we should never underestimate the critical role of evidence which was so eloquently and accurately summarised four times a year in Health Stream. Carl Sagan, an amazing scientist and public advocate for science, who died far too young, had written extensively about the role of science and evidence, but the following extracted quotations are particularly germane to the discussions in this edition:

> ***"Of course we must be willing to change our minds when warranted by new evidence. But the evidence must be strong. Not all claims to knowledge have equal merit."***
>
> ***"...at the heart of science is an essential balance between two seemingly contradictory attitudes***
>
> - ***an openness to new ideas, no matter how bizarre or counterintuitive,***
> - ***and the most ruthlessly sceptical scrutiny of all ideas, old and new.***
>
> ***This is how deep truths are winnowed from deep nonsense."[1]***

In our current world of information overload and increasing access to disinformation, Sagan's wise counsel is vital to ensuring success. We can all thank Martha and her team for providing us with a remarkable window over the past 25 years on current evidence about water and health to assist us all in facing the huge challenge of winnowing deep truths from deep nonsense.

**Steve E. Hrudey** Guest Editor
**Elizabeth J. Hrudey** Associate Guest Editor

[1] Sagan, C., 1996. *The Demon-Haunted World: Science as a Candle in the Dark*. Random House, New York.

# PERSPECTIVES ON 25 YEARS SEEKING BETTER MANAGEMENT OF DRINKING WATER RISK

**Many of the 17 invited commenters who follow are certainly well placed to discuss first hand the progress in reducing risk to drinking water supplies in Australia, but I found the following quote from an interview of a President of the Australian Water and Wastewater Association (as it was named then) published in the December 1983 issue of the Journal of the American Water Works Association to be informative about perspectives preceding the past 25 years. He was asked to comment on whether there were any problems concerning waterborne disease in Australia and answered: *"For many years the isolation of Australia made this an almost germ-free continent, and the level of waterborne pathogenic organisms was not significant."* Against that baseline, any progress can be viewed as substantial, but there is clearly much more that has been achieved and shared with the world.**

When invited by Don Bursill to spend a sabbatical with his new research network based in Adelaide, Don asked if we could pursue something to implement a risk management perspective. I had just completed a five-year term as the Eco-Research Chair in Environmental Risk Management in the Department of Public Health Sciences, Faculty of Medicine and Dentistry at the University of Alberta. When Don asked whether one of my graduate students might be willing to come to Australia to work with the network on developing a risk management framework, I immediately thought of Samantha Rizak, a brilliant young engineer who had completed her MSc on risk issues with me. Sam became the staff person who joined Martha Sinclair at Monash and served with an NHMRC working group that launched the concept of the Framework for Managing Drinking Water Quality at a workshop in Adelaide in September 1999 (see **HS16**) and worked on the many iterations of the Framework thereafter.

Although the water industry was certainly receptive to taking some action after the 1998 Sydney water incident, the often-stated opening position was along the lines of *"just give us the numbers and we'll meet them…we don't need to have regulators poking their noses into how we operate"*. Of course, the near total reliance on drinking water guideline numbers for endpoint testing was a primary target of our efforts to implement an alternative risk management approach seeking total quality management to focus on effective operations from source to tap. As we were working on this effort, in May 2000, the fatal Walkerton, Ontario outbreak happened and I joined Justice Dennis O'Connor's public inquiry team in August 2000 (see **HS18–21, 26**). This public health disaster certainly raised the profile of drinking water safety in Canada.

Because we were aware of the efforts of Jamie Bartram (WHO) to bring a more rational approach to drinking water guidelines, we invited his expert microbiology team to Adelaide for a joint workshop in May 2001 to compare notes. Just before I traveled to Adelaide, news broke of Canada's next major drinking water outbreak, cryptosporidiosis in North Battleford, Saskatchewan (see **HS22, 25**) so I found myself fielding Canadian media calls in the middle of the night in Adelaide.

The Adelaide workshop was an enormous success, ultimately leading to the WHO water safety plan approach being closely aligned with the NHMRC framework. A key achievement was the product of a half-day session in break-out groups charged with a stated challenge: *"If you could only tell someone operating or managing a drinking water system two (or three) things, what would they be?"* The impetus for this exercise was that the Manager of the Walkerton system testified at the public inquiry that he had shelves loaded with guidance and technical documents but he had not read any of them. Given that we were aiming on updating the 1996 Australian Drinking Water Guidelines (ADWG) to make a 8 cm thick binder even bigger, I believed we needed to have an upfront, *"Read Me First"* set of guidance that we should expect anyone responsible for providing drinking water to know and to understand. The product of our workshop became the six guiding principles that are at the very beginning of all editions of the ADWG published since 2004. With that introduction, I will turn the messaging over to a very talented and experienced group of Australian and international water professionals to share their wise perspectives with you.

# Australia

## Don Bursill

Founding CEO, Cooperative Research Centre for Water Quality and Treatment (the CRC) & former Chief Scientist, SA

The CRC, now Water Research Australia (WaterRA) commenced operations in 1995 at a time when substantial economic and structural reform was underway in the water sector in Australia. It was a time when attitudes among some of the key decision makers in the sector were less informed and water quality issues were viewed to be well in hand. Interestingly, this came at a time when many in the water sector in Australia had never heard of Cryptosporidium.

Prior to the economic and structural reform of that time, some State government agencies had responsibility for water systems from source to tap. Water resources authorities and environmental protection agencies are now responsible for water resources and catchment areas, with newly structured water utilities (whether private sector or publicly owned business organisations) having the responsibility for the public water supply systems. In some cases, retail organisations were set up to manage just the distribution and customer billing. Management structures of this period had a heavy emphasis on economic theory, rather than a structure designed to facilitate the delivery of safe and reliable water to the community.

The Framework for the Management of Drinking Water Quality (the Framework) in the Australian Drinking Water Guidelines (ADWG) was largely the result of a very productive long-term collaboration of the CRC with Steve Hrudey. Apart from other key features, the Framework had the added benefit of forcing the various organisations involved in the water cycle to collaborate in the development and implementation of individual water system specific risk management plans. It was also promoting an understanding of the complete water cycle to those responsible for managing aspects of it. One might be forgiven for thinking this should not have been necessary, but at the time, it was an uncommon practice for senior executives in water utilities to have any mention of water quality targets in their annual performance agreements.

One of the key features of the CRC was to integrate a Health Program involving (mainly) medical researchers from Monash University in Melbourne with the science and engineering researchers in other programs covering source waters through storage and treatment to distribution. As far as I am aware, this was the first time this was done on a significant scale in Australia, and it proved an outstanding success. It also tended to remind us that the provision of safe water supplies is a key public health activity and that meeting its challenges should be a joint exercise between both sectors.

The introduction of Health Stream (HS) was initially seen as a mechanism of sharing information and expertise across the various disciplines in the CRC and to make the CRC's stakeholders more aware of public health related challenges to public water supply systems. Under the expert guidance of Martha Sinclair,the circulation of HS escalated rapidly from its small beginnings to its international reach.

Water quality management and public health seem to be benefitting greatly from the work of the CRC and then Water Research Australia. The valued collaborators undoubtedly made a strong contribution in improving the security of our water supply systems. Features like HS and the Framework in the ADWG (and its associated water re-use equivalent) are among the many positive outcomes to be proud of.

The World Health Organisation (WHO) introduced Water Safety Plans almost 20 years ago and drew very heavily on the ADWG Framework in the process. This initiative has made a substantial improvement to the safety of water supplies across many parts of the World. Of course, complacency is always a risk.

## Richard Walker

Former Manager of Drinking Water Quality, Water Corporation, WA

I heard about Walkerton from Steve Hrudey at a WHO meeting in May 2001. I had been following the events at Walkerton since the outbreak via **HS** (**19, 20, 21** & **26**). Hearing it live from Steve was a *"Eureka"* moment. The impact on the families at Walkerton made me realise the responsibilities that came with managing drinking water. In my previous 4 years as Manager we had implemented the 1996 ADWG, conducted barrier surveys on all 250 schemes and commenced a major capital improvement program. But it was still management by numbers. I was looking for how to take our operators to the next level in terms of personal commitment. This was the opportunity!

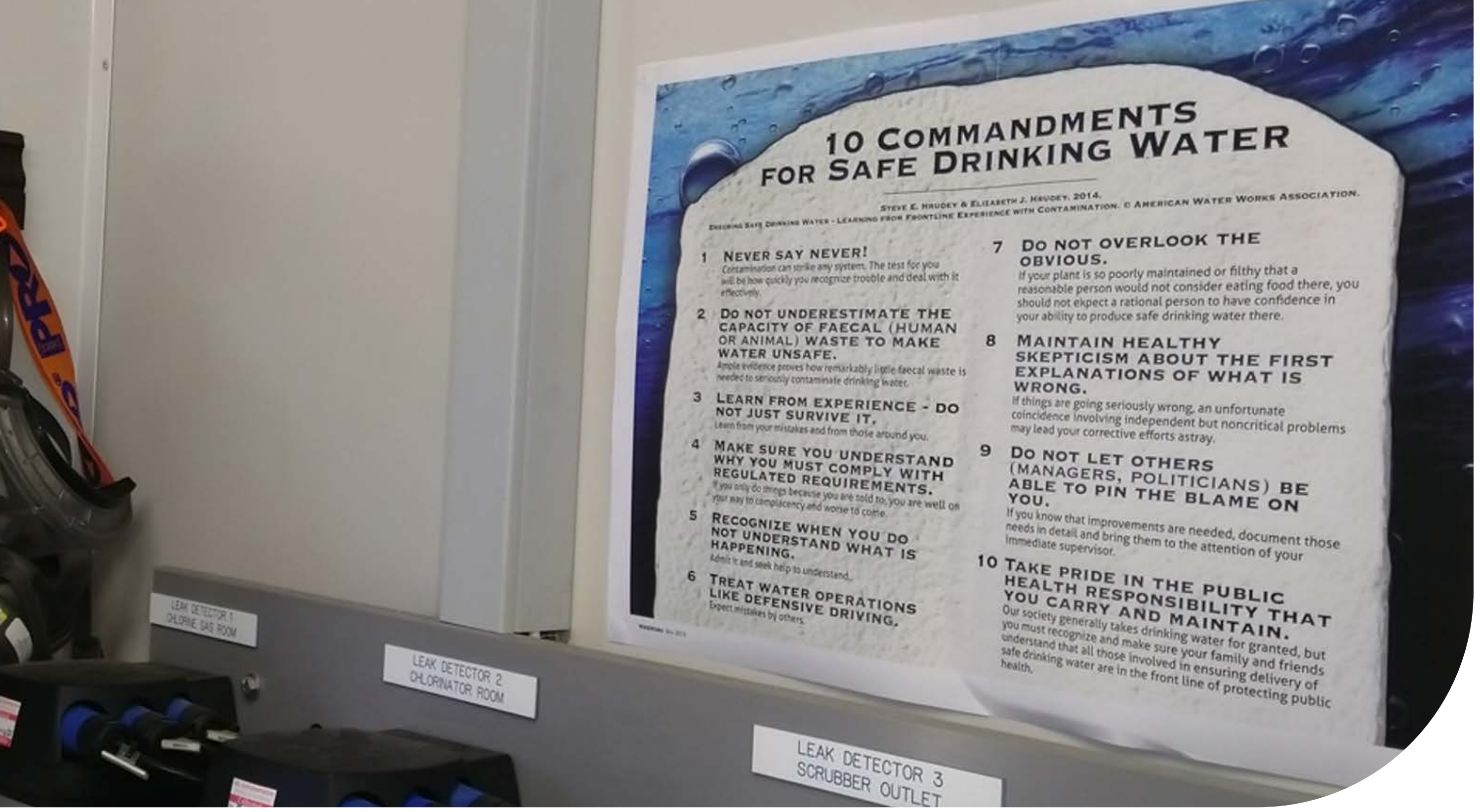
Steve came to Perth in late 2001 and mesmerised a large audience at Water Corporation with the Walkerton findings. Over lunch with the General Managers who comprised the Corporate Water Quality Committee (CWQC) the conversation was along the lines, *"So the misery of Walkerton could have been avoided if the chlorinator had fulfilled its purpose! I wonder how well our chlorinators are working?"* Perth had SCADA so we knew that was OK. But no SCADA or continuous chlorine residual monitoring for the 225 towns in the country. Remember this was pre-Framework so no requirement for critical control point (CCP) monitoring. I decided to run a survey for the next month and asked the operators to send me an email if during their routine checks they found any chlorinator not working or faulty. The survey results were not pleasant reading at the next CWQC. The policy decision from that meeting was that the Corporation WILL NOT supply undisinfected water. Customers could be temporarily out of water rather than supply water which may not be safe. Accordingly, all schemes were to be made *"failsafe"* and shut down if disinfection fails.

So one hundred years of water supply tradition was turned on its head. Operators who prided themselves on keeping a water supply available for customers under almost all circumstances were now told you are authorised and expected to stop supply if there is a problem with disinfection! Looking back, this was a pivotal moment in turning hindsight into foresight. Learning from your own mistakes and those of others. This continuous improvement approach became a cornerstone of the way the Corporation managed drinking water quality and was one of the most satisfying aspects of my job. I used to read every issue of HS and paid particular attention to the *"Incident Reports"*. If it happened there, could it happen here?

## David Cunliffe

Principal Water Quality Adviser, Health Regulation and Protection, SA Health

A key element in the improvement of drinking water safety over the last 25 years has been the advent of risk management frameworks providing much greater confidence for ensuring safe drinking water. The frameworks systemise and document good practice from catchment to tap. They provide a common language including risk management, health-based targets and treatment validation and have moved us toward quantifiable and measurable targets. Critically the frameworks identify operational monitoring as the focus for maintaining and measuring water safety. Implementation has been a journey of many years but acceptance is broad, organizational structures are improved, uncertainty has been reduced and communication is enhanced. Public health agencies are far more engaged. Gaps remain, there is more to do and there will always be threats but we are better than we were at managing water safety.




## Paul Byleveld

Team Leader, COVID-19 Public Health Response Branch (previously Manager Water Unit) NSW Health

The 1998 Sydney water incident was the catalyst for the NHMRC to introduce the 'Framework for Management of Drinking Water Quality' beginning in 1999 (see **HS16**), released for public review in 2001 (see **HS22**) and formally adopted in 2004. In NSW, the larger water utilities quickly adopted the Framework. Elsewhere, since 2004, we've had a journey of incremental improvement. The Framework continues to be a powerful tool to improve drinking water risk management and benefit communities across NSW from cities, to regional towns and remote and Aboriginal communities.

## Brian Labza

Senior Policy Officer, Environmental Health Directorate, WA Department of Health

Over the past 25 years I have seen drinking water quality management in Australia evolve and mature, into a holistic catchment to tap risk management process that focuses on the capabilities and resilience of the entire system, not just reactive measures of quality at the point of supply. WA has applied this developing body of knowledge to create a scalable risk management system that is effective across the vast remoteness of one third of Australia, as well as the main metropolitan area.

The goal of "*knowing your own system*" is therefore paramount. As a simple example, the "*Ten Commandments*" of water treatment plant operations is being rolled out across WA, as seen in the accompanying image of the poster (after Hrudey & Hrudey 2014)[1] displayed at a key disinfection plant at Busselton WA. This approach is also being adopted into recycled water management in WA, and will continue to be applied successfully to challenges such as the treatment of recycled wastewater to drinking water standards for future generations.

## Dan Deere

Principal, Water Futures Pty Ltd, NSW

Health Stream is well known for identifying, summarising and reporting on objective evidence of associations between drinking water exposure and health effects. However, Health Stream has had broader coverage and presciently predicted all of the major issues in water and health during its 25-year history. Looking at Health Stream from a personal perspective, in the areas of water and health with which I'm most familiar, it has reported ahead of time on the evolution and application of setting health targets by quantitative microbial risk assessment (QMRA) and the water safety plan (WSP) approach.

In relation to the WSP approach, **HS16** reported on the first national planning workshop in Adelaide, September 1999, **HS22** first introduced the *Framework for Management of Drinking Water Quality* in June 2001, that has since been adopted in the Australian drinking water and recycled water guidelines and that became a key foundation document for developing the global WSP approach. **HS33** and **HS34** covered the International Water Association's and World Health Organization's formal commitments to the WSP approach in the *Bonn Charter* and *Guidelines for Drinking-water Quality*, respectively. Later Health Stream covered the evolution and implementation of the Framework and WSPs over time, including the *Aquality* and *Requality* benchmarking and self-assessment tools.

Health Stream has been much more than just a summary of the literature on water and health. It has alerted us to, and documented the conception, development and implementation of, the full range of water and health initiatives over the past 25 years.

## Darryl Day

Former Regional and Water Supplies Program Leader CRC for Water Quality & Treatment; Former utility general manager

Looking back 25 years, "water – health" research in Australia focused on the issues of coastal cities, and temperate climates where 80% of the population live. The advocacy for regional, rural and remote communities focused on water security and sanitation, not water quality. The CRC for Water Quality and Treatment shone a light on the health risks of small water systems, provided the science, piloted the risk-based approach and provided resources. Drinking water safety plans and regulatory obligations have driven utilities to prioritise drinking water quality on the corporate risk register. This has transformed the approach to drinking water. However, the journey is not over. There are still rural and remote communities not serviced by utilities, or the focus of health regulators, without access to safe drinking water. Australia requires more investment in science, capacity and infrastructure to provide access to safe drinking water for all. The journey continues.

[1] *Hrudey, S.E. & E.J. Hrudey. 2014. Ensuring Safe Drinking Water – Learning from Frontline Experience with Contamination. American Water Works Association. Denver, CO. 269pp.*

### Nick Ashbolt

Dean, School of Environment, Science & Engineering, Southern Cross University, Lismore, NSW, Editor-in-Chief, Journal of Water and Health, IWA Publishing

Due to history and related development of governance structures, the water industry (not alone) is siloed in its research and practices. In many ways this has served communities well, but as recognised now across society, to reduce unintended consequences we must apply a more "systems" understanding – well illustrated over the emerging recognition of environmental pathways of antimicrobial resistance. A leading tool addressing microbial water quality in this systems analysis has been quantitative microbial risk assessment (QMRA). While initially rudimentary, QMRA was necessary as our traditional measures of water quality, faecal indicators, lose their disease index relationship over time and by differential entrapment/inactivation by natural and engineered treatment processes. QMRA has provided a science-based approach to derive treatment requirements, as part of the proactive, performance-based approach adopted in Australian guidelines, and globally.

A second key finding was that human enteric viruses appeared to be the most important enteric pathogen group to manage human health risks via water exposures. A third key finding was that even when sewage is the minor faecal source of contamination (against say dominant wildlife sources), human enteric viruses drive gastrointestinal risks.

In summary, to fully address the intent of our proactive risk management approach we need to evolve a systems framework within our drinking water guidelines, so as to better engage with communities, address the web of contaminant pathways and manage environmental pathogens from source to tap. Without this systems framework we will be forever chasing the next (predictable) issue in drinking water quality.

