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Editor Martha Sinclair
Assistant Editor Pam Hayes

WQRA Internet Address: www.wqra.com.au

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Health Targets for Waterborne Disease

In the developed world, two major approaches have been adopted for setting tolerable limits for infectious disease risks from enteric pathogens drinking water. The US EPA defines tolerable risk in terms of an annual risk of 1 infection per 10,000 people per year, while the World Health Organisation defines the tolerable risk level in terms of a health burden of 1 microDALY (Disability Adjusted Life Year) per person per year resulting from pathogen infection. The US EPA target for waterborne infection risks was developed during drafting of the Surface Water Treatment Rule in the early 1990s. This target relates to infection regardless of whether symptoms occur, and does not differentiate between the variable consequences of infection by different pathogens.

The WHO health burden approach was first incorporated into the 3rd Edition of the WHO Drinking-water Guidelines in 2006, but had been proposed in the literature several years before. This approach takes into account differences in morbidity and mortality associated with different pathogens.

Both approaches utilise Quantitative Microbial Risk Assessment to estimate the number of infections resulting from exposure to reference pathogens (viruses, bacteria, protozoa) in drinking water. The EPA approach then sets water treatment requirements appropriate to expected pathogen levels in source water to reduce infection risks in treated water to the target level. The WHO approach, on the other hand, estimates the proportion of infections that are symptomatic, and characterises the spectrum of disease severity and duration that occurs among symptomatic cases, and the health consequences in terms of life years lost or life years lived with a
disability. The calculated average disease burden per case is then used to estimate water treatment requirements to achieve the tolerable health burden taking into account source water pathogen concentrations.

The suitability of target levels for tolerable risks set by both methods have recently been the subject of debate within WHO (1), and a recent article in the Journal of Water and Health focuses on concerns over the appropriateness of the chosen WHO target level for drinking water and for wastewater irrigation, but also discusses the US EPA approach (2). The author notes that the WHO target level for waterborne disease was set by reference to the existing target level for water-related cancers (10^5 cancer cases per 70 years of exposure), and contrasts the chosen cancer risk level with actual cancer incidence rates in the US. The comparison suggests that the target for water-related cancer risk is at least four orders of magnitude (i.e. 10,000-fold) lower than actual total cancer incidence in the US. This indicates that the target value for cancer risk, and therefore the corresponding target value derived for waterborne disease is, in the words of the author, 'extremely overcautious and unlikely to be cost-effective'.

While the WHO Guidelines for Drinking-water and Wastewater Use in Agriculture both acknowledge that a less stringent level of acceptable risk (perhaps 10 to 100-fold higher) may be appropriate if setting a 10^6 DALY burden per person per year from waterborne exposure alone will have little impact on the overall disease burden, the more stringent level appears to have been accepted by default with no serious debate over the appropriateness of this value and the importance of water in relation to other sources of diarrhoeal disease or other types of public health risk. The author proposes that a target level of 10^4 DALYs per person per year for waterborne disease would be more reasonable while still providing a substantial margin of safety. Similar arguments can be advanced by comparing the current regulatory targets for waterborne disease risk with actual rates of diarrhoeal disease in both developed and developing countries. If the target for waterborne disease was changed to 10^4 DALYs per person per year, the increment in actual disease burden would be minimal, and probably well below the limit of detection by public health surveillance. Similar arguments are applicable to risks from helminth infections such as Ascaris in developing countries. To further illustrate the consequences of current target values, two examples are given where application of the target values to wastewater used for crop irrigation produces clearly illogical and cost-ineffective consequences.

The author concludes that:

- the current WHO target value of 10^{-6} DALYs per person per year for the disease burden from waterborne or wastewater-related disease cannot be considered realistic or cost-effective, even in high income countries,
- that a target of 10^{-4} DALYs per person per year is likely to be much more cost-effective yet still provide adequate margins of public health safety for water-related cancer, diarrhoeal disease and Ascaris in all countries, and
- that legislators/regulators should always be asked to justify the decisions they make on levels of tolerable risk and to detail the cost implications and cost-effectiveness of these decisions.