### Susan Petterson

Director, Water & Health Pty Ltd; Associate Professor, Griffith University, QLD; Editor Journal of Water & Health, IWA Publishing

Significant changes in guidance for the management of water safety globally followed the WHO meeting in Stockholm in 1999 towards development of a health target, risk-based approach to ensuring water safety. This was recommended in the 2004 edition of the WHO guidelines for drinking water quality consistent with the risk management approach of the 2004 Australian Drinking Water Guidelines. Even though quantitative risk-based microbial targets relying on Quantitative Microbial Risk Assessment (QMRA) were recommended as part of the preventative risk framework, these quantitative targets struggled to gain international traction. The Netherlands were an exception, who boldly embedded a quantitative risk target in legislation, however, most countries did not develop national quantitative targets due to local data limitations and complexities in interpreting uncertainty and variability. Australia, which was one of the first countries to embed quantitative microbial targets in their guidelines for wastewater recycling in 2006 is still yet to agree upon quantitative microbial targets for drinking water. Hopefully an agreement on those targets which are necessary to define safety and provide a level playing field for all providers, will be forthcoming soon. Quantitative approaches to inform water safety have matured over the past 25 years with an increasing mandate to provide a transparent evidence-based approach.

## New Zealand

### Jim Graham

Principal Technical Advisor, Taumata Arowai, New Zealand

The development of modern drinking water regulation in New Zealand began when Dr Michael Taylor joined the Ministry of Health in the early 1990s. Sadly, Michael died in 2020 but his legacy continues with the establishment of Taumata Arowai, New Zealand's new national drinking water regulator (see News). Michael introduced a number of regulatory 'tools', but progress to ensure safe drinking water accelerated after May 2001 when he returned from the expert workshop in Adelaide, Australia. Michael brought the idea of water safety plans back to New Zealand. I was fortunate to work with Michael on the introduction of drinking water legislation which mandated the preparation of water safety plans and compliance with drinking water standards. But the water-borne illness outbreak at Havelock North (see **HS83**, **100**) strongly indicated that something in the system had failed. The Government Inquiry (see **HS84**, **86**, **88**, **95**) found that, while the required regulatory regime was in place (legislation, standards and water safety plans), effective implementation of the regime was not. This failure has led to the establishment of Taumata Arowai, an independent crown entity, which is now building on the foundation Michael put in place. Taumata Arowai seeks to change the water sector's approach to water safety plans. Other jurisdictions may wish to consider this approach. The requirements for having plans became increasingly prescriptive on the compliance requirement to have a plan approved, more than the value and usefulness of the plan as a risk management tool. Taumata Arowai seeks to change this culture from a focus on **having a risk management plan** to a focus on effective **risk management planning**.

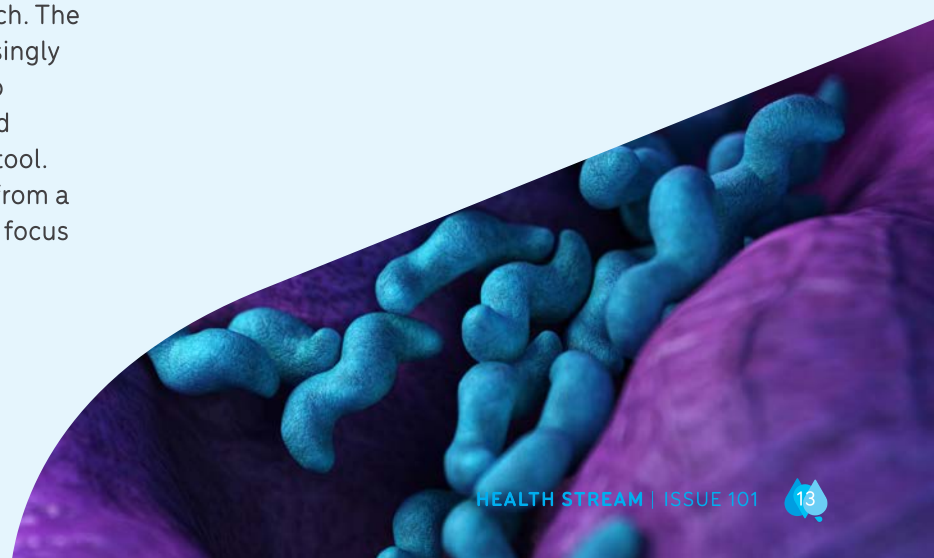
### Brent Gilpin

Science Leader, Institute of Environmental Science and Research Ltd, New Zealand

In the late 1990s, New Zealand was busy establishing guidelines and regulatory frameworks for safe drinking water. However, under-resourcing, political pressure and complacency meant that many of the safeguards that should have been there, were never fully implemented.

As a result in August 2016, the town of Havelock North, joined the ranks of Walkerton, as a place that will now forever be associated with a huge waterborne outbreak, that should have been avoided. Heavy rainfall, inadequate source protection, no treatment, inadequate monitoring, and failure to recognise a change in risk resulted in over 7,000 illnesses and at least four deaths.

The benefit of this outbreak however is that at least for next few years, drinking water has recognised importance and priority. The new drinking water regulator, Taumata Arowai, has a broad mandate and the opportunity to secure safe drinking water for all in New Zealand.



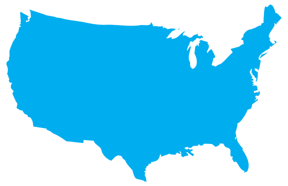
## Canada


### Bernadette Conant

CEO, Canadian Water Network (CWN)


The last 25 years have witnessed a fundamental transformation in the water space –an undeniable movement of the needle from a dominantly *reactive, systems-compliance* to a *proactive, risk management* approach. It has involved moving on from the assumption that everything can be predicted or modelled, to acknowledging the complexities of the physical, governance and political issues impacting water. Proactive management sees regulations as important ground rules and boundaries within which priorities and competing issues must be considered; explicitly responding to significant "uncertainty" in managing both known and unknown risks.

In bringing science to these real-world water decisions, I have often found Australian colleagues to be mentors in the space. Andrew Campbell was an early champion in knowledge mobilization for water and agriculture. Don Bursill was a key action leader who advised the Canadian government about creating CWN in 2001, after Walkerton. Martha Sinclair was a key invited expert for CWN's 2009 international project on advancing Management of Uncertainty in the Provision of Safe Water. Their collective input and ongoing interaction with Steve Hrudey, have made me persistent in seeking to lead Canada towards becoming more of a Water Safety Plan nation.



## USA


### Joan Rose

Homer Nowlin Chair in Water Research,
Michigan State University, USA

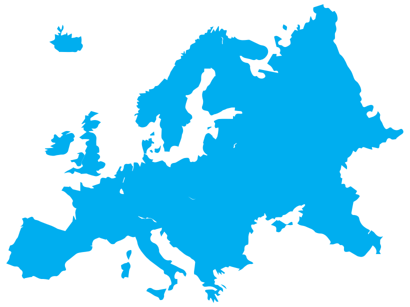

Over the past 100 years it was the convergence of technology, science, engineering and medicine that led us into the 20th century where great strides were made toward producing what was understood to be safe drinking water. Now as we enter the Anthropocene we are struggling with aging infrastructure, emerging contaminants, climate change and dramatic land use changes which have threatened water quality and health in the developed and developing world alike. Yet we have developed techniques to measure new contaminants including waterborne pathogens associated with significant morbidity and mortality over the past 20 years including *Cryptosporidium* a zoonotic pathogen found in surface water and *Legionella* a pathogen found in premise plumbing. Powerful new metagenomic technologies have allowed us to evaluate any microorganism of interest. This coupled with advanced instrumentation means that we can monitor watersheds for source tracking markers, source and treated waters for pathogen's occurrence and ultimately assess appropriate management. The future of water security, approaches using the *One Water* concept including water reuse, means that the measurement of water quality will be more important than ever. The water community must invest in advanced water quality laboratories around the world and develop big data for water sciences which will be imperative for safe water 100 years hence.


### Jen Clancy

Chief Scientist, Environmental Science,
Policy and Research Institute, USA


Australian scientists and engineers have been pioneers in drinking water quality and treatment. Australians began to deal early on with issues that came later to the rest of the world, e.g., toxic algae and the lethal brain-eating amoeba (*Naegleria fowleri*). When my team was hired in 2014 by the State of Louisiana to address deaths due to *N. fowleri* (see **HS96**), we looked to Australia and the expertise of Dr. David Cunliffe of SA Health. David joined our expert panel and provided us with invaluable expertise, having dealt effectively with *N. fowleri* in water supplies for decades. Dr. Geoffrey Puzon at CSIRO Land and Water provided technical assistance as we got the laboratory methods for sample collection and analysis up and running to conduct a statewide sampling program to assess *N. fowleri* occurrence in Louisiana drinking water supplies in 2014 and 2015.

I was an early subscriber to Health Stream and always look forward to the next issue. If I happened to miss anything in the literature, I was assured I would catch it in Health Stream.



## Europe

### John Fawell, UK

Independent Water Consultant and Visiting Professor, Cranfield University, UK

In 25 years much has changed, with increased knowledge and awareness of both microbial and chemical contaminants, particularly a wide range of micropollutants at very low concentrations. Some, such as cyanobacterial toxins and chlorination by-products just keep on going but contaminants of emerging concern such as PFAS create new challenges. The introduction of water safety plans has been the biggest and most beneficial change in terms of assuring drinking water safety. This is now being widely adopted and has been incorporated into legislation in many countries. It is perhaps the first time that a single approach has proved suitable for any water supply. WSPs need to be backed by suitable standards for individual chemicals but it remains important that the affordability of drinking water and the impact on carbon footprint are kept in mind while developing standards along with the primacy of microbial pathogen safety.

### María J. Gunnarsdóttir, Iceland

Senior Research Scientist, Institute of Environmental Engineering, University of Iceland

Drinking water has been defined as food for a quarter of a century in Iceland, with the demand for systematic preventive management originally built on the food risk management system (Hazard Analysis and Critical Control Point – HACCP) and now the Water Safety Plan (WSP). This is not surprising as safe water is fundamental to nearly all food production. In the beginning most of the large supplies and some of the medium size ones implemented WSP or a simpler version developed by the sector. Since then, the progress has been slow. The status now is that there are around eight hundred regulated water supplies in Iceland, from large, medium to small, with the small being the most numerous. By the end of last year, 2020, only forty-three water supplies had implemented systematic risk-based approach or around 5% of the regulated water sector. That does, however, not tell the whole story as these forty-three serve around 86% of the population so the majority is well protected when at home. This approach has been shown to improve both water quality and health in Iceland. It is of concern that the smaller size supplies are often the ones serving popular tourist sites and summerhouse areas with large seasonal use. With the new EU Drinking Water Directive demanding risk-based approach there is hope that it will speed up the WSP process in the medium and small size supplies. The sector is now in the process of adapting the new WHO's Sanitary Inspection form to Icelandic conditions to assist the small size supplies in safeguarding water quality.

### Ingrid Chorus Germany

Head (retired), Division of Drinking Water and Swimming Pool Hygiene, Federal Environment Agency of Germany

Twenty-five years of developing concepts for keeping water safe have revolved around both ends of the challenge: the many chemicals and microorganisms newly observed in water and the need for an overarching concept of risk assessment and management. The list of hazards we happen to regulate has evolved historically over decades, driven by the somewhat coincidental scientific and public attention to the "substance of the year" – but are they really the ones that are relevant to public health today? For the 'emerging' chemicals and pathogens Health Stream has been ever so helpful with critical reviews of what we do and don't know. From the sheer multitude, particularly of chemicals, it has become clear that the only effective regulatory approach to their POTENTIAL occurrence in water is locally specific risk assessment and management. WHO's response, the recommendation to develop site-specific Water Safety Plans, was first born at a meeting in Australia. Health Stream publications supported the current wide acceptance of Water Safety Plans.

## Closing Thoughts | Steve E. Hrudey

The outstanding summary provided of the regulatory changes and influential drinking water incidents over the past 25 years in Health Stream 100 should be required reading for anyone working in this field.

The following *Guest Commentary from the Field* by Dan Deere as well as the summary of Hasan & Alam (2020) in the *From the Literature* section, draws attention to the needs to make safe drinking water more commonly accessible across the globe. However, the reality is that we do know how to make drinking water safe for consumers if we consistently apply our current knowledge. The remaining incremental health risks that we are seeking to manage pale by any rational comparison with the risks that we know how to control. Yet, we still have occasional serious outbreaks of waterborne disease (read about two recent 2018, 2019 examples in *From the Literature*) despite all of the practical knowledge we hold.

A common denominator in many of these failures is the irrational practice of delivering drinking water that is not, or is not adequately, disinfected. Allowing such continuing defiance of the overwhelming scientific evidence that water must be disinfected to be safe presents a major challenge for all jurisdictions that have the economic means to deliver safe drinking water. Politicians and/or bureaucrats who choose to ignore the overwhelming scientific evidence, preferring to accept strongly-held biases not grounded in reliable evidence, should read the feature about the *Flint Water Crisis* to see how that worked out for those *"leaders"*. They believed that they knew best and could simply dismiss the scientific evidence. Any jurisdictions that waiver from the duty to protect the public's health, surrendering to misinformed lobbying by opponents of disinfection, must at a minimum fully consider and disclose all feasible disinfection alternatives, the full true costs of viable alternatives and their effectiveness relative to chlorination. If such decision-makers fail to do so, they must accept responsibility for the adverse health consequences that they make much more likely to happen by failing to require effective disinfection of community drinking water.

# GUEST COMMENTARY FROM THE FIELD

**Safe Drinking Water Remains too Rare on Earth.
The importance of setting, monitoring, benchmarking and reporting on goals for water safety.**

*Dan Deere*

**There have been many advances in safe water in Australia over the past 25 years. At the same time it is worth considering the steady advances made in relation to the provision of safe drinking water globally over this same period. The simple act of showing leadership by setting global targets and commitments, and then monitoring and benchmarking progress against them, has been an important advance in safe drinking water.**

For instance, the Millennium Development Goal (MDG) target – of halving the proportion of the population without sustainable access to safe drinking water between 1990 and 2015 – was exceeded (dropping from 24% in 1990 to 9% by 2015) (WHO, 2015).

More recently, the Sustainable Development Goal (SDG) aspirational target – achieving universal and equitable access to safe and affordable drinking water for all by 2030 – has reported a ten percentage points increase in the proportion of 'people using safely managed drinking water services' since the year 2000 (from 61% to 71%) (WHO, 2017; World Bank, 2017).

Definitions of 'safe' water vary (WHO, 2017), but estimates of the proportion of the population that still lack adequate access to it approximate the one billion mark. Hence there is still a pressing need to continue with, or ideally accelerate, this historical rate of progress over the coming 25 years, including in areas in our region, such as Papua New Guinea. It is important to continue to set out the contribution that we can make as a nation, as organisations and as individuals to continue to advance water safety globally. Many in the Australian water sector already play a major role in this through a wide range of forums, such as the **Australian Water Partnerships**.

The Australian Government Department of Foreign Affairs and Trade (DFAT) is continuing with its program of providing support to further improve access to safe drinking water via the Australian Water Partnerships with the Australian Water Association as well as other programs. DFAT works with, and contributes millions of dollars annually in funding support to, the Asian Development Bank Water Finance Partnership Facility, the WHO Water Sanitation and Hygiene programs and similar programs undertaken with the United Nations Children's Fund. You and your organisation can contribute to these programs by providing advocacy, funding, technical advice, training, mentoring and research.


WHO, 2015. Twenty-five years progress on sanitation and drinking water – 2015 Update and MDG Assessment, **United Nations Children's Fund and World Health Organization**.

WHO, 2017. Safely managed drinking water – thematic report on drinking water 2017, **United Nations Children's Fund and World Health Organization**.

World Bank, 2017. People using safely managed drinking water services (% of population), **The World Bank Databank**.

HYPERLINK "https://protect-au.mimecast.com/s/RG7HCBNqL2uD0mQMuzYdm4?domain=data.worldbank.org" https://data.worldbank.org/indicator/SH.H2O.SMDW.ZS


Readers are also referred to Hasan and Alam (2020) in the ***From the Literature*** section for more details on access to improved drinking water in low and middle income countries.

# DISINFECTION BY-PRODUCTS

## A HEALTH RISK PERSPECTIVE

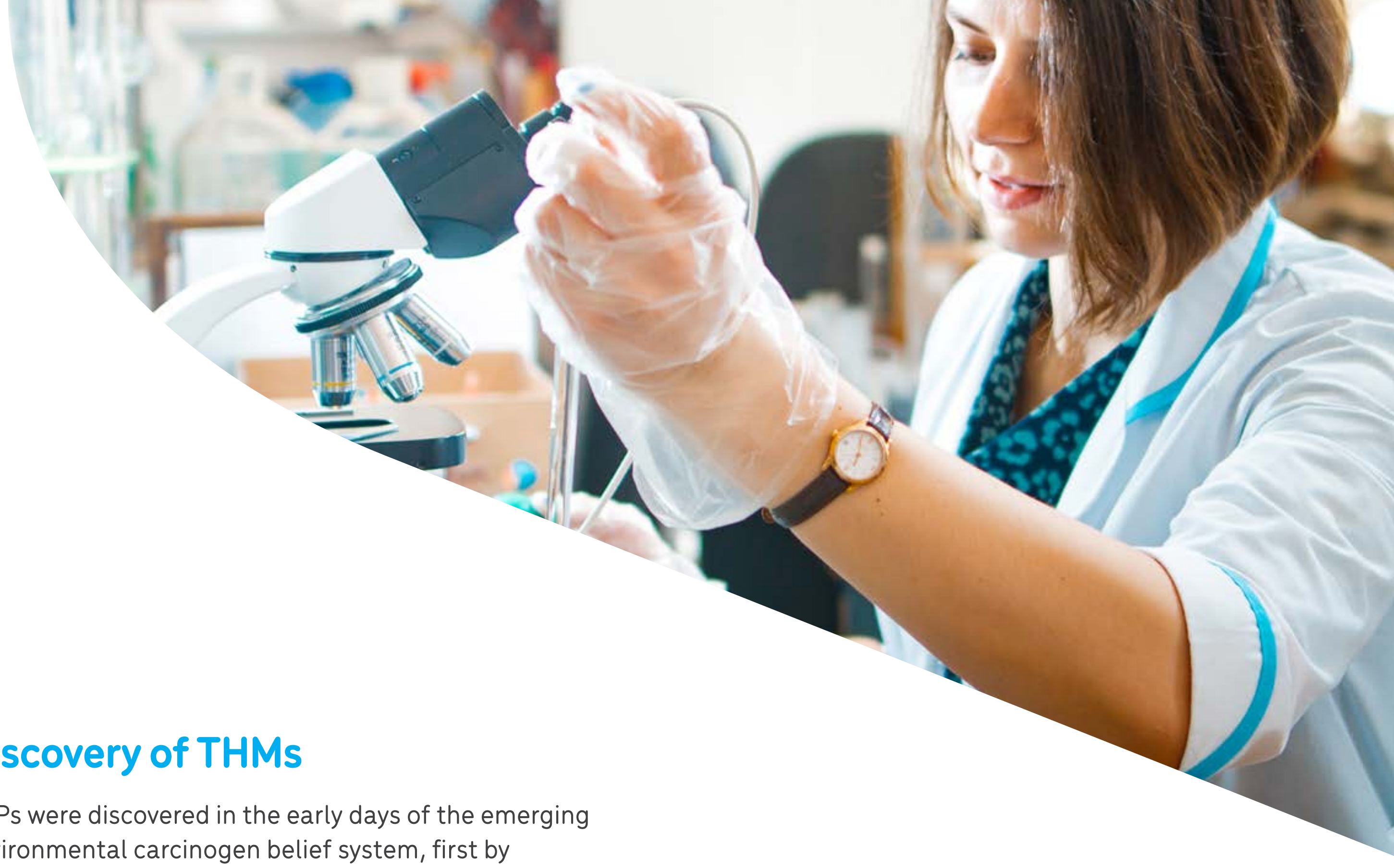
**The 2004 edition of the Australian Drinking Water Guidelines was one of the key aspects of progress towards a greater ability to ensure safe drinking water. One innovation of those guidelines was to provide a set of *"Read Me First"* principles at the beginning of the document with the intention that anyone seeking to produce drinking water needs to understand these six principles, the first of which was:**

***"The greatest risks to consumers of drinking water are pathogenic microorganisms."***

**Put another way, drinking water that is not disinfected is not safe. Unfortunately, the very nature of disinfection, ensuring that living or reproducible (in the case of viruses which are not truly "alive') microorganisms are inactivated such that they cannot infect humans and cause disease, involves disruption of these microorganisms at the molecular level. Processes capable of causing such disruption are inevitably reactive and will produce unintended by-products in water, what we now refer to as disinfection by-products (DBPs).**

Tang et al. (2020) did a bibliometric analysis of DBPs in drinking water and identified 3570 papers published between 1975 and 2018, after manually culling papers judged not to be relevant to this scope. It is clear from reviewing their results that they did not capture, to any significant degree, papers specifically addressing health risks from disinfection by-products in drinking water. Regardless, even a cursory look at the literature on DBPs reveals that there are an overwhelming number of research publications on the topic. Tang et al. (2020) found that the number of DBP papers per year returned by their search increased from 40 per year in 1998 to 326 in 2018, so how did we get to this overwhelming level of research attention?

*"The reality about DBPs is that ever since Rook discovered THMs in 1974, no one in the water industry can or should ignore DBPs.*



## The Dawn of Environmental Science

To understand the history and emergence of the DBP issue, there is a need to recognize that environmental science was essentially born and became a focus in society during the 1960s and 1970s leading to major expansion of environmental legislation in the 1970s with the creation of the U.S. Environmental Protection Agency and similar agencies around the world. Major journals focusing only on environmental science research like *Water Research* and *Environmental Science & Technology* began publication in 1967. These original journals have grown enormously in the number of papers they publish and there has also been a literal explosion to hundreds of environmental research journals.

An important feature of the early 1970s was an inadvertent creation of an expectation that "environmental chemicals" could explain the majority of human cancers. This is a long story that deserves more attention than can be devoted here, but the details are presented in the introduction to the subject of a long range perspective about DBPs (Hrudey 2009). A key element of this story was that Dr. John Higginson, the founding Director of the International Agency for Research on Cancer (IARC), expressed the view in 1969 that 90% of human cancers could be explained by "extrinsic" factors, i.e. factors not attributed to genetics. Although that estimate might need a serious update now, given the explosion of scientific understanding about genetic predisposition determining human disease over the past 50 years, it was not an unreasonable perspective to hold when it was stated. The misunderstanding that arose and is still widely expressed is that extrinsic factors only means environmental contaminants (i.e. chemicals) rather than the wide variety of cancer-causing factors that we all experience after birth. Higginson, when he realized how his statements were being misinterpreted, provided an interview with *Science* (Maugh 1979) in which he explained: "*Environment is what surrounds people and impinges on them. The air you breathe, the culture you live in, the agricultural habits of your community, the social cultural habits, the social pressures, the physical chemicals with which you come in contact, the diet and so on. A lot of confusion has arisen in later days because most people have not gone back to the early literature, but have used the word environment purely to mean chemicals*." When asked if his comments about 90% of cancers being caused by extrinsic as opposed to genetic factors had been misjudged, Higginson said: "*They have been misinterpreted, funnily enough, not among the majority of scientists with whom I have contact, but by the chemical carcinogen people and especially by the occupational people*."

This experience is an example in which two things that apparently conflict can both be true, but in which the meaning and comparative importance of those truths can be misunderstood. There are a number of fully natural environmental exposures that cause cancer, including natural background radiation such as radon (lung cancer), ultraviolet radiation (skin cancer) and biologically produced agents like aflatoxin (liver cancer) and infectious disease, such as hepatitis (liver cancer). There are also specific carcinogens with more human-related sources that unquestionably have caused human cancers, perhaps most notoriously in the case of asbestos fibres, but also for chemical carcinogens like arsenic, benzene, vinyl chloride and chemical mixtures like tobacco smoke. There is no question that contaminants such as these have caused human cancers. Those established truths do not mean that the majority or even a substantial number of human cancers are caused by trace chemical exposures such as DBPs or other chemical contaminants in drinking water. This example of two simultaneous truths requires us to invoke the inevitable tension that was captured by Carl Sagan's quotation about scientific evidence (see *Letter from the Guest Editor*) to determine what evidence is most important for basing decision-making on.

## Discovery of THMs

DBPs were discovered in the early days of the emerging environmental carcinogen belief system, first by Johannes Rook (1974) and within months by Bellar et al. (1974). Rook was a chemist originally trained in the brewing industry where flavour compounds are an important consideration and he applied the newly emerging analytical technology of gas chromatography to develop techniques for analysing trace organic compounds that could be purged from drinking water at a time when a primary standard method for detecting trace organics in water was the carbon-chloroform extract. That method involved absorbing trace organics from water onto activated carbon and desorbing them into an essentially non-water soluble solvent, chloroform. Obviously, this established technique was blind to the presence of chloroform in any water being analysed.

Rook's landmark publication, in which he documented discovery of the presence of trihalomethanes (THMs) in chlorinated drinking water, also demonstrated that these were formed by reactions between chlorine and natural organic matter in water and that if bromide was present in the raw water, the brominated species, bromodichloromethane (BDCM), dibromochloromethane (DBCM) and bromoform (TBM) were also created. Almost immediately after Rooks' paper was published in a British journal which appears to have ceased publication in 1975, Bellar et al. (1974) published a 4 page paper in the December, 1974 issue of the Journal of the American Water Works Association (JAWWA). They reported that the U.S. EPA had confirmed detection of organohalides in drinking water that had been chlorinated, but they incorrectly identified ethanol as the likely precursor. The JAWWA lead-in to the article presciently stated: "*The national media have reported that the chlorination of water during treatment is responsible for the formation of potentially harmful chlorinated organic materials - notably chloroform - in, the nation's water supplies… The report concludes that the number of organohalides formed during the chlorination process does not constitute any immediate threat to the public health or welfare, but that more research into possible long-term effects is warranted*." Jim Symons (2001), a Chief in the Drinking Water Research Division of the US EPA, recounted his views at the time as being not overly concerned about health implications of chloroform because it was widely used in toothpaste and other consumer products. Moreover, the likelihood of ethanol being widely present to serve as a precursor in drinking water seemed unlikely. However, after consulting with Rook and becoming convinced that the actual precursor for THMs was natural organic matter that will be present to some extent in all surface water supplies, Symons became more concerned about widespread occurrence of THMs. These concerns were soon realized with publication of a US national survey (Symons 1975). At the time of these discoveries, the health risk evidence for chloroform was sparse, but the National Cancer Institute (NCI) published results of a rodent cancer bioassay (NCI 1976) that soon amplified health concerns by reporting strong evidence of chloroform causing liver tumours in mice, but not in rats. This finding largely drove the health risk perspective about THMs for another 20 years and to some extent still does today.

The meaning of these results will be elaborated further below based on the methodology used, but there was a comparatively rapid regulatory response, including from drinking water agencies. The U.S. Food and Drug Administration banned the use of chloroform in cosmetics, a major reversal for chloroform which had been pioneered as an anaesthetic in the mid-1800s and was used by the generally-acknowledged father of epidemiology, Dr. John Snow, who made his living as anaesthesiologist, and administered chloroform to Queen Victoria during childbirth.

Health Canada set a maximum acceptable concentration (MAC), on a not-to-exceed basis of 350 µg/L for total THM4 (sum of all four chlorinated and/or brominated halomethanes) in 1978, followed closely by a U.S. Safe Drinking Water Act maximum contaminant level (MCL) of 100 µg/L for total THM4 in 1979 as a running annual average of quarterly samples, citing recognition that cancer risk from THMs in drinking water was not an acute risk and that THM levels vary substantially with season. The World Health Organization (WHO) set a MAC of 30 µg/L for chloroform in 1984, but, by 1993, WHO had increased the chloroform MAC guideline to 200 µg/L and added MACs of 100 µg /L for TBM, 100 µg /L for DBCM, and 60 µg /L for BDCM. Australia added a MAC of 250 µg /L for THM4 in 1996. Health Canada adopted the running annual average of quarterly samples approach in 1996 to set a new MAC of 100 µg /L for THM4 that was reconfirmed in 2006. In 1998 the US EPA adopted a MCL of 80 µg /L for THM4 that was reconfirmed in 2006. In 1998, the European Commission (EC) adopted a MCL of 100 µg /L. Finally, WHO raised its MAC for chloroform to 300 µg /L in 2011.

Readers may well find all these changes confusing, but the underlying evidence on chloroform carcinogenesis, with chloroform usually the dominant THM found in chlorinated drinking water, were revisited following refined toxicology research in the 1980s (Bull et al. 1986; Jorgenson et al. 1985) that rejected the validity of the NCI bioassay, specifically of applying chloroform as a once a day, bolus oral gavage dose dissolved in corn oil near the acutely lethal dose of chloroform which had been experimentally adopted to overcome the limits on chloroform's solubility in water. The new research provided the chloroform to the laboratory rodents in their drinking water at water concentrations (up to 1,800,000 µg/L) and produced no significant carcinogenic response. This research confirmed that chloroform exerted its carcinogenic effect by a mechanism that had a demonstrable threshold below which no cancer risk would occur (Fawell 2000), meaning that its risk assessment should not be based on a non-threshold model that is reserved for genotoxic (DNA-damaging) carcinogens. Extensive debates and legal action in the U.S. until 2001 delayed full implementation of new THM4 regulations until 2006. In the meantime, these insights explain how WHO applied this threshold evidence to raise its MAC for chloroform from 30 µg/L in 1984, to 200 µg/L in 1993 and as at present, 300 µg/L in 2011.

Of course, the subject of DBPs in drinking water has expanded well beyond THMs and chloroform, but for many water purveyors, THMs remain their primary concern. The subject of other DBPs and their importance to human health risk will be addressed later in this article, but there is much to be learned from some detailed experience with THMs and chloroform.

## Disinformation and Misleading Messages about THMs and Cancer

Unfortunately, the foregoing critical story about cancer risk, or lack thereof, from chloroform, the dominant THM, is not widely understood in the drinking water industry and also unfortunately is not adequately understood among many of those performing and publishing research on DBPs and their associated health risks. In one case, a paper was published (Chowdhury and Hall 2010) that claimed to provide estimates of elevated annual cases of cancer and associated healthcare costs for 20 Canadian cities, i.e., Montreal (94 per year) and Toronto (53 per year), based on a calculation that fundamentally **misapplied** the U.S. EPA reference dose (RfD) from the Integrated Risk Information System (IRIS) data base as if it was a cancer slope factor. The difference between a cancer slope factor and an RfD is profound. An RfD is effectively the threshold dose below which no cancer risk is expected whereas the cancer slope factor is a parameter that is multiplied times an estimated dose to predict the number of cases of cancer. The slope factor necessarily has units that are the inverse of dose because when it is multiplied times an estimated dose, it yields risk that has no units.

Ultimately, the journal **retracted** this paper when presented with clear evidence that not only was the paper in error, the corresponding author was aware of the error and failed to notify the Editor, thereby violating the publication ethics policy. This paper now appears with a large diagonal watermark on every page stating that the paper is "**RETRACTED**". Yet, I have found at least a dozen papers have since cited this paper and in at least one case, even listed it in the reference list as "Retracted" while relying on its message.

This story did not end there because a companion paper (Chowdhury et al 2011) was published by the same corresponding author that used the same erroneous approach to calculate the number of cancer cases per year by Canadian province, claiming: "*In Canada, approximately 700 cancer cases may be caused by exposure to THMs in drinking water. Medical expenses associated with these cancer incidents are estimated at some $140 million/year*." The editors of the publishing journal were provided with a full explanation of the erroneous foundations for this paper, but declined to retract it, offering only an option to write a commentary about the paper. That commentary (Bull et al. 2011) pointed out that this paper used only THM monitoring data for the cancer risk predictions and that chloroform comprised 74-97% of the THMs in the data set used. Furthermore, even if there were a valid cancer slope factor for chloroform, which there clearly was not, its use would estimate a 95% upper bound lifetime (70 year) cancer risk, not an **annual** cancer risk. The corresponding author replied by not responding directly to the criticism, but by presenting revised cancer risk calculations relying to some degree on estimated cancer risk for chloroform by inhalation and dermal contact as well as some means of estimating cancer risk for BDCM, DBCM and TBM, the result of which was a revision from the original claim of 700 cancer cases per year in Canada to 227 cancer cases per 70 year lifetime (or 3.2 cases per year), although not clearly stated. Even these drastically reduced cancer risk numbers are an over-estimate. As noted (US EPA 2001), the cancer slope factor for oral ingestion of chloroform was removed and replaced by a RfD, which is described as: "*A dose of 0.01 mg/kg/day (equal to the RfD) can be considered protective against cancer risk*" in October 2001[1]. Specifically, this regulatory toxicology reference stated: "*Chloroform is not likely to be carcinogenic to humans by any route of exposure under exposure conditions that do not cause cytotoxicity and cell regeneration*." Moreover, the inhalation cancer risk for chloroform listed in IRIS for chloroform is qualified with the disclaimer: "*The following evaluation of cancer risk from chloroform inhalation was developed in 1987 and does not incorporate newer data or the 1996 or 1999 draft cancer assessment guidelines. EPA is currently working to revise the assessment for inhalation exposure.*" In other words, the cancer slope factor for chloroform exposure by inhalation has not yet been withdrawn, nor has it been reconciled with the evidence that led to the ingestion cancer slope factor being withdrawn. The cancer risk assessment for BDCM was last updated in 1993 so it does not reflect the findings of a 2006 National Toxicology Program (NTP) bioassay on BDCM that delivered it dissolved in drinking water to

[1] *This cancer risk-free chloroform threshold dose corresponds to a 70kg adult consuming/exposed (accounting for inhalation exposure) to an ingestion equivalent of 4L of water per day with a lifetime chloroform concentration of 175 µg/L*

find that it did not appear to cause cancer in laboratory animals in contrast to the 1987 NTP corn oil dosing study that yielded the IRIS cancer slope factor for BDCM was calculated from. The experience with BDCM is essentially equivalent to the prior experience with chloroform, but IRIS has not yet been updated. TBM has not had an update from its original corn oil dosing study and DBCM is listed with no cancer risk estimate. These limitations on evidence all undermine any attempt to calculate cancer risks from THMs in drinking water.

Unfortunately, Chowdhury et al. (2011) has been cited more than 50 times since publication, including a new paper (Kali et al 2021) that still cites the totally incorrect 700 THM-caused cancer cases **per year** for Canada.

Drinking water professionals cannot be expected to discern all of these subtle details that bear on what should be their priorities, but there is certainly scope for regulators to recognise this challenge and seek to provide clear messages about health risk where there are such obvious errors being published. Society has come to understand that disinformation is proliferating on the internet, but everyone needs to understand that serious disinformation is also being propagated in the "refereed" scientific literature. Some tolerance is clearly warranted for the public's misunderstanding of drinking water safety issues when the scientific research establishment is apparently unable to deal with disinformation, even when it has been clearly documented.

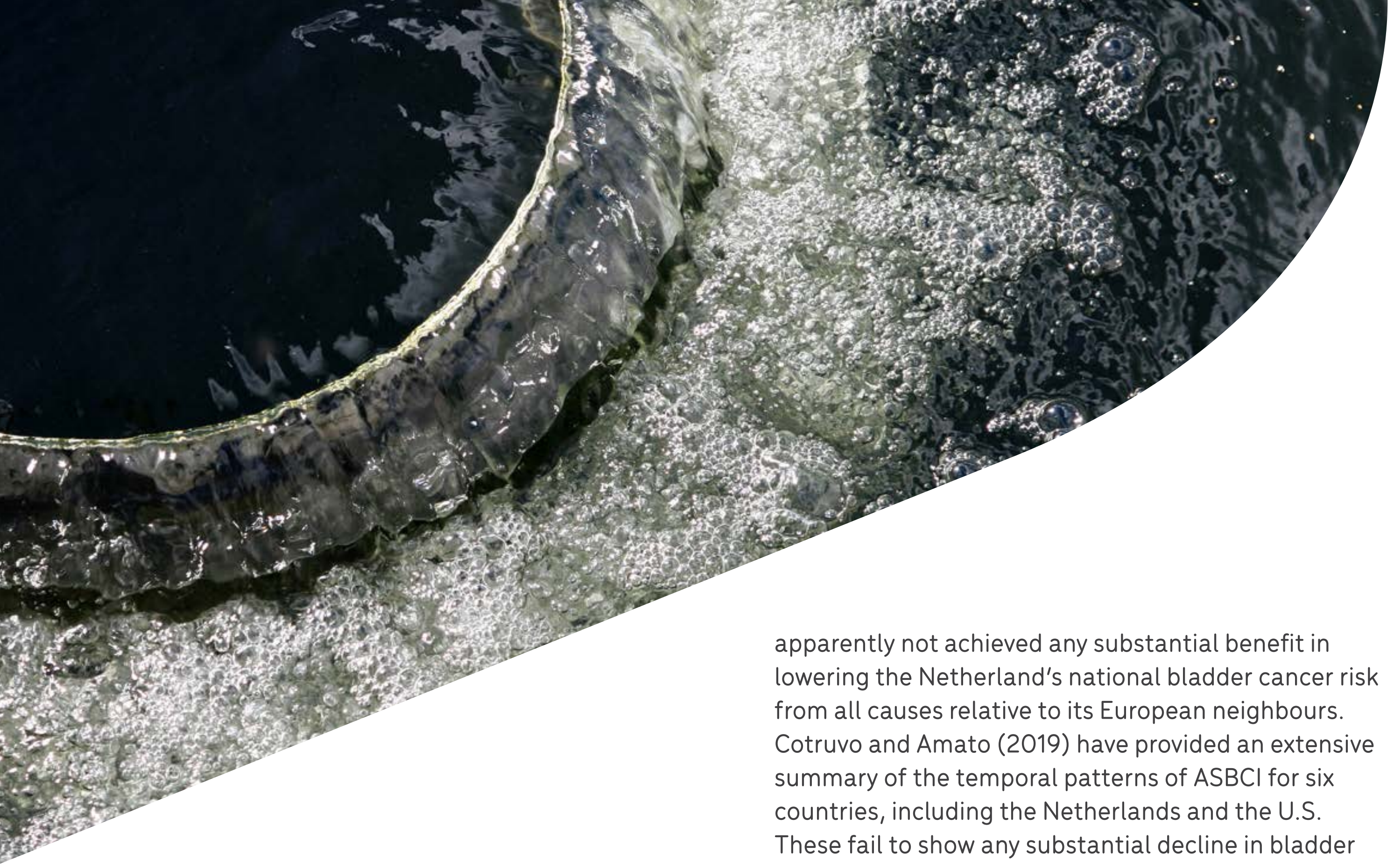


The scope of this discussion does not allow an extensive look into the epidemiology studies that have been conducted since Rook's discovery in 1974, but there have been a large number looking for evidence of human cancer caused by DBPs, most often focusing on DBPs caused by chlorine disinfection. The results of these studies for determining a causal relationship were summarised by the US EPA (2001) as "*inadequate*", but for the purposes of developing precautionary drinking water guidance for THMs, the greatest consistency of evidence was judged to be the possibility of an association between chlorination DBPs and bladder cancer. This possibility was given new support by an international study based in Spain (Cantor et al. 2010) that attempted to address one of the major weaknesses of previous studies, improving assessment of individual exposure slightly and applying elements of genetic susceptibility to their analysis. The Water Research Foundation convened a 2014 international expert panel in Washington, DC to review the strengths and limitations of the available evidence concerning chlorination DBPs causing human bladder cancer. The findings (Hrudey et al. 2015a,b, see **HS80**) were that while a causal association between chlorination DBPs and bladder cancer remained a viable research hypothesis, the available evidence was unable to inform risk management in a manner that warranted any further tightening of U.S. regulations on chlorination DBPs. A total of 13 analytical[2] epidemiology studies on the topic were reviewed in detail. In other words, no case has been made to abandon current DBP regulations, but more stringent regulations on chlorination DBPs cannot be justified on the basis of human health risk evidence. An important finding in Appendix C of the full panel report (Hrudey et al. 2015b) was the large discrepancy that exists between estimates of cancer risk from the inevitably imprecise epidemiology studies and the summation of cancer risks from toxicological risk assessment for individual DBPs based on animal experiments, with the latter being more than two orders of magnitude lower.

If scientific research was performed only in an ivory tower, without any possibility of having research results that are not adequately qualified contribute to public beliefs and fears that can lead to unhealthy behaviours, some of the concerns expressed here might be unwarranted or at least unnecessary. But of course, scientific research findings have become part of the daily news and the public can readily adopt, uncritically, findings that align with their personal beliefs.

A case in point arose with a recent publication (Evlampidou et al. 2020) that presented estimates of annual bladder cancer cases for 28 European countries coming up with a total estimate of 6,561 bladder cases per year (95% CI 3,389 – 9,537) for a total resident population of 404,672,106. Oddly, the journal this research appeared in, published by the U.S. National Institute of Environmental Health Sciences, does not accept written commentary on research papers that it publishes. Submitted commentaries provide a vehicle that is important to allow meaningful discussion of scientific research. In this case, a critical commentary on this paper had to be published elsewhere (Cotruvo et al. 2020). In summary, that critique notes that the methodology used was so hypothetical that presenting a table of annual bladder cases to the precision of a single case (even if confidence intervals were reported) is seriously misleading to anyone unfamiliar with how unjustified were the assumptions that had to be made to enable these calculations. Without belabouring the details of the critical discussion, annual average THM levels, without speciation among the individual THMs were assigned to each country, along with an exposure response function derived from a single study that analyzed six epidemiology studies (two from the U.S., one each from Canada, France, Finland and Spain) to derive an odds ratio of 1.004 (95% CI 1.002 – 1.006), per 1 µg/L THM exposure. This was adjusted for each country to determine a population attributable fraction (PAF) for each country. Cancer statistics consistently show that male and female risks for bladder cancer are substantially different, but this gender difference

*[2] Only Case-Control, Cohort and Clinical Trial studies that involve data collection on both indivudal exposure and outcome are regarded as being "Analytical" epidemiology studies that are capable of informing causal inference. Clincial trials that are commonly used for judging efficacy of drugs and vaccines are not possible, or ethical, for studying decades long exposure to DBPs. Many additional population-wide studies have been performed, typically termed "ecological" studies, but these are judged to be only capable of generating causal hypotheses, not testing them.*



was not mentioned in the analysis. Use of PAF tacitly assumes that the agent it is applied to, in this case THMs, are causal for the disease under analysis, in this case bladder cancer. This is an essential causal assumption that is not accepted by drinking water health regulatory agencies because the epidemiological evidence remains inadequate. Despite the enormous uncertainty inherent in the Evlampidou et al. (2020) analysis, with its 30 co-authors, the predictions made are wholly hypothetical and they provide almost no useful insight for ensuring safe drinking water in Europe, the target audience.

Ironically, Denmark and the Netherlands that were assigned negligible bladder cancer risk by Evlampidou et al. (2020), presumably because of low use of chlorine disinfection, are listed as third and fifth highest among 25 countries for age-standardized bladder cancer incidence (ASBCI) per 100,000 population while the U.S. which is among the highest users of chlorine disinfection in the world, ranks 20th (WCRF 2018). Another anomaly is that Malta (ranked 18th of 25 by WCRF 2018), which Evlampidou et al. (2020) assigned the third highest PAF (179 times higher than the Netherlands), has an ASBCI that is only 77% of the ASBCI for the Netherlands in 2018. Such population level statistics cannot tell us anything directly about causes of specific cancers, but the findings about Denmark and the Netherlands inevitably suggest that any conceptual national strategy to lower bladder cancer incidence by reducing THM exposure by minimizing chlorine disinfection has apparently not achieved any substantial benefit in lowering the Netherland's national bladder cancer risk from all causes relative to its European neighbours. Cotruvo and Amato (2019) have provided an extensive summary of the temporal patterns of ASBCI for six countries, including the Netherlands and the U.S. These fail to show any substantial decline in bladder cancer incidence in either country over decades, despite the almost total reduction in THM exposure in the Netherlands over that time as wells as substantial reductions in THM exposures in the US. Population level data such as these have shown valuable temporal trends evident in most countries when comparing lung cancer incidence with prior declining rates of tobacco smoking that is known to be the dominant cause of lung cancer.

## Countless Other DBPs

One did not need to be a Nobel Prize-winning chemist to recognize that Rook's discovery of THMs was not only the tip of an iceberg, more like the tip of Mount Everest. Disinfectants, to be effective, must be able to react with organic matter and there is likely no quantifiable limit to the number of possible unintended by-products that could be DBPs. Haloacetic acids were the next major class of DBPs to attract regulatory interest. Among major international regulations or guidelines for drinking water, there are now published concentration limits specified for monochloroacetic acid (MCAA), dichloroacetic acid (DCAA), trichloroacetic acid (TCAA) and HAA5 (sum of MCAA, DCAA, TCAA, monobromoacetic acid and dibromoacetic acid), chloral hydrate (trichloroacetaldehyde), chlorophenols, cyanogen chloride, dichloroacetonitile, dibromoacetnitile, formaldehyde and nitrosodimethylamine (NDMA). There are also some inorganic DBPs with quantitative limits like bromate (attributable to ozone disinfection), chlorite and chlorate (attributable to chlorine dioxide disinfection). Finally, some DBPs of interest are discussed in guidelines (e.g., chlorinated furanones, such as 3-chloro-4-[dichloromethyl]-5-hydroxy-2[5H]-furanone, abbreviated as MX, chloroketones, chloropicrin) even though evidence for them is judged to be inadequate to set a drinking water guideline or standard.

> *“What seems clear is that cancer risk cannot be explained by THM exposures, indicating that other, as yet unidentified DBPs, need to be identified.*

A frequently cited reference (Richardson et al. 2007) had suggested that more than 600 DBPs had been reported in the literature. The total number of possible DBPs is unknown and likely unknowable, given the virtually unlimited diversity of chemical structures that can serve as precursors for DBP formation. More recently 700 is commonly cited. Even only a small fraction of the 700 have been evaluated for toxicity and testing them in mixtures in a manner that can prove instructive is a huge challenge. What seems clear is that cancer risk cannot be explained by THM exposures, indicating that other, as yet unidentified DBPs, need to be identified. Bull et al. (2011a) considered plausible reaction products involving known substrates comprising natural organic matter, evaluated available toxicological literature and applied quantitative structure toxicity relationships to predict DBPs that might be found and could be relevant as contributors to carcinogenicity. One predicted group of potential carcinogens from this exercise, halobenzoquinones were confirmed in disinfected drinking water (Anachina et al. 2010, Qin et al. 2010), although their typically found concentrations are inadequate to support them posing a substantial cancer risk to consumers.

The foregoing theme has been repeated with nitrosamines, a class of nitrogen-containing compounds identified as a carcinogenic risk in foods and beverages. NDMA was first reported as a DBP in Ontario in 1993. After being rediscovered by others, NDMA and related nitrosamines became the subject of numerous research studies because NDMA, unlike chloroform and other THMs, was unequivocally established as an animal carcinogen by a genotoxic mechanism. Drinking water guidelines have been adopted for NDMA at very low concentrations (WHO, Australia at 0.10 µg /L, Canada at 0.04 µg/L) because of concerns for its toxic properties. Fristachi and Rice (2007) first raised the question of whether NDMA exposures from drinking water comprised a large enough proportion of total human consumption to warrant the drinking water concern. Hrudey et al. (2013) had the benefit of access to data from the US EPA for the second Unregulated Contaminant Monitoring Rule (UCMR2) program that analysed for six volatile N-nitrosamines: NDMA, N-nitrosodiethylamine, N-nitrosodipropylamine, N-nitrosopyrrolidine, N-nitrosomethylethylamine and N-nitrosodibutylamine, assessing their occurrence in U.S. drinking water and providing results for over 18,000 water systems. These data confirmed that nitrosamine concentrations were higher for systems using chloramines (often to reduce THM formation) compared with using free chlorine for disinfection. This massive nitrosamine occurrence data base and a detailed evaluation of evidence from several sources about the quantities of natural, human endogenous metabolic nitrosamine formation were used to establish estimates for what proportion of total human exposure to NDMA (the dominant nitrosamine found by a large margin in drinking water) could be expected from drinking water consumption. A Monte Carlo simulation model was developed to determine that drinking water contributes a mean proportion of the lifetime average daily NDMA dose, ranging from between 0.0002% and 0.001% for surface water systems using free chlorine or between 0.001% and 0.01% for surface water systems using chloramines. The main driver for these contributions to human NDMA exposure from drinking water consumption being so minor came from the much larger, entirely natural endogenous production of NDMA resulting from human metabolism of nitrogen containing foods.

# The Challenge of Trace Chemical Exposures and a Logical Way Forward

The unquestioned complexity and diversity of DBPs raises the serious question about how can we deal with this issue. The first thing that must be understood is that detecting chemicals with complex, exotic names in drinking water in trace amounts does not mean that drinking water poses a health risk. The very reason that considerable resources are invested in setting maximum acceptable values for individual contaminants in drinking water is that it is **not** merely the fact that we can detect a contaminant in drinking water, it must be whether the amount detected is sufficient to be able to cause an adverse health effect, i.e., approaches or exceeds guidelines.

What is apparently not widely understood is how enormous is the scope for true contaminants, such as DBPs, to be detected in drinking water. To visually depict this challenge, Figure 1 shows a scientific reality, the numerical range of concentrations that is possible for a substance that is totally miscible (soluble at all concentrations) in water. For this purpose, Figure 1 is based on a completely known and widely consumed, biologically active toxic substance, ethyl alcohol (ethanol). Ethanol has a density of 0.78945 g/mL. This means that 1 litre of ethanol will correspond to 789.45 g of ethanol, which is 17.136 moles of ethanol. Given that l mole of a substance, according to Avogadro's number, consists of $6.02214 \times 10^{23}$ molecules per mole, 1 L of pure ethanol will have $1.03 \times 10^{25}$ molecules.

The other annotated points are mostly approximate given the variable alcohol content of the beverages and human biological indicators mentioned. The lethal number of molecules of ethanol in human blood is about $6 \times 10^{22}$ based on the mean blood alcohol concentrations reported in autopsies of 28 lethal alcohol poisonings studied in Scandinavia (Poikolainen 1984), i.e., authentic evidence. The legal impairment blood alcohol level of 0.05% corresponds to about $7 \times 10^{21}$ molecules of ethanol per L of blood.

Figure 1 also shows the comparative position (expressed as molecules or atoms per litre) for maximum acceptable concentrations for existing drinking water guidelines as well as showing the very small number of viable microbial pathogens needed to infect human consumers. Finally, there is an enormous gap between the lowest identified DBP chemical concentrations and the actual lower limit in terms of molecules per litre. This gap ensures that as analytical technology continues to improve, new DBPs can and will be found, but not necessarily with corresponding evidence that such low level exposures are capable of causing any adverse human health effects. In contrast, we know, with absolute certainty that microbial pathogens can and do cause human disease via drinking water exposures. The numbers required to cause infection, although somewhat uncertain, are inherently small, presumably because pathogens can replicate themselves, versus the number of molecules of a chemical toxic agent necessary to cause human illness. Chemical contaminants cannot replicate themselves.

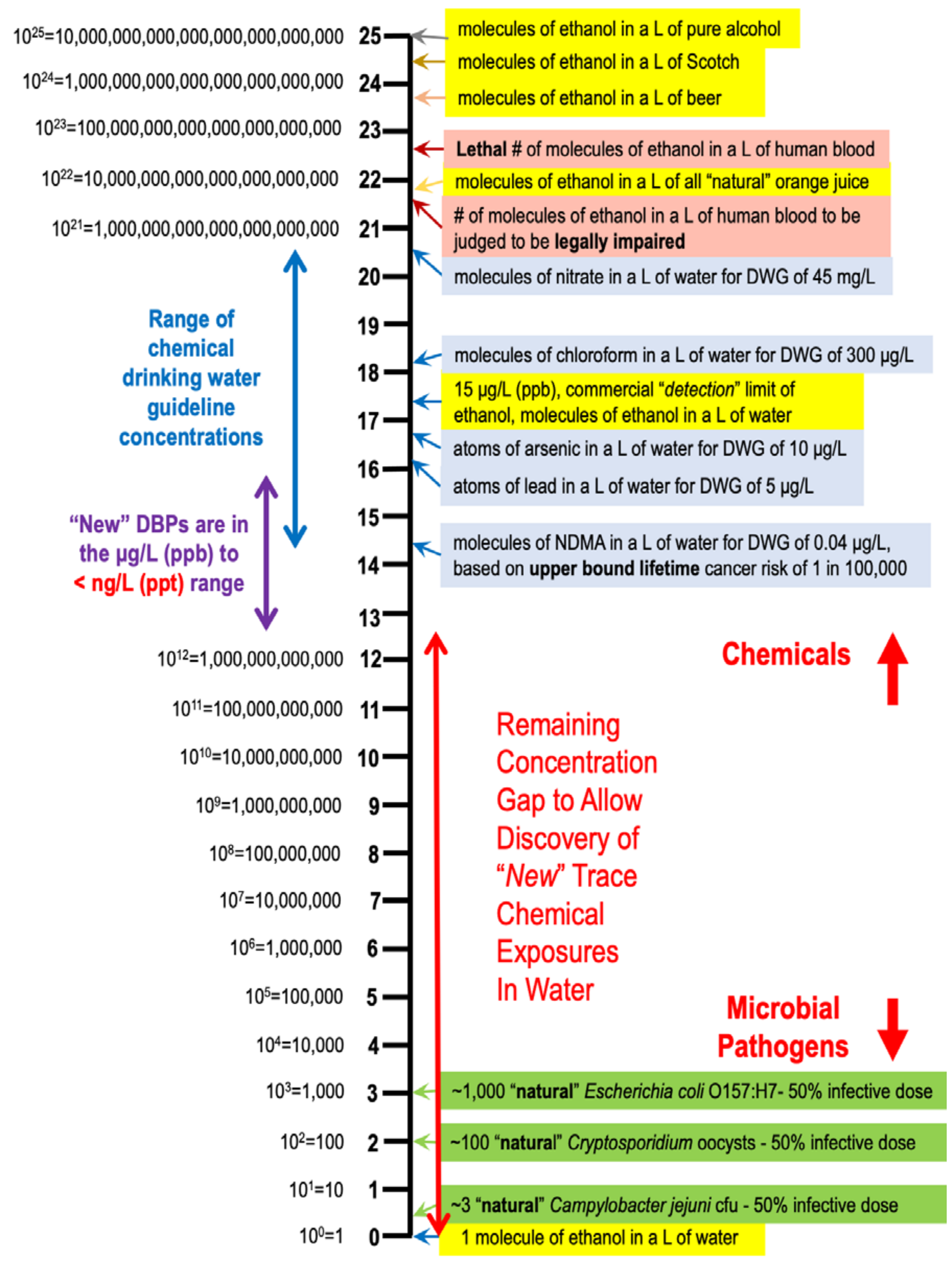



*Figure 1 Illustration of concentrations on a log scale with a common toxic substance, ethanol*

A number range this expansive can only be visually depicted by resorting to a logarithmic scale, in this example using logs to the base 10. This depiction of reality shows that although we should be rightfully impressed by our ability to detect substances in water, there is clearly enormous scope to detect ever lower concentrations of substances in water as analytical technology continues to improve. Likewise, the range of concentrations over which biological effects are caused is usually not greater than two or three decades, compared with the 25 decades shown. Trace detection of contaminants is, by itself, only an indication of the analytical technology used to achieve detection and does not necessarily carry any meaning about health effects unless the detected concentration is close to or exceeds a health-based maximum acceptable concentration. Even exceeding a maximum acceptable concentration does not signal imminent harm because most guideline levels are set for lifetime consumption and the values determined are set with intentional and substantial margins of precaution, often 1,000 fold (3 decades on Figure 1).

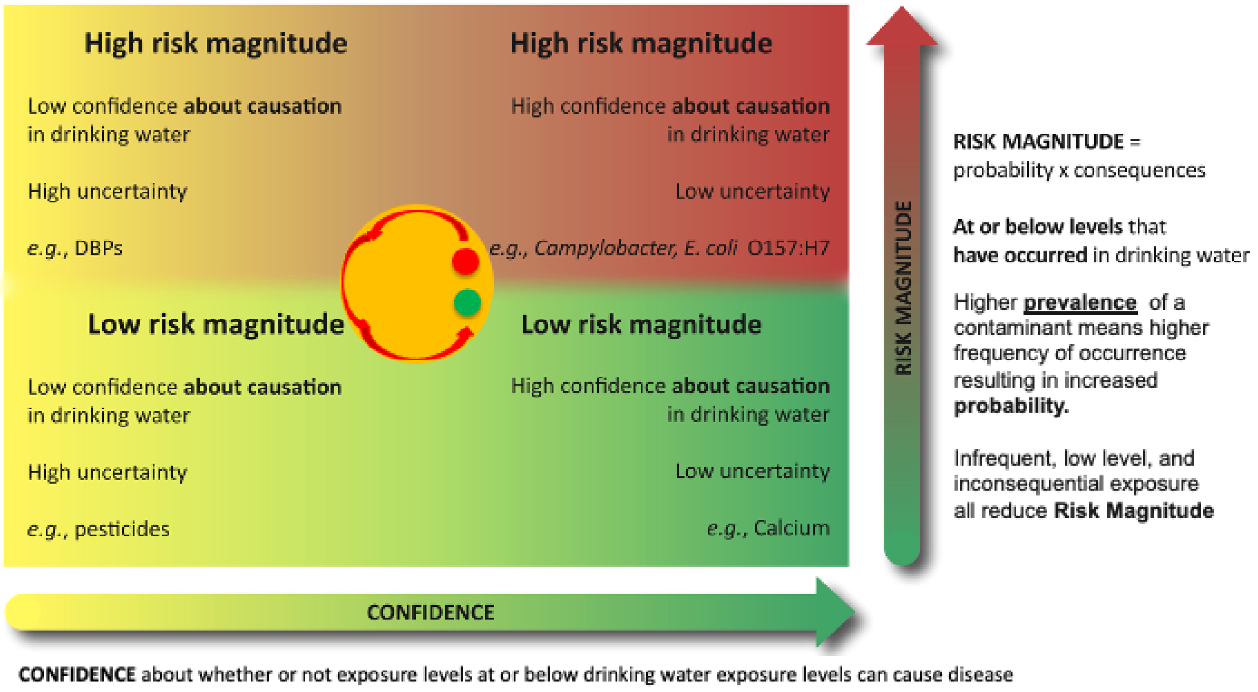



*Figure 2 Hierarchy of health risks based on characteristics of risk magnitude and comparative confidence in evidence of causation of illness from drinking water (Hrudey et al. 2012)*

This reality of an open-ended array of contaminants that can be detected is a challenge, not only for DBPs, but for countless other substances that will be detected in drinking water sooner or later. The question for us is how do we cope with this challenge and once we confront this reality what can we do to address it. With that challenge in mind, the Canadian Water Network assembled a group of drinking water experts, including Martha Sinclair, Joan Rose and John Fawell to address how to deal with the pervasive uncertainty that underlies the assessment and management of health risk for drinking water (Hrudey et al. 2012). That panel report recommended recognition of a hierarchy of drinking water risks based on fundamental properties of comparative risks:

**1 Highly certain and pervasive risks (requires action for any water system)**

These are best represented by the microbial pathogens that are known to cause human disease via drinking water exposure and because of their fecal origin present a pervasive risk to all surface water systems, many groundwater sources and to all distribution systems.

**2 Reasonably certain but less pervasive risks (appear in some drinking water systems)**

These should be identified and addressed as demonstrably necessary – various parameters have provided essentially certain evidence of causing human illness (or adverse health effect) via drinking water exposure at some time, somewhere in the world (e.g., arsenic, fluoride, nitrates and lead – WHO 2007). These will be site-specific and only apply to some water providers.

**3 Common but comparatively uncertain risks (possibly produced in water treatment)**

These require a rational precautionary response – various parameters (e.g., DBPs, aluminum, water treatment chemicals) warrant scrutiny because they are produced or added in the water treatment process, are very common and may be amenable to reduction through process refinements.

**4 Site-specific contaminants with noteworthy toxic potential**

These require localized plans commensurate with risk – various parameters (e.g., pesticides, cyanobacterial toxins) with toxic potential relevant to drinking water exposure and that can be found in water need to be assessed to determine site-specific relevance, levels of exposure and appropriate local action.

**5 Emerging contaminants**

These require research to characterize the nature of problem – advances in analytical chemistry guarantee that many contaminants will continue to be identified in drinking water and these require research to characterize their nature to determine if they pose a drinking water health problem vs. a hypothetical problem. Once research has adequately characterized the risks, and the importance of drinking water exposure relative to other sources of human exposure, such emerging contaminants may be classified into an appropriate category above. In the meantime, treatment barriers should not be altered unless there is reasonable certainty that such alterations will not simply create other, as yet uncharacterized risks.

Another means of comparing and recognizing differences among risks is captured in Figure 2 which acknowledges that there is no truly zero risk (just as there is no zero on a logarithmic scale, $10^0=1$, $10^{-1}=0.1$, $10^{-2}=0.01$, etc., *ad infinitum*). Likewise, we need to recognize, although not illustrated in Figure 2, that differences in risk magnitude for different risk agents will span many decades. The challenge in risk management is to recognize objective differences among different risks so that bigger risks can receive greater management attention than smaller risks. The key features illustrated in Figure 2 are similar to the foregoing hierarchy of risk in considering the possible magnitude of risk together with our confidence that the risk under evaluation can truly cause adverse human health impacts by drinking water exposure. Put in simple terms, not all risks are created equal. Put another way, if all risks are treated as equally important, given the open-ended range of risks that can be described, then the most serious risks will not receive the priority risk management attention that they warrant.

## A Bottom Line about DBPs

The reality about DBPs is that ever since Rook discovered THMs in 1974, no one in the water industry can or should ignore DBPs. As with any chemical substance, sufficient exposure to any particular DBP can pose a human health risk. There is no such thing as zero risk. However, if drinking water providers and regulators are going to honour a commitment to rational risk management, they and all of us must be prepared to rationally distinguish higher risks from lesser ones and ensure that the higher risks are managed with greater priority than much lesser ones.

Formation of DBPs to some measurable degree is inevitable as long as drinking water is disinfected. We cannot escape the reality that microbial pathogens will inevitably cause human disease if drinking water is not disinfected because the source of microbial pathogens, faecal wastes from humans, pets, livestock or wildlife / wildfowl, exist anywhere humans reside (i.e., pathogens are not only a certain health risk, they are a pervasive one).

Debates about disinfection are frequently transposed into debates about using chlorine disinfection or not. Because chlorination is the most cost-effective, reliable and easy to use disinfectant and the only disinfectant that can maintain a residual throughout a piped distribution system, it is not surprising that chlorination is the most widely used form of disinfection. The main disadvantage of chlorination is that when managed inconsistently, chlorination causes a taste that many consumers find offensive. This feature allows consumers to know about chlorination being practiced without having to resort to any laboratory analysis. This feature alone seems insufficient to explain the numerous examples of consumers rejecting chlorine disinfection. The uncertain claims about adverse health effects being caused by chlorination DBPs seems, if only superficially, to provide a stronger basis for the rejection of chlorine disinfection. Some of the many cases of documented opposition to chlorine disinfection with resulting disease outbreaks (six with fatalities) are: Creston / Erickson, B.C. (1980s-1900s), Walkerton, Ontario (2000), un-named town, Québec (2018), Canada; Cabool (1989) and Gideon (1993), Missouri, Alamosa, Colorado (2008), USA; Darfield (2012) and Havelock North (1998, 2016), NZ; Tune (2009) and Køge (2010), Denmark; Askøy (2019), Norway (Hrudey and Hrudey 2004, 2014, 2019; Soto et al 2020; Hyllestad et al 2020 – the latter two references are summarised in the *From the Literature* section).

There may be authentic aesthetic reasons for opposing chlorination, but opposing disinfection of drinking water, given the overwhelming evidence and experience of serious waterborne disease outbreaks caused by microbial pathogens, makes even less sense than opposing vaccination, a public health measure that has saved countless lives over the past century. Invocation of health concerns about DBPs as a reason to oppose disinfection is simply not rational because the DBP health risks remain hypothetical after almost 50 years of research, contrasted with the absolute certainty that pathogens in drinking water can and continue to cause human illness.

If the majority of rate-paying consumers are opposed to chlorination, they need to be prepared to pay the extra costs for alternative disinfection processes and for greatly enhanced distribution system maintenance and monitoring. A minority opposed to chlorination of drinking water has a wide range of individual options to avoid chlorinated water, but it is not reasonable that they should be able to impose personally-preferred risky behaviour on other drinking water consumers. The bottom line is that there is no valid risk-based evidence that supports the provision of undisinfected drinking water to consumers.

To leave the reader with a more optimistic perspective about our ongoing pursuit of ensuring safe drinking water, despite the potentially infinite variety of mutations of microbial genetic material, all microbial pathogens, emerging or otherwise, are microscopic particles. This reality means that the multiple barrier approach to safe drinking water that employs optimized fine particle removal and disinfection processes to inactivate any infective pathogens that escape the fine particle removal step provides a high degree of assurance that drinking water can be free of infective agents, regardless of any emerging, novel genetic makeup.

## Relevant New DBP Literature

A few selected relevant new DBP research papers are provided in the *From the Literature* section of Health Stream.

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# THE FLINT WATER CRISIS POLITICIANS AND BUREAUCRATS TAKE HEED

**What has become colloquially known as the Flint Water Crisis was first described in Health Stream (HS81) in April 2016 where a detailed summary of the drinking water disaster was provided. Updates on Flint were provided in Health Streams issues 82, 83, 86, 87, 89, and 91.**

This crisis occurred in the under-privileged community (40% of the population below the U.S. poverty level) of Flint, Michigan following a political decision to change its drinking water source for economic reasons.

In short, the decision imposed by the State in April 2014 to abandon the existing drinking water supply from the City of Detroit, which was providing corrosion control by addition of phosphate, in favour of drawing water from the Flint River resulted in a series of unfavourable water quality changes, these included a marked increase in corrosivity leading to elevated lead levels at consumers' taps along with other aesthetic signals of corrosion (e.g., discoloured water, off flavours) over a period of 17 months. Evidence of elevated lead levels in children led to declaration of a public health emergency with a "Do Not Drink" water advisory issued on October 1, 2015. Flint was reconnected to the Detroit water supply on October 16, 2015. Subsequent evidence of a possible contribution of Flint water to an outbreak of Legionnaires' Disease (LD) in Genesee County, where Flint is located, has added considerable notoriety and scientific controversy to this issue.

**HS82** (July 2016) reported that three people had been criminally charged for their roles in the Flint Water Crisis and a civil law suit was lodged with two engineering companies for damages arising in this matter. **HS83** (October 2016) reported that six further state employees , three each from the Michigan Department of Health and Human Services (MDHHS) and the Michigan Department of Environmental Quality (MDEQ), had been charged. **HS86** (July 2017) reported that five city officials had been charged with involuntary manslaughter relating to deaths from LD, bringing the total legal action to 51 criminal charges.

> *“Elevated lead was the original serious health concern for Flint’s drinking water supply.*

Since then, the story has continued to evolve with increasing controversy. In June 2019, after a change in State government and the firing of the Special Counsel retained by the former Attorney General who had laid the foregoing charges, the new Attorney General announced that all remaining charges were being dropped, without prejudice (meaning that they could later be re-instated), citing concerns with the investigative approach and legal theories of the Special Counsel, particularly concerning the pursuit of evidence. Up to that time, seven individuals had accepted guilty plea agreements to misdemeanor charges that involved no fines or jail time. The new Attorney General also announced that she was putting a conflict wall in place to ensure the criminal investigation and civil litigation following the Flint Water Crisis were conducted by completely separate teams and that she would lead the civil case herself.

On January 14, 2021, the State Attorney General announced new indictments for nine individuals, including the former Governor and his former Chief of Staff as well as one of the Governor’s former Senior Advisors. The former Governor was charged with two counts of wilful neglect of duty, both only misdemeanors with a maximum of sentence of one year in jail and/or $1000 fine, but his former Chief of Staff was charged with one count of perjury and his former Senior Advisor was charged with one count of perjury, one count of official misconduct in office, one count of obstruction of justice and one count of extortion. The perjury charges carry a maximum sentence of 15 years and extortion a maximum of 20 years. The other six individuals charged were among those previously charged in the original round of charges now dismissed, in June 2019. The new charges included nine counts of involuntary manslaughter each against the former Chief Medical Executive of the Department of Health and Human Services and against a former of Director of that department. These latter charges, in particular, are likely to involve competing scientific evidence since the deaths involved were all attributed to LD, as further elaborated below. Likewise, the extortion charge against the Senior Advisor to the Governor alleges he communicated a threat to cause harm to the reputation and/or employment of a leader of the state-appointed Flint Area Community Health and Environmental Partnership (FACHEP) with the intent to coerce that investigation leader to act against his will during FACHEP’s investigation into the source of the LD outbreak in Genesee County, Michigan.

**HS89** reported in April 2018 on a multidisciplinary research team operating under the FACHEP with a US$ 3.35 million funding agreement between the MDHHS and Wayne State University (WSU) to investigate the role of the Flint water quality incident and the outbreak of LD in Genesee County. A multi-university research team published their findings (Zahran et al. 2018) with a subsequent disclosure that two of the authors had been subpoenaed to testify in the trials of the Director of MDHHS and the Chief Medical Executive of MDHHS. **HS89** reported that MDHHS had strongly criticized the published findings which acknowledged that there had been an outbreak of LD at a Flint hospital but maintained that the hospital outbreak could not completely account for the cases that occurred during the period of the water quality crisis in Flint. **HS89** further reported that MDHHS had retained the Netherlands Watercycle Research Institute (KWR) to undertake independent oversight of the FACHEP investigation. When Zahran et al. (2018) was published online, February 5, 2018, MDHHS posted a statement criticizing their findings and claiming that the authors had ignored the Department’s criticisms and concerns.

The KWR-led team that included a range of investigators from U.S. and other Netherlands research organizations published its own findings in December 2019 (Smith et al. 2019) about the 2014-2015 LD outbreak. They confirmed that there was an outbreak in Genesee County with observed incidence of LD 3.49 times higher than expected (95% credible interval 1.98 – 6.25) in 2014 and 3.67 times higher than expected in 2015 (95% credible interval 2.10 – 6.48). They identified 3 possible causes: exposure to Hospital A in Flint, exposure to the Flint water system and proximity to some cooling towers in the region. 49% of confirmed cases (42 of 86) were associated with exposure to Hospital A, but even after exclusion of hospital cases observed incidence of LD in Genesee County was 2.04 times higher than expected (95% credible interval 1.08 – 3.84) in 2014 and 1.78 times higher than expected (95% credible interval 0.93 – 3.33) in 2015. In 2014, residents receiving Flint water were significantly more at risk of LD with an Incidence Rate Ratio (IRR) of 3.9 (95% credible interval 2.0 – 7.7), but no excess risk was found for 2015 with an IRR of 0.9 (95% credible interval 0.4 – 1.9). IRR = 1 signifies no observed excess risk. A possible independent third cause was geographic proximity to cooling towers, but the statistical evidence was substantially weaker and numbers became too small for sufficient statistical power in analyses when hospital A exposure cases were excluded. Smith et al. (2019) reported that the MDHHS (2018) descriptive study noted the hospital exposures, but not the residential exposures to Flint water while the Zahran et al. (2018) study had recognized only 25 cases rather than the 42 cases confirmed by Smith et al. (2019) who were also critical of the modeling done with regard to chlorine residual in Flint water. Neither of the previous studies had considered the cooling tower proximity, but that is a comparatively small aspect of the causal analysis presented by Smith et al. (2019).

A different approach was taken by Nelson et al. (2020) who estimated that Genesee County had experienced an excess of 70 pneumonia deaths during the period (June 2014 to October 2015) of the LD outbreak (which caused 10 deaths among 90 confirmed cases) and the areas of high pneumonia mortality overlapped with those of high LD incidence, suggesting that the LD outbreak may have been larger than reported. Although this analysis is limited in its ability to validate the hypothesis, the authors noted that Cassell et al. (2019) estimated that only 10.6% of hospitalized LD cases are clinically diagnosed and NASEM (2020) suggested that the actual number of LD cases in the U.S. could be 7 to 10 times higher than officially reported. The latter, valuable, authoritative expert panel report is available as a free pdf download on the National Academy Press website (see *News Items*). Joan Rose chaired this panel along with co-author Nick Ashbolt and the report was reviewed by Jennifer Clancy, all of whom have offered their own personal perspective comments for the feature article of this issue *Review of 25 Years of Progress Towards Safe Water*.

Martin et al. (2020) used laboratory experiments to assess the potential for the water quality changes that occurred in Flint during the period when water from the Flint River was being treated locally without corrosion control to contribute to the LD outbreak. Simulated distribution systems (SDSs) and simulated premise plumbing reactors (SPPRs) made of either cross-linked polyethylene or copper pipe were able to reproduce water chemistry changes and *Legionella* proliferation that were experienced in Flint before, during and after the LD outbreak. The chlorine deficient conditions during the outbreak allowed elevated *L. pneumophila* in the polyethylene pipes during stagnation, but not in the copper pipes. This was explained by noting that copper corrosion under these conditions created bacteriostatic conditions.

> *Although the health implications of elevated lead in drinking water and an outbreak of LD that involved fatalities have rightfully dominated the tragic story of the Flint Water Crisis, adverse mental health impacts have also been investigated.*

Knowledge of the Flint story informed a retrospective investigation of a smaller (58 cases, 12 deaths) LD outbreak in Quincy, Illinois (Rhoads et al. 2020). Although the overall evidence available was not conducive to definitive answers, a provocative circumstantial case was made that mismanagement of water quality by ill-informed decisions could have contributed to this LD outbreak as well as possibly contributing to elevated blood lead levels in children in this community. Clopper et al. (2021) took the issue of classifying the environmental and water management root causes of LD outbreaks to a more generic level by analyzing 14 Centers for Disease Control and Prevention (CDC) investigations between 1 January 2015 and 21 June 2019. They found that 72% of LD cases and 81% of fatalities occurred at facilities without a water management program, a process element recommended and guided by CDC (Messonier and Breysse 2017). The analogy between this recommended plan for premise plumbing and the drinking water safety plan recommended for public water utilities is important (Baum et al. 2016). A broader perspective on *Legionella* spp. and other opportunistic pathogens, including *Pseudomonas aeruginosa*, *Mycobacterium avium*, *Stenotrophomonas maltophilia*, and *Acinetobacter baumannii* that can develop in drinking water premise plumbing systems has been reviewed by Falkinham (2020). These issues, along with lead contamination, present some of the most intractable problems for drinking water purveyors because they involve serious health consequences and can be influenced by water quality parameters under the control of purveyors but are not subject to the control of and resolution by them.

Elevated lead was the original serious health concern for Flint's drinking water supply. **HS97** (April 2020) reported that Roy et al., (2019) had demonstrated that routine monthly analysis of biosolids from Flint's wastewater plant for metals provided a viable record of metals release from the Flint water distribution system. Roy et al. (2020) extended this novel approach to demonstrate that the enhanced corrosion control treatment from December 2015 to the present, combined with removal of ~80% of the lead and galvanized service lines by early 2020, resulted in an estimated 72 to 84% reduction in citywide lead exposure. While that finding is encouraging, the authors are left to conclude that remaining legacy sources of lead in the water system, including leaded brass, lead solder and remaining lead in pipe scale will continue to release lead mass from 16 to 28% of that wastewater sludge prior to the Flint Water Crisis. Santucci and Scully (2020) provide a detailed perspective of the complex water chemistry and underlying corrosion science (kinetics and thermodynamics) that contributed to the lead release in Flint. They elaborated on some of the counter-intuitive outcomes that may arise, such as the possibility of the elevated calcium and magnesium hardness, rather than reducing corrosion by forming scale, potentially interfering with the phosphate corrosion inhibitor by sequestering it out of solution by forming calcium or magnesium phosphate precipitates. As consumer pressures will continue to mount for drinking water purveyors and regulators to solve lead contamination of drinking water, all parties will need to invest in fully understanding the fundamental corrosion chemistry that will depend on local water quality characteristics and avoid simplistic interventions, often driven by economics, that may worsen rather than resolve lead contamination of drinking water.

Although the health implications of elevated lead in drinking water and an outbreak of LD that involved fatalities have rightfully dominated the tragic story of the Flint Water Crisis, adverse mental health impacts have also been investigated. Sobeck et al. (2020) studied a random sample of 320 Flint residents to document increased stress and reduced resilience / capacity to recover. Ezell and Chase (2021) studied a random sample of 331 residents to find that 29% were experiencing post-traumatic stress disorder and 26% were experiencing depression / anxiety. Obviously, trust in government and its agencies has been severely undermined by the Flint Water Crisis.

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# NEWS ITEMS

## Implementation of Taumata Arowai, National Drinking Water Regulator, New Zealand

Following passage of the Taumata Arowai – Water Services Regulator Act in July 2020, the new regulator officially came into being as a new Crown entity in March 2021. Once the Water Services Bill, expected in the second half of 2021, Taumata Arowai will take over from the Ministry of Health as the drinking water regulator for New Zealand. This initiative is one pillar of the Three Waters Reform programme to provide safe and reliable drinking water and improved management of waste and storm water. These initiatives follow from the recommendations of the two part Government Inquiry (see **HS83**, **84**, **85**, **86**, **88**) into the fatal Havelock North outbreak of campylobacteriosis in August 2016. Despite New Zealand's low population density, it has a large population of livestock, meaning that rural towns and villages face substantial risks from microbial pathogens. This reality combined with a strong anti-chlorination movement, even in major urban areas like Christchurch, suggest that Taumata Arowai faces a substantial challenge to ensure consistently safe drinking water for New Zealand residents, not to mention the substantial tourist population it hosts.

## Release of *Toxic Cyanobacteria in Water* 2nd Edition, Ingrid Chorus & Martin Welker (Eds)

This important major reference work, subtitled: A Guide to Their Public Health Consequences, Monitoring and Management, was published in its first edition in 1999, (reported in **HS14**). The new edition continues to have major contributions from Australia, including several Australian lead authors: Justin Brookes, U. of Adelaide; Mike Burch, formerly SA Water; David Cunliffe, SA Health; Andrew Humpage, U. of Adelaide formerly SA Water; Gayle Newcombe, formerly SA Water; and Nicholas J. Osborne, U. of Queensland. This 859 page book has chapters covering: Cyanobacterial toxins, Cyanobacteria, Exposure to cyanotoxins, Assessing and managing cyanobacterial risks in water-use systems, Assessing and controlling the risk of cyanobacterial blooms - nutrient loads and waterbody conditions, Managing cyanotoxin risks at the drinking-water offtake, Controlling cyanotoxin occurrence: Drinking water treatment, Planning monitoring programmes for cyanobacteria and cyanotoxins, Fieldwork, Laboratory analyses of cyanobacteria water chemistry, cyanobacterial toxins and bioassays, and Public health surveillance, public communication and participation. The book, sponsored by WHO, is available in open access and can be downloaded by chapter or in its entirety at: https://www.who.int/publications/m/item/toxic-cyanobacteria-in-water---second-edition

## Cyanobacterial toxins: microcystins. Background document for development of WHO Guidelines for drinking-water quality and Guidelines for safe recreational water environments

This extensively documented update to the technical background for microcystins was led by Andrew Humpage, University of Adelaide (formerly SA Water) and the expert panel included David Cunliffe, SA Health and John Fawell, Cranfield University, UK. The document retained the provisional long term, chronic drinking water guidance value for microcystin-LR of 1 µg/L, but also introduces a provisional short term drinking water guidance value for microcystin-LR of 12 µg/L and a provisional recreational water guidance value for microcystin-LR of 24 µg/L.

https://apps.who.int/iris/bitstream/handle/10665/338066/WHO-HEP-ECH-WSH-2020.6-eng.pdf?sequence=1&isAllowed=y

Background technical document links are also available for: anatoxin-a and analogues, cylindrospermopsins, saxitoxins, bentazone, chromium, iodine, organotins, tetrachloroethene and trichloroethene.

https://cdn.who.int/media/docs/default-source/wash-documents/wash-chemicals/chem-background-documents-dec-2020-updated.pdf?sfvrsn=c0c8f05b_10&download=true

## Release of *Management of Legionella in Water Systems* (2020), U.S. National Academy of Sciences, Engineering & Medicine (NASEM)

The expert committee convened by NASEM was chaired by Joan Rose and included Nick Ashbolt. Initiation of expert committee was covered in **HS88** (January 2018). The authors reviewed the state of the science including, biology, taxonomy and ecology of *Legionella pneumophila*, outbreaks and disease surveillance, environmental data from building water systems, control methods, rules and guidelines for dealing with *Legionella* contamination. The report provides conclusions and recommendations to provide better management of *Legionella* contamination of water systems and better control of Legionnaires' disease. This important report is available for free download as a pdf at: https://www.nationalacademies.org/our-work/management-of-legionella-in-water-systems

## Microbial Pathogens and Waterborne Outbreaks

### Spatial and temporal distributions of enteric viruses and indicators in a lake receiving municipal wastewater treatment plant discharge

Hata A, Shirasaka Y, Ihara M, Yamashita N, Tanaka H

Science of the Total Environment. 2021, **780**: 146607

Lake Biwa, Japan's largest lake, is located in the south central region, northeast of Kyoto. The southern arm of the lake, named "South-lake", was the focus of this study. This portion of Lake Biwa has a surface area of 58 $km^2$ and an estimated retention time of 15.7 days. South-lake receives discharges from three wastewater treatment plants serving a population equivalent of 930,000 and provides the drinking water source for approximately 14 million people as well as being a location for water-based recreation. The study was performed with monthly sample collection at six sites for 14 months to assess the occurrence and distribution of enteric viruses in the major drinking water source. Water samples were subjected to concentration RNA extraction with gene copy quantification by quantitative reverse transcription polymerase chain reaction (RT-qPCR) looking for Aichi virus (AiV), noroviruses (NoV), sapovirus (SaV), rotavirus (RV), pepper mild mottle virus (PMMoV) and F-specific RNA bacteriophage (FRNAPH). Samples were spiked with murine norovirus (MNV) for analytical quality control. Noroviruses, sapovirus and rotavirus are known causes of acute gastrointestinal disease, potentially by waterborne transmission. AiV has been found as an indicator of wastewater pollution of source waters and it may be a cause of waterborne disease. PMMoV is a virus that is commonly found in human faecal waste and thereby acts as an indicator of wastewater impact on receiving water.

The results indicate that AiV is not a good indicator of wastewater viral impact for this region. PMMoV was consistently detected in high concentrations. Results for infectious enteric viruses were different from the first year (2014) to the second year (2015), with NV and RV detected in the first year but were consistently non-detected after April 2015. Considering that the RT-qPCR monitoring method responds to genetic signals from viruses and cannot confirm the presence of viable and infective viruses, the results suggest that viral contamination of treated drinking water derived from this source was not a substantial human health risk at that time.

### Risk assessment of parasites in Norwegian drinking water: opportunities and challenges

Robertson LJ, Jore S, Lund V, Grahek-Ogden D

Food and Waterborne Parasitology. 2021, **22**: e00112

Experience with waterborne disease outbreaks in Norway, a country that was noted to have the highest wealth per capita in the world in 2018, including: the 2004 giardiasis outbreak in Bergen that had over 1500 cases diagnosed and likely infected around 6000; in 2007, pathogen contamination of the Oslo water supply that resulted in a 5-day boil water advisory; then in 2019, Askøy experienced a waterborne outbreak of campylobacteriosis involving over 1500 cases. Against this background, the Norwegian Food Safety Authority requested in 2008 and in 2019 that an independent scientific body (VKM, Norwegian Scientific Committee for Food and Environment) perform a risk assessment about the presence of parasites in drinking water supplies in Norway.

The first assessment (VKM 2009) https://vkm.no/english/riskassessments/allpublications/riskassessmentofparasitesindrinkingwater.4.72c3261615e09f-2472f48acc.html) posed 10 questions:

*"1) How important is drinking water, in total or relatively, as a transmission route for cryptosporidiosis or giardiasis in Norway? How might this change in the next few years?*

*2) How many people in Norway are at risk of becoming ill due to these parasites?*

*3) Are today's reporting systems adequate? What should be done if necessary?*

*4) Are humans or animals the most common source of contamination of water in Norway with parasites?*

*5) How is the risk associated with contamination of the water source compared with contamination of the distribution network?*

*6) What effect do current water treatment methods have on the removal of these parasites?*

*7) What monitoring methods are available for these parasites and to what extent are they suitable for waterworks for monitoring purposes?*

*8) Are models available that owners could use to assess the risk in a specific water supply? If not, is it possible/appropriate to develop such a model for Norwegian water supplies?*

*9) If current analysis methods are not sufficient or available to meet routine requirements, what should be done, based on an assessment of what is necessary?*

*10) What general advice can VKM provide to NFSA regarding the risk of parasitic infection via food and drink? If NFSA wants to advise the public on this subject, what should such advice entail and how should it be communicated."*

Although this first assessment found that it could not answer most of these questions with any specificity, the first assessment modeling outcomes estimated the daily individual probability of infection with *Cryptosporidium* as between $5x10^{-6}$ to $8x10^{-4}$ and with *Giardia* as between 0 and $4x10^{-4}$, leading to expected daily cases of cryptosporidiosis of 5 with optimal treatment and 40 with excess precipitation (weather) and expected daily cases of giardiasis of 1 with optimal treatment and 15 with excess precipitation. These findings were interpreted as indicating a relatively low risk of infection, but was likely underestimated, with an expectation that there is likely widespread, low level contamination of source supplies.

The mandate for the second assessment (VKM 2020, cited web link not yet functional) focused on what drinking water providers needed to include in plans for sampling for addressing this risk. NSFA included three points on this topic:

*"1) An update of information on the occurrence of Giardia and Cryptosporidium in both water sources and treated drinking water in Norway.*

*2) Information on factors that make it more likely that parasites can be a challenge for the production of sufficient, safe drinking water (for example, the type of raw water source or the activities in the vicinity of the water supply).*

*3) Criteria that should be met by methods used for analysis of water in order to be adequate, and an update on information regarding the available methods for analysis of drinking water for contamination with Giardia and Cryptosporidium."*

There was inadequate information to answer the first question, the second and third questions were only partially answered. The second assessment did find substantial improvements in the national diagnosis of infection, addition of cryptosporidiosis as a reportable disease in 2012, an increase from 50% of the population receiving UV-disinfected water to around 85% receiving UV-disinfected water. Ozonisation and membrane filtration have not increased substantially but large water treatment plants have generally upgraded their treatment to improve effectiveness for protozoan parasites. From no laboratories accredited for parasite analyses, there is now one accredited laboratory and several performing parasite analyses without accreditation.

The authors conclude with an appeal to water providers to carefully evaluate their water supply catchments in a collaborative manner to develop risk-based sampling plans.

**Askøy, Norway, Campylobacter outbreak, June 2019**

(1) Hyllestad S, Iversen A, MacDonald E, Amato E, Borge BAS, Bøe A, Sandvin A, Brandal LT, Lyngstad TM, Naseer U, Nygård K, Veneti L , Vold L. Large waterborne Campylobacter outbreak: use of multiple approaches to investigate contamination of the drinking water supply system, Norway, June 2019. Euro Surveillance. 2020, **25**(35): pii=2000011

(2) Paruch L, Paruch AM, Sorheim R. DNA-based faecal source tracking of contaminated drinking water causing a large *Campylobacter* outbreak in Norway 2019. International Journal of Hygiene and Environmental Health. 2020, **224**: 113420.

(3) Mortensen, N, Jonasson SA, Lavesson IV, Emberland KE, Litleskare S, Wensaas K-A, Rortveit G, Langeland N, Hanevik K. Characteristics of hospitalized patients during a large waterborne outbreak of *Campylobacter jejuni* in Norway. Plos One https://doi.org/10.1371/journal.pone.0248464

The authors of the Askøy outbreak investigation (1) note that drinking water contamination in distribution systems caused by pipe breaks, cross connections and contaminated water intrusion is being increasingly reported as a cause of waterborne disease outbreaks. They report on an outbreak first detected by the Medical Officer in Askøy, Norway when 10 people had been hospitalized with fever, abdominal pain and diarrhoea over a 24 hour period on 6 June 2019 with more consumers seeking medical attention from after-hours healthcare services. Medical staff were astute enough to notice that many of those seeking medical care had addresses near each other. Askøy is an island offshore from the city of Bergen with about 29,500 inhabitants that is served by three different water systems, one of them serving about 12,000 from nine water reservoirs, including three that are unlined mountain caverns. One of these was under immediate suspicion because of the geographic clustering of cases.

A boil water advisory was immediately issued on June 6, the suspected contaminated reservoir was taken out of service on June 7 and a text message (SMS) cohort survey was initiated on June 13. The SMS survey was distributed to 4,409 individuals with mobile phone numbers registered with the water provider. An online questionnaire received data from 6,192 individuals with 1,913 reporting having been ill. Of these 1,829 reported at least one of the following case-relevant symptoms: diarrhoea, abdominal pain, headache, nausea, fever, abdominal distention, vomiting or bloody stool. 1,573 individuals were assigned to meet the case definition for an attack rate of 26%. There were 181 lab-confirmed cases of campylobacteriosis, 24 isolates of *Campylobacter jejuni* were sequenced, no close genetic matches were found, but birds were suggested as a possible source (1).

These authors (1) reported that no faecal indicator bacteria had been detected in routine monitoring of water quality, other than occasional detection of total coliforms, but the location chosen for routine monitoring would not have captured water flowing out of the reservoir, making these monitoring results of little value relative to this outbreak investigation. In addition to reporting cracks in the reservoir walls, there were leaks observed in concrete wall structures and water was seen running inside the roof. Finally, there was an antennae and power lines above the reservoir that could be expected to attract birds.

A risk analysis done in 2006 for this water provider had identified the unlined reservoirs as a vulnerability. Although not ignored, a new replacement reservoir had been completed in February 2019, but it had not been put fully into service so that the contaminated reservoir was still in use at the time of the outbreak. This Norwegian experience makes a compelling case for the need for effective drinking water safety plans that are continuously maintained and expeditiously implemented.

A separate source tracking team (2) retained by the water provider confirmed that the source of outbreak was the mountain water reservoir (Høydebasseng HB 168) that was connected to the Kleppe Waterworks in Askøy and which distributed water to about 15,000 people. This old reservoir was drained and was laser scanned to reveal numerous cracks in the walls of the cave which provided paths for faecally-contaminated water to seep into the reservoir. Heavy rains, which are common in the Bergen region, preceded this outbreak after an extended dry period. A three-step faecal source-tracking approach was applied consisting of: 1. screening for faecal contamination using *E. coli*, 2. using *E. coli* positive samples, detect and quantitate host-specific *Bacteroidales* 16S rRNA genetic markers using qPCR and 3. profiling the faecal origin relying on the relative contribution of markers defined in the selected samples. The authors (2) concluded that the faecal contamination was entirely zoonotic (i.e., not from humans), attributing 69% to horses, 6% to ruminants generally and the remaining 25% to other animals (wild animals or birds). While possible routes of transport of the faecal contamination were discussed, no definitive description of the contamination scenario was provided. Disinfection and chlorination was only mentioned as a reaction to the incident along with the boil water advisory, adding this serious outbreak to the number of eminently preventable drinking water outbreaks that keep occurring in nations that have the economic and scientific resources and public health know-how to ensure safe drinking water. In total, this 2019 incident that was predominantly attributed to campylobacteriosis resulted in approximately 2,000 ill, 76 being hospitalized and was linked to two deaths, one being a one-year old infant (3).

**Waterborne outbreaks: a public health concern for rural municipalities with unchlorinated drinking water distribution systems**

Soto JC, Barakat M, Drolet M-J, Gauvin D, Huot C

Canadian Journal of Public Health. 2020, **111**: 433–442

This study reports on an epidemiological investigation of a waterborne outbreak of acute gastrointestinal disease that occurred in July 2018 in a rural Québec, Canada municipality with a total of 2320 residents, about 880 of whom were served by the distribution system providing unfiltered and unchlorinated water from five wells and a surface storage tank that was suspected as being the contaminated drinking water supply. The remainder of the community was supplied with drinking water from private "artesian" wells. This report is primarily a description of the epidemiological study methodology and findings. The paper does not provide much information to readers seeking details of how the contamination occurred or what risk management measures were taken to prevent such outbreaks from re-occurring to ensure a safe drinking water supply for this community going forward.

The Regional Public Health Department (RPHD) learned that nine cases of *Campylobacter jejuni* infection had been reported by the provincial laboratory of public health between July 11 and 23, 2018, with eight of the nine cases being residents of what is described only as municipality A. This drew attention because the July incidence rate for campylobacteriosis was eight times higher than the average monthly rate over the previous 18 years. Interviews with the reported cases revealed that drinking water source was the only common factor and eight of the cases were located close to the surface drinking water reservoir providing unfiltered, unchlorinated water. A boil water advisory was issued for the community on July 17, 2018.

Public health officials performed a population-based retrospective cohort study in the community using a case definition of: a resident of the community between June 23 and July 22, experiencing symptoms of acute gastrointestinal disease with at least two of the following : diarrhea, abdominal cramps, fever, nausea and or vomiting. These symptoms were selected from the symptoms reported by the confirmed cases of campylobacteriosis. From a sample of 140 randomly selected individuals, 22 of whom satisfied the case definition, the study found a risk ratio (RR) of 24.31 (95% CI : 1.50 – 393.4) for exposure to the drinking water suspected of contamination. In contrast, those who derived their drinking water from a private "artesian" well had a protective RR of 0.28 (95% CI : 0.09 – 0.90). The authors reported in their abstract first that the cases showed an "illness" attack rate of 15.7% among the 140 participants. But not all of the 140 participants were served by the suspected contaminated water supply, so that quoted attack rate does not represent a proportion of individuals exposed to the suspected contamination who became ill. The "illness" attack rate was used to estimate that 364 cases of acute gastrointestinal disease occurred in the overall community in this outbreak. The authors also report that the attack rate for those respondents who drank municipal water (87) was 24.1%. They noted in their introduction that a literature estimate has shown a range of between 18 and 39 cases of campylobacteriosis in the community for every laboratory confirmed case. For this outbreak, those reported ratios would correspond to from 162 to 351 cases in the community for the 9 laboratory confirmed cases reported, suggesting that this outbreak likely involved between 150 to 400 cases of campylobacteriosis.

In their data reporting (Table 3), "exposed" refers not to water exposure but to exposure to a case(s) of acute gastrointestinal disease, a factor that was found to be the second most significant risk factor for disease cases with RRs of 4.63 (95% CI : 2.24 – 9.55) and 3.87(95% CI : 1.90 – 7.91) for contact (exposure) with case(s) of acute gastrointestinal disease, outside or within the household, respectively.

The authors reported that *Escherichia coli* and/or enterococci were found (data not reported) in 6 of the 10 water samples taken between July 26 and 28, four to six days after the last incident case of illness. Another 40 samples were collected between August 8 to September 12. Not surprisingly, no *C. jejuni* was detected in water samples. Among the factors mentioned as possibly contributing to this outbreak was 5 days of rain (7.8 to 19 mm/ day) and 4 consecutive days of a relative heat wave (for Québec) between 30.5 to 33.6°C per day. Reportedly, an extended drought period followed by heavy rain has been speculated as a cause for water contamination episodes. There was also distribution system flushing between June 19 and 26 that may have caused low system pressure and possible contamination intrusion. Inspections also found the lack of backflow valves in several buildings served by the distribution system. Although not explicitly stated as a facility lacking a backflow valve, one facility located near (300 m) from the bacterially contaminated water storage tank was described as a chicken coop. Clearly, apart from the foregoing factors, the critical flaw that allowed this outbreak to occur was the absence of any disinfection.

Oddly, this paper does not cite anything about the infamous, fatal Havelock North, New Zealand outbreak of campylobacteriosis in 2016 that is discussed elsewhere (in the News section). This paper also makes no mention of any remedial risk management measures to address the lack of disinfection for this drinking water system.

***Editor's Note:*** *This paper does not name the Québec community that experienced this outbreak. That practice is reminiscent of the failure of a 1991 paper, also published in the Canadian Journal of Public Health, to name an Ontario, Canada rural community that experienced a 1985 campylobacteriosis outbreak that was in Orangeville (100 km from Walkerton) and was caused by livestock manure contamination of a set of shallow municipal wells. This 1985 anonymous community outbreak of an estimated 241 cases was prescient of circumstances causing the disastrous Walkerton outbreak in 2000 that caused 7 deaths and over 2,000 cases of illness attributed to Campylobacter spp and E. coli O157:H7 from livestock manure contaminating a shallow well. When the Walkerton outbreak happened, there were countless expressions of surprise and bewilderment about how such a thing could happen in Ontario. Regarding the 2016 Havelock North, New Zealand fatal outbreak, the community had experienced a previous waterborne outbreak of campylobacteriosis in 1998 that was apparently not widely known, even among those responsible for the drinking water supply in 2016. More recently, in June 2019, Askvay, Norway experienced another major and fatal outbreak of campylobacteriosis with a vulnerable, unchlorinated drinking water supply (see report in this section). These tragic experiences suggest that the public health community does a disservice to the public when it allows the location of a drinking water outbreak to be kept anonymous.*

## Arsenic

### Valuing the cancer mortality risk reduction from lowering the arsenic maximum contaminant level in New Hampshire municipal water supplies

Lemos S, Halstead, JM, Mohr, RD, Susca, P, Woodward, R

Environmental Management. 2020, **65**: 725–736

Arsenic contamination of drinking water has been shown to be associated with urinary bladder cancer among consumers in studies done in many countries. The U.S. Environmental Protection Agency (US EPA) lowered the maximum contaminant level (MCL) for arsenic under the U.S. Safe Drinking Water Act to 10 µg/L from 50 µg/L in 2001 and the Governor of New Hampshire further lower the arsenic limit for New Hampshire drinking water to 5 µg/L in 2019. The authors of this paper study explored the willingness of 800 New Hampshire residents to pay for reduction in drinking water exposure to arsenic by conducting an online stated preference survey using a contingent valuation method tied to a hypothetical question requiring a yes or no answer about changes to their monthly water bill. The sampled population was limited to adults (over 18 years of age) who consumed a minimum of 25% of their drinking water from their household tap.

The sample population contained a higher proportion of females than the state overall (66.7% to 50.5%) with household income lower than the state mean (US$63,291 vs. US$70,936), but was otherwise similar in average age and education level. Respondent location was similar to the state population distribution. About half used some form of home drinking water filtration system and 13% indicated that they used bottled water because of health concerns with the public water supply. The latter was a bit confusing as presented because it included a footnote stating: "*47.6% of respondents report drinking bottled water at least a couple of times per week.*" Over 78% of survey respondents perceived only minor or no health concerns with their drinking water. Households that perceived themselves as vulnerable to arsenic exposure are willing to pay more, based on indicators like: expressing concern over arsenic exposure, already using a home treatment system and those who had children being willing to pay approximately US$10 per month more than the overall survey average, while those with no children were only willing to pay approximately US$5 less than the survey average. The respondents were presented with risk information derived from a report (not cited) prepared by the New Hampshire Department of Environmental Services to the State legislature that estimated a reduction in a lifetime (70 year) risk of arsenic in drinking water from 10 µg/L down to 3 µg/L as being 2.4 in a thousand. The authors did not show exactly how this rather intangible cancer risk information was presented to survey respondents.

Those households on a public water supply (those affected by the regulated arsenic level) were willing to pay US$35.43 per month to lower the MCL from 10 µg/L down to a hypothetical level of 3 µg/L, while those households on private wells were only will to pay US$29.19 per month. The survey data was also extended to estimate perceived values of a "*statistical*" life based on the reported willingness to pay, finding values of US$4.61 million for those on municipal systems and US$3.48 million for those on private wells. The authors note that their methodology was not optimal for this latter estimation because they used the total household willingness to pay divided by the average number of individuals residing in households. Alternate processing of their data could yield an estimate for the value of a statistical life as high as US$12 million. They also note that having respondents try to determine what they are willing to pay as an increase in a monthly payment that is based on their understanding of the meaning to them of reducing their cancer risk over a 70 year lifetime presents a logical challenge that most likely inflates the estimated value of a statistical life.

### Effect of low- and high-level groundwater arsenic on peripheral blood and lung function of exposed rural women

Prasad P, Sarkar N, Sinha D

Regulatory Toxicology and Pharmacology. 2020, **115:** 104684

The authors noted that chronic arsenic poisoning has been reported in 105 countries, with arsenic contamination of the Ganges-Brahmaputra river system of India (West Bengal) and Bangladesh affecting over 100 million people. Although the World Health Organization (WHO) drinking water guideline has been lowered from 50 µg/L down to 10 µg/L, in India only the higher limit is legally enforceable with the lower limit deemed to be desirable. Because arsenic has been shown to adversely affect multiple organs, peripheral blood was selected as a target for investigation, along with lung function because of recent reports of non-cancerous respiratory illness occurring with long term arsenic exposure. This was a cross-sectional study of women who were judged to be asymptomatic for established arsenic-caused disease.

The study subjects from rural Bengal were assigned to be low arsenic-exposed (11 – 50 µg/L in drinking water) , high arsenic exposed (>50 µg/L) or control (<10 µg/L). Inclusion criteria were 10 or more years of water consumption from the village tube well and being a non-smoker with no prior history of chronic obstructive pulmonary or other respiratory disease. Exclusion criteria were the presence of arsenic-related skin lesions, being under medication, prior history of malignant disease and pregnancy or lactation. The study recruited 93 women in low-exposed, 70 in high-exposed and 118 in the control population. The groups were reasonably comparable for age, body mass index, years of schooling. Although not found statistically significant (P<0.05 in one-way ANOVA) the high exposed group had a lower proportion of office job/trader/self-employed, a higher proportion of biomass fuel use for home cooking and the lowest family income. Oddly, the table of results and commentary noted a significant difference (p=0.04) in the number of family members, even though the tabulated data showed the results comparison to be (mean±SD / 95% CI): Control 6±2 /5-6; Low 5±2 /4-5; High 5±2 /4-5. This apparent anomaly may only reflect the report of family members as integral values.

Arsenic content of nails as a biomarker of arsenic exposure was assessed and found to be correlated with reported arsenic in drinking water (low 22.5±19.2 µg/L, high 67.8±26.9 µg/L, control 1.02±2.3 µg/L), largely confirming the arsenic exposure classifications. A variety of blood parameters were tested relative to water arsenic and nail arsenic and only haemoglobin (Hb) and lymphocyte reduction were found to correlate with both arsenic measures. Anticipating a finding of adverse effects on immunity with higher arsenic exposure, the study did find that the high arsenic exposure group had reduced CD8+ T cells that would likely compromise adaptive immunity that would increase susceptibility to pathogenic infection given the key immune response role these cells play. Lung function parameters were also found to decrease with increased arsenic exposure indicated by nail arsenic content. Overall, this study suggests that chronic arsenic exposure should be minimised to the maximum degree possible.

**Bayesian benchmark dose analysis for inorganic arsenic in drinking water associated with bladder and lung cancer using epidemiological data**

Kan Shao, Zheng Zhou, Pengcheng Xun, Samuel M. Cohen

Toxicology. 2021, **455:** 152752

The evidence for inorganic arsenic in drinking water causing human cancer has been derived almost exclusively from human epidemiology studies because animal models for evaluating arsenic carcinogenesis in laboratory studies have proven to be of limited value to date, making cancer risk assessment for inorganic arsenic necessarily reliant on the less precise dose-response evidence available from epidemiology. In particular, such studies provide limited ability to determine the presence or absence of a threshold. Laboratory experiments with animals, while attracting considerable uncertainty in translating results to human cancer risk, have the distinct advantage of knowing with a reasonable degree of certainty what doses have been applied in contrast to epidemiology studies that cannot control exposure, but only observe and estimate what exposures have occurred which generally brings considerable uncertainty into the dose estimation.

Toxicology studies have shown little meaningful evidence of inorganic arsenic being able to damage DNA, i.e. cause mutations, meaning that inorganic arsenic should not be regarded as genotoxic.

Accordingly, cancer risk assessment guidance that pays attention to evidence for the mode of action for a contaminant to cause tumours calls for the risk assessment to recognise a threshold, i.e., a level of exposure below which there is no cancer risk, as opposed to the no threshold risk model that extrapolates from observed experimental results down to zero dose to yield a linear low dose response model typically represented by a cancer slope (potency) factor. Early evidence about inorganic arsenic in drinking water causing human cancer, primarily from studies in Taiwan, had been interpreted as not showing a threshold, but subsequent regulatory risk assessments applying a linear low dose response model for estimating cancer risk have been operating on a questionable foundation.

This study has made use of the numerous epidemiologic studies with improved dose-response data collection performed since 2004, using 8 studies addressing bladder cancer in Argentina, Bangladesh, Chile, Finland and the U.S. (4 studies) and 5 studies addressing lung cancer in Bangladesh, Chile, Taiwan and the U.S. (2 studies). Some of these studies also had the benefit of having much lower arsenic exposures than typically reported for Argentina, Bangladesh, Chile and Taiwan, thereby providing better evidence for adverse effects of lower exposure levels from drinking water.

In the absence of evidentiary justification for applying the no threshold model that predicts a linear low dose response, the method of choice for lower dose extrapolation is the benchmark dose (BMD) approach that can yield a non-linear dose response prediction. The statistical methods used for modeling dose response are sophisticated. The authors claim three advantages for their modeling approach: *"(1) focusing on modeling dose-response data in low dose region (i.e., human exposure relevance) to avoid extrapolation from high dose data; (2) employing a flexible four-parameter Hill model to quantify the dose-response relationship in low dose to avoid making linear vs. non-linear assumption; (3) implementing a Bayesian hierarchical model to take uncertainty from various sources into account and to generate probabilistic estimates."* They explain with reliance on the extensive toxicology research that has been performed on inorganic arsenic that the accepted mode of action of inorganic arsenic is one that leads to cytotoxicity (killing of cells), causing regenerative cell proliferation that increases the odds of DNA replication errors that can initiate tumours. If exposures are not sufficient to cause cytotoxicity, the regenerative cell proliferation will not occur and there is no associated cancer risk caused as a result. An analogy is made with the generally accepted premise that is not widely understood within the water industry about how chloroform can be considered a carcinogen, but one that poses no cancer risk below its identified threshold. The resulting conclusion from this research is that the current drinking water guideline of 10 µg/L of arsenic is protective against cancer being caused by drinking water consumption. Relying on the analysis performed and the evidence it is based upon, there is no conflict between this finding and acceptance that drinking water exposures to much higher levels of inorganic arsenic (i.e., > 50 µg/L) does cause cancer in humans at those higher exposure levels that exceed the thresholds.

### Lead

**A field survey on elution of lead and nickel from taps used in homes and analysis of product test results.**

Asami M, Furuhashi Y, Nakamura Y, Sasaki Y, Adachi Y, Maeda N, Matsui Y.

Science of the Total Environment. 2021, **771**: 144979

Lead contamination of drinking water has been (see Flint Water Crisis article) and continues to be one of the biggest and most intractable challenges facing drinking water providers. In the beginning, the focus had been on lead piping in the distribution system under the control of the water provider, but the focus has had to shift to lead service lines on residential property and premise plumbing, raising concern about lead contribution from lead solder and plumbing fixtures. This research addressed lead and nickel coming from taps in Japan where the objectives for lead and nickel are 10 and 20 µg/L respectively with a focus on sampling to compare first flush samples with subsequent samples.

Nickel is rarely detected in source water in Japan, so leaching from plumbing fixtures is regarded as the dominant source for any nickel detected at the tap.

Although lead justifiably receives more attention as a leached metal in drinking water, nickel is regarded as posing a health risk for causing allergic contact dermatitis.

This study focused on sampling first flush (the first 100 mL from a tap not used overnight, i.e., more than 6 h) and a fully flushed sample (100 mL after 5 L of flow) with a program of 110 samples. Taps in domestic dwelling and office buildings were sampled. A second phase of the study evaluated sequential sampling involving 20 successive collections of 100 mL. A third phase was also analysed for two cases where nickel was detected at higher levels, collecting first flush after intervals of 1, 2, 4, 6 and 8 h with no intervening use of the water and then repeated in duplicate, with at least 5 L flushed before repeating.

The first flush study found that 32 out of 110 samples exceeded the lead objective and 22 out of 110 samples exceeded the nickel objective. None of the fully flushed (after 5 L) samples exceeded the objective for either metal. There was a general correlation between taps providing higher lead also providing higher nickel. Newer taps tended to have higher nickel levels, but this was not found for lead. Sequential sampling was performed on a set of 11 taps that had shown elevated nickel. In all cases, after 300 mL or more flushing, nickel levels were below the objective. In this set, none of the taps were above the lead objective, although measured concentrations did decline after the first two flushes for 10 of the 11 taps, with one tap only declining to background after six flushes. Faucet material was shown to be a factor for nickel, with highest levels for bronze, followed by brass and plastic. Although not clearly explained, the plastic faucets were likely nickel coated. Finally, the number of years in service was found to be a factor for nickel, but not for lead.

**Association between lead in school drinking water systems and educational outcomes in Ontario, Canada**

Buajitti E, Fazio X, Lewis JA, Rosella LC

Annals of Epidemiology. 2021, **55**: 50e56

Given the established association between childhood blood lead levels and negative impacts on neurological function, this study has performed an analysis of a very large Ontario, Canada data base for 3051 schools in the province, providing outcome measures of academic performance that are arguably distant and somewhat detached from the tested causal variable, measured lead concentrations in the school drinking water supply. Performance data was available for 719,975 grade 3 students and 745,201 grade 6 students over the period from 2008-09 to 2015-16. Academic performance was measured according to performance in standardized testing for performance in reading, writing and mathematics provided by the Ontario Education Quality and Accountability Office. Linkages between these performance results and school drinking water monitoring for lead were achieved for 76% of schools in 2010-11 and for 79% of schools in 2015-16, with an overall average of 78% for the entire study period. Viewed another way, over 20% of the intended study population was not captured in the overall data analysis.

The Ontario lead concentration criterion was 5 µg/L. The authors of this paper studied data over the seven year period from 2008-09 to 2015-16, excluding 2014-15 when some academic testing data were not available because of a labour disruption. The good news is that the number of schools that failed the lead monitoring of school drinking water decreased steadily from 754 in 2008-09 (25%) to 336 in 2015-16 (11%), with median values declining from 2.5 µg/L to 1 µg/L. Maximum levels measured in a given year ranged from 354 to 981 µg/L, raising an obvious question that would not likely have been available to the study team about what remedial measures were taken with schools reporting such extreme variable values.

The main finding was that over the study period, schools that failed the lead in drinking water testing also under-performed in the academic testing results. The authors describe their overall findings as showing a *"small association between drinking water lead levels and educational outcomes"*. In schools failing to meet the lead objective in drinking water, 8% more students failed to achieve the provincial test standard for math, 6% more for reading and 10% more for writing when data was minimally adjusted for potential confounding factors. When fully adjusted for identified confounders, the results were 2% for math, 2% for reading and 1% for writing. The authors acknowledge several limitations to their study methods and results including: having no information about students' homes with regard to lead exposure, students may or may not consume drinking water at school, excess lead levels may have been remediated before students were exposed and the data set did not allow for adjustment according to socioeconomic factors affecting individual students.

Despite these limitations, the possibility that such data could be demonstrated for any given school system should be taken to heart by school administrators and water providers alike. The tolerance of parents for hearing that their children may have had their intellectual capacity impaired by lead contamination of school drinking water is not a revelation that anyone in either jurisdiction should want to experience.

## Nitrates

**Prenatal Exposure to Nitrate from Drinking Water and Markers of Fetal Growth Restriction: A Population-Based Study of Nearly One Million Danish-Born Children**

Coffman VR, Jensen AS, Trabjerg BB, Pedersen CB, Hansen B, Sigsgaard T, Olsen J, Schaumburg I, Schullehner J, Pedersen M, Stayner LT.

Environmental Health Perspectives. 2021, **129**(2): 027002 1-11

Nitrate has long been a substantial concern in drinking water because the possibility of causing methaemoglobinemia particularly among infants. This condition, colloquially named *"blue-baby disease"* has been demonstrated in case reports of nitrate poisoning. Nitrate commonly contaminates groundwater because of infiltration following use of nitrogen fertilizers in agriculture, so nitrates are a common concern for groundwater supplies. Denmark is almost totally reliant on groundwater for its drinking water sources. This study was undertaken to investigate impacts on fetal development from lower level nitrate, below risk levels for methaemoglobinemia. There are plausible toxic modes of action that nitrate and conversion to nitrite could pose a risk to the developing fetus.

The study took advantage of a national database to study 898,206 Danish births between 1991–2011, providing data on birthweight, body length, and head circumference. Maternal nitrate exposure was estimated from a national monitoring data base by linkage to maternal home address. Of the total, 852,348 births satisfied the inclusion criteria of Danish-born parents, live-born, full term, singleton birth and at least eight monthly nitrate measurements linked to the maternal address. The median nitrate exposure was low, median of 2.2 mg/L as nitrate over the entire pregnancy, but 4% (33,809) experienced elevated nitrate exposure, >25 mg/L (e.g. over 50% of the EU limit for nitrate) in a strongly skewed nitrate exposure profile.

The large national database provided scope for consideration of possible confounders including: maternal smoking, maternal age, education and employment, geographic region, season of birth, water supply (public vs. private) and delivery (Caesarean section or not). The authors found evidence of slightly reduced term birth weight and body length being associated with mean exposure to nitrate during the pregnancy. Using a continuous model, they found that birthweight was decreased 9.71 g (95% CI: -14.60 to – 4.81), 0.3% for 25 mg/L compared with 0 mg/L and an even smaller decrease in body length, but they found no evidence in support of an association of nitrate exposure with clinically-defined low total birthweight (2,500 g or less) or small head circumference (2 standard deviations below the mean).

The authors acknowledge limitations to their study include: no information on maternal dietary nitrate exposure, drinking water consumption, bottled water consumption (known to be very low in Denmark) and no adjustment for any other drinking water contaminants.

## Cyanobacteria

**Cyanobacteria and their secondary metabolites in three freshwater reservoirs in the United Kingdom**

Filatova D, Jones MR, Haley JA, Núñez O, Farré M, Janssen EM-L

Environmental Sciences Europe. 2021, **33**: 29

This paper addresses the topical water quality concern that cyanobacteria produce secondary metabolites, some known to be toxins including microcystins, cylindrospermopsin, anatoxins, and saxitoxins. The issue was studied using high-performance liquid chromatography–high-resolution tandem mass spectrometry/tandem mass spectrometry (HPLC–HRMS/MS) in raw drinking water sources in the UK. Eight cyanopeptides were isolated and quantified with reference standards and a further 20 cyanopeptides were identified by detailed interpretation of exact mass, fragmentation patterns, and detailed reference data on standards. This sophisticated analytical study has provided unique information on the complex array of cyanobacterial metabolites that are found in water reservoir cyanobacterial blooms.

One September sample was found to contain 21 cyanopeptides totaling over 60 µg/L. The main classes of compounds identified were described as Anabaenopeptins and Cyanopeptolins with Microcystins (including MC-LR and MC-RR together with variants of both) being the third most prevalent, followed by Aeruginosins a class that was second most prevalent in another reservoir September sample.

The authors discuss their findings in relation to a new WHO provisional guideline (see WHO story in the *News Items* section) for short term exposure to total microcystins of 12 µg/L and recreational short term exposure to total microcystins of 24 µg/L to conclude that their finding of ~10 µg/L for total microcystins did not exceed these new, proposed short term provisional guidelines. However, the maximum chlorophyll-a concentrations recorded of 37 µg/L and 22 µg/L, respectively, and cyanobacterial cell counts of $6 \times 10^4$ cells/mL did exceed the WHO recreational water guideline levels for relatively low probability of adverse health effects of 10 µg/L chlorophyll-a and cyanobacterial cell count of $2 \times 10^4$ cells/mL.

This study revealed, in much greater analytical detail than typically found, the diversity and complexity of biologically active, but, fully natural, secondary metabolites that are produced by cyanobacterial blooms in drinking water reservoirs.

## Disinfection By-Products

### Reactivity-directed analysis – a novel approach for the identification of toxic organic electrophiles in drinking water

Prasse C

Environmental Science: Processes & Impacts. 2021, **23**: 48–65

This extensive review paper (217 cited references), although not mentioning DBPs in its title, is very much focused on and relevant to the challenge of exploring whether drinking water DBPs pose a human health risk. The premise that is developed and explored is that electrophilic reactive compounds will readily interact with nucleophilic biomolecules, including proteins and DNA, a key step in a variety of known mechanisms of toxic action including mutations and initiating carcinogenesis. Five examples of such reaction mechanisms are provided along with a list electrophilic compounds produced by various oxidative disinfection processes: ozonation, advance oxidation processes, UV photolysis, chlorination, and chloramination. The electrophilic compounds listed include: aldehydes, haloaldehydes, chlorinated hydroxyfuranones, haloketones, haloacetonitriles, haloacetic acids, haloacetamides, quinones, quinone imines, epoxides, cyclic anhydrides, organo-phosphorus esters, cyanogen halides and hydro-peroxides.

The key premise is that this knowledge can be used to recognise critical molecular initiating events (MIEs) that can be simulated via *in chemico* assays versus the more common *in vitro* assays being used for assessing toxic potential combined with conventional chemical analyses (see Stalter et al. 2020 review following in this *From the Literature* section). The author provides 10 examples of reactivity-directed analyses including: amino acid derivative assay, direct peptide reactivity assay, electrophilic allergen screening assay, direct peptide reactivity assay, electrophilic allergen screening assay and peroxidase peptide reactivity assay. Because the diversity and complexity of DBPs in drinking water poses such challenges to interpretation of DBP health risks, the potential of this largely analytical chemistry, reactive-directed analysis approach should be applied to DBP research.

### Mixture effects of drinking water disinfection byproducts: implications for risk assessment

Stalter D, O'Malley, E von Gunten U, Escher, BI

Environmental Science: Water Research & Technology. 2020, **6**: 2341–2351

One of the vexing issues about assessing possible human health impacts of DBPs is how to deal with the toxicity of a complex mixture of compounds. This paper notes (as noted in the Feature article on DBPs) that there have been indications from epidemiological studies suggesting increased bladder cancer risk from life-long ingestion of chlorinated drinking water and the paper mentions the US EPA (2006) mandated calculation of regulatory economic costs / benefits for its DBP rule used an estimate that 2-17% of bladder cancers could be avoided if DBP exposure was eliminated. While the authors of this paper also noted that causation of urinary bladder cancer has not been "conclusively" proven, it should also be noted that a recent expert panel review (Hrudey et al. 2015a) found that DBP causation of bladder cancer remains only a viable hypothesis but the epidemiological evidence remains uncertain. Likewise, the US EPA (2006) did acknowledge that the fraction of cases of bladder cancer used for their economic analysis could well have been zero because of the uncertainty about causation of bladder cancer then, uncertainty which has not been resolved since.

This paper addresses the challenge of interpreting the combined toxic effect of a mixture of DBPs, recognizing that there are so many individual DBPs and that if their toxic effects were combined, they might bridge the acknowledged gap between cancer risk predictions based on individual DBP toxicity, considering the levels at which they occur, and the much higher, but uncertain, epidemiological cancer risk estimates. In this regard, it is important to recognize the discrepancy in risk estimates is large (Hrudey et al 2015b; Appendix C), a median ratio of over 200 fold between simple addition of individual DBP cancer risk estimates, based on assumptions of occurrence concentration, compared with recent epidemiologic estimates. However, the toxicology estimate was based on summing only DBPs that had a cancer risk estimate and it is clear that there are many DBPs either not yet identified, or identified without knowledge of their cancer risk potency, if any.

The authors set out to evaluate whether a concentration addition (CA) model applies to a mixture of DBPs for toxic responses to a common set of reporter gene assays (derived from human cell lines) as well as Microtox. These are different toxic endpoints than cancer risk measured at the whole organism level, given the competing effects of detoxification and metabolic activation, but they still offer some useful insights at the cellular level. The authors evaluated 12 mixtures of the following DBPs - trihalomethanes, halonitromethanes, haloacetonitriles, haloketones, haloacetic acids, chloral hydrate, haloacetamides, 3-chloro-4-(dichloromethyl)-5-hydroxy-5H-furan-2-one (MX) and concluded that the CA model worked for additivity for the toxicity endpoint they used. They also determined that the sum of these identified DBPs explained less than 6% (e.g., <1/16) of the overall effect in most cases. Two exceptions were found for purge and trap (as opposed to solid phase) extracts where 29% and 92% of the total toxicity could be explained by identified DBPs. Most of the toxicity from drinking water DBPs, according to these *in vitro* toxicity assays, was attributed to haloacetonitriles, haloketones, and monohaloacetic acids.

Hrudey SE et al. Evaluating evidence for association of human bladder cancer with drinking water chlorination disinfection by-products. Journal of Toxicology and Environmental Health – Part B. 2015a **18**(5); 213-241.

Hrudey SE *et al.*, Evidence for Association of Human Bladder Cancer With Chlorination Disinfection By-Products. Web Report #4530. 2015b, Water Research Foundation, Denver, CO.

US EPA. 2006. Economic Analysis for the Final Stage 2 Disinfectants and Disinfection Byproducts Rule. U.S. Environmental Protection Agency. Office of Water (4606-M) EPA 815-R-05-010 December 2005 www.epa.gov/safewater

### New methods for identification of disinfection by-products of toxicological relevance: Progress and future directions

Wawryk NJP, Craven CB, Jmaiff Blackstock LK, Li X-F

Journal of Environmental Sciences. 2021, **99**: 151-159

Although the past 50 years has seen a substantial growth in the amount of interdisciplinary research into environmental health issues, the divide in understanding the meaning and implications of methodology between epidemiologists / public health researchers and analytical /toxicology researchers remains large. This paper, despite its detailed dive into sophisticated analytical technology, should be required reading for epidemiologists / public health researchers. To the extent that the latter are not able to follow the analytical details, they should find an analytical chemist with whom they can discuss this review paper. Simply put, a key take-away message has to be that how analyses are done will strongly determine what is found. The best historical example is that in the 1960s and early 1970s, the method of choice for determination of trace organics in water was the carbon-chloroform extract, a procedure involving adsorption of trace organics onto activated carbon, followed by desorption with chloroform and analysis of the organics found in the chloroform. Not surprisingly, this method was blind to THMs that are primarily chloroform, until Johannes Rook developed a head-space gas chromatographic analysis that did not require use of this solvent in the analysis. Put another way, there is no universal analytical method that can tell any analyst everything that is in a sample, the results depend on the analytical "workflow", i.e., how the sample is prepared (concentrated / extracted / interferences removed, etc.), how it is analysed (chromatographic separation, mass spectrometric detection) and how output data is processed (sorting of enormous quantities of output data, comparison with data bases, etc.).

This review explores recent advances in analytical approaches to DBPs, to reveal the many challenges that exist and how some of these challenges are being addressed. The paper correctly notes that DBPs are an important topic because human exposure to them in drinking water is ubiquitous. Likewise, that has come about because disinfection of drinking water to reduce waterborne disease transmission is one of the greatest public health advances in human history. The sample preparation stage is too often overlooked with regard to the profound effect it has on what is finally detected. The authors demonstrate for a large number of known DBPs, how differences in just two characteristics, polarity and volatility will impact the ability to detect those DBPs when gas chromatography, liquid chromatography or super critical fluid chromatography are used. Obviously, those characteristics will also play an enormous role in how individual DBPs will respond to various sample preparation procedures. All advanced techniques involve mass spectrometry which in turn relies upon ionization of the analyte for the process to work. There are critical differences in the stability of various compounds to different ionization techniques, meaning that those compounds unable to survive a given ionization procedure will not be detected by mass spectrometry.

The considerable advances in mass spectrometric analyses over past decades has only been possible because of the enormous advances in computing power to acquire and analyse data. The authors note the important distinction between targeted and non-target analyses of mass spectrometry data. Obviously, if you know what you are looking for, targeting the analysis to find the target will be easier than collecting all the mass spectrometric data that may be generated and asking the computer to process that data in a manner that can reliably identify previously unknown compounds. Substantial progress in the latter category has been made to help researchers avoid inadvertently adopting the commonly cited streetlight anecdote about an inebriated person who is looking at night for his lost keys only under a lamp post because the light is better there.

This paper will not provide all the answers to progress in better understanding and characterising human health risks posed by DBPs. However, it does provide an informative window on the range of possibilities now available for improving progress. Readers should also be able to accept the possibility that countless new DBPs can be identified and characterized as the authors correctly note mostly in the μg/L (ppb) to ng/L (ppt) or even lower concentration range. That truth does not exclude the possibility that none of these future DBP discoveries will lead to evidence that shows they occur at a high enough level of exposure that they will represent a human health risk that must be managed (see Figure 1 in the feature article *Disinfection By-Products – A Health Risk Perspective*). If serious DBP human health risks are discovered, they will need to be effectively researched and managed.

## Access to Improved Drinking Water

### Inequality in access to improved drinking water sources and childhood diarrhoea in low- and middle-income countries

Hasan MM, Alam K,

International Journal of Hygiene and Environmental Health. 2020, **226**:113493

The United Nations Sustainable Development Goal 6 for Clean Water and Sanitation lists as the first target: "*By 2030, achieve universal and equitable access to safe and affordable drinking water for all*". This is an ambitious target, given that: "*3 in 10 people lack access to safely managed drinking water services and 6 in 10 people lack access to safely managed sanitation facilities*" and "*Each day, nearly 1,000 children die due to preventable water and sanitation-related diarrheal diseases.*" https://www.un.org/sustainabledevelopment/water-and-sanitation/ Providing access to improved drinking water sources (IDWS) is a key aspect of reducing the incidence of childhood diarrhoea (ICD). The authors of this paper accurately note that unsafe drinking water is generally understood to be a major factor causing childhood diarrhoea in South Asia and Sub-Saharan Africa. Their analysis provides a much more granular understanding of the geographic distribution of these problems.

The authors undertook an ambitious, high level data analysis for detailed results for 81 countries and from 1.63 million households to evaluate the degree to which unequal access to IDWS is a factor in ICD. The nations studied were categorised on national access and sub-national inequality in access to IDWS to explore associations between access to IDWS and ICD. Low access to IDWS (<70%) was most prevalent in Sub-Saharan Africa and none of the 23 countries with >95% access to IDWS were from that region. Only three of the 17 countries with <70% access to IDWS were outside that region (Yemen, Afghanistan and Haiti).

Of the 81 countries studied, 18 were found to have substantial inequality, i.e. at least one location with >90% IDWS and at least one with <50% IDWS. 14 of these were in Sub-Saharan Africa with two each from North Africa / West Asia / parts of Europe and South / Southeast / Central Asia. The countries with the highest geographical inequalities in IDWS included: Chad, the Democratic Republic of Congo, the Palestinian Territories, Afghanistan, Yemen, Mozambique, Senegal, Sudan, Central African Republic and Angola.

While the overall expected findings that higher access to IDWS shows clear negative correlation with the ICD (i.e. IDWS reduces ICD as expected), the demonstration of geographical inequality in accessibility to IDWS highlights that international aid and development programs need to be targeted more specifically to geographic regions of low access to IDWS rather than simply provided at a national level. Although the findings of this study are clearly intuitive, it is valuable to have the data evidence analysed in sufficient detail to support such intuition.

## SARS-CoV-2 Surveillance in Wastewater

### Epidemiological evaluation of sewage surveillance as a tool to detect the presence of COVID-19 cases in a low case load setting

Black J, Aung P, Nolan M, Roney E, Poon R, Hennessy D, Crosbie ND, Deere D, Jex AR, John N, Baker L, Scales PJ, Usher SP, McCarthy DT, Schang C, Schmidt, Myers JS, Begue N, Kaucner C, Thorley B, Druce J, Monis P, Lau M, Sarkis S.

Science of the Total Environment. 2021, **786**: 147469

There has been an enormous uptake of monitoring wastewater for SARS-CoV-2 globally since the onset of the COVID-19 pandemic in early 2020. WaterRA launched the ColoSSoS project to investigate and implement sewage surveillance for SARS-CoV-2 and the collaborators in this paper are all members of the ColoSSoS initiative. The novel idea explored in this paper is to use grab samples collected from sewer sites in southern Victoria (centred on Melbourne and environs) for genetic signals of SARS-CoV-2 and analyse the timing and geographic locations of these samples in relation to clinical test data that provided the location and time course of confirmed clinical cases of COVID-19. This project was aided by having a high enough number of cases to provide detectable quantities of SARS-CoV-2 in sewage but a low enough, manageable number of cases to allow complete data collection for those cases during the study period between August and October 2020. Notified cases peaked at 148 cases per 100,000 during July 2020 before commencement of the study but declined substantially thereafter. The location of each confirmed case was determined for each day from two days before disease onset to 55 days after across 46 sewer catchments in the region.

The study set out to answer a number of questions about the presence of COVID-19 in the community, specifically:

*"Does the presence of people known to be infected with SARS-CoV-2 in the catchment from which a sewage sample is taken influence the odds of detection of the virus in a sewage sample?*

*What stage in the course of SARS-CoV-2 infection can best be detected by sewage sampling?*

*How far upstream from the sampling site can infected people be detected?*

*What is the minimum number of infected people in a catchment needed for reliable detection (and how does this relate to distance from the sampling site)?*

*As a diagnostic test for the presence of infected people in the relevant sewage catchment, what is the sensitivity and specificity of sewage testing for SARS-CoV-2?*

*Will it be best used to detect cases where none are known to exist, or to provide reassurance that there really are no cases, or both, or neither?*

*What combination of definitions of 'infected people' and 'in the catchment' most increases the odds of detection of virus on a given day?*

*What is the sensitivity and specificity of each combination of these definitions as a diagnostic test?*

*What is the probability of detecting SARS-CoV-2 in a sample, for different numbers of infected people, at various distances in the catchment?"*

For the benefit of physical scientist readers (chemists and engineers), the meanings of sensitivity and specificity used in epidemiology and medical diagnostics are subtly but profoundly different from what such readers may be used to, i.e., sensitivity meaning how little of something can be detected and specificity meaning that detection discriminates the analyte from other confounding analytes. For the purposes of this paper, the epidemiological meanings apply which can essentially be expressed as conditional probabilities:

**Sensitivity**: given that the analyte is present, how likely will an analysis be able to detect it being present

**Specificity**: given that the analyte is absent, how likely will an analysis confirm its absence.

This study used the data analytical model adopted from case control studies, but for these purposes a case did not refer to a case of COVID-19, for this study a case: "*was a **sewage catchment-sampling-day** with positive detection of the SARS-CoV-2 subgenome in the sewage sample*" and a control "*was a **sewage catchment-sampling-day** with a negative qRT-PCR result for SARS-CoV-2 subgenome in the sewage sample.*" For this construct, the calculated Odds Ratio was: "*the change in odds of detecting virus in a sewage sample when there is one or more infected people in the catchment within the relevant band of time and distance from the sampling site.*" For a total of 71 positive and 275 negative sewage samples using 354,155 person days of location data, the odds were between 5 and 20 times higher where known COVID-19 cases were present. Sensitivity was moderate (31% to 76%) but specificity was high (87% to 94%), meaning that a positive detection should not be casually dismissed because it provides good evidence of a COVID-19 case being present even though a non-detect does not guarantee the absence of COVID-19 cases. For this study, the probability of detection was still about 10% when only a single COVID-19 case was present, with probabilities rising with higher COVID-19 case numbers and closer proximity of COVID-19 cases in distance or time from the sampling site.



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