**Update on Rabbit Cryptosporidium**

Researchers in the UK have recently published the final results from a research program to characterise the ‘rabbit genotype’ of *Cryptosporidium* and determine the contribution of this genotype to human infections in the UK (1). The study was one of several investigations prompted by an outbreak attributed to contamination of a drinking water supply by a rabbit that gained entry to a tank within
the Pitsford Water Treatment Works (2). The event was initially detected due to routine continuous monitoring of oocyst levels in finished water, rather than recognition of cryptosporidiosis cases in the community. Although the levels of oocysts detected in the finished water were low (less than 0.1 oocysts per litre on average), the incident triggered a 10-day boil water notice in June/July 2008 which affected over 250,000 people in the East Midlands region of England. A total of 23 cases of cryptosporidiosis attributable to the rabbit genotype were eventually identified by genetic typing of oocysts in faecal specimens from people suffering gastroenteritis. These included two cases with delayed symptom onset dates which may have arisen by secondary transmission within households rather than directly from consumption of contaminated water. The outbreak raised questions over the significance of rabbits as a reservoir of potentially human-infectious Cryptosporidium as no instances of human infection by the so-called ‘rabbit genotype’ had been reported in the published literature prior to this event. Genetic analysis of the outbreak strain showed that it could not be distinguished from C. hominis isolates during standard PCR-RFLP analysis of three different genetic loci (SSU rRNA, HSP70 and COWP) which are commonly used to discriminate between Cryptosporidium species and genotypes. The rabbit genotype has since been named Cryptosporidium cuniculus.

As a consequence of the outbreak, the Cryptosporidium Reference Unit (CRU) of the UK Health Protection Agency was commissioned to undertake a research program to improve understanding of the human health risk posed by C. cuniculus. The results of these studies have now been published in a report to the UK Department of Environment, Food and Rural Affairs and several peer reviewed papers. The researchers began by undertaking a literature review to assess current knowledge on the occurrence of Cryptosporidium in animals of the Order Lagomorpha (rabbits, hares and pikas) and any available information on genetic characterisation of Cryptosporidium isolates found in these animals (3). Although 74 relevant papers reporting testing of wild, farmed or laboratory rabbits for Cryptosporidium were found, most involved only small numbers of animals and few had any information on genetic characterisation. Only two studies had surveyed more than 100 wild rabbits, with a UK study reporting detection of one positive sample among 109 samples of rabbit droppings (0.9% prevalence; 95% CI 0.2–5.0) and a German study reporting no detections among 232 samples tested (0.0% prevalence; 95% CI 0.0–1.6). Nine other studies of wild rabbits involving smaller numbers of samples gave prevalence estimates ranging between 0% and 7.1%. None of the studies provided information on the age or sex of infected animals. Incidental (i.e. not deliberately established) Cryptosporidium infections have also been reported in farmed and laboratory rabbits. A small amount of genotyping information on oocysts isolated from natural infections in rabbits was reported for four published studies and one unpublished study. For the published studies, the data were sufficient to confirm the ‘rabbit genotype’ had been detected; for the unpublished study the data were insufficient to draw conclusions. There are also literature reports of experimental infections being successfully established in rabbits using oocysts of C. parvum, C. meleagridis and C. muris.

A detailed molecular genetic analysis of C. cuniculus was undertaken by DNA sequencing of segments of five genes commonly used for comparison of Cryptosporidium isolates (4). A total of 38 human clinical isolates of C. cuniculus were tested (23 from the waterborne outbreak and 15 from sporadic cases) along with the isolate obtained from the intestinal contents of the rabbit which was believed to have been the source of the outbreak. These tests showed that C. cuniculus is identical to C. hominis at the COWP and LIB13 genes. Small differences between C. cuniculus and C. hominis were observed in the DNA sequences for three other genes tested: SSU rRNA: 4 bp differences in 787 bp (0.51%), HSP70: 1 bp difference in 403 bp (0.25%), and Actin: 1 bp difference in 833 bp (0.12%). The degree of difference between C. cuniculus and C. hominis detected in these comparisons were considerably less than the sequence differences that exist between the two species C. hominis and C. parvum (sequence differences of 1.02, 1.51, 1.51% at these loci respectively). The researchers noted, however, that
only a tiny fraction of the Cryptosporidium genome has been analysed for these comparisons, and that DNA sequence differences or similarities are not in themselves sufficient grounds to define species boundaries.

Morphological studies undertaken by the CRU showed that C. cuniculus oocysts were very similar in size and appearance to those of C. hominis and C. parvum, therefore these species cannot be distinguished by microscopy. C. cuniculus oocysts are readily detected by immunomagnetic separation and immunofluorescent microscopy techniques originally developed for detection of C. parvum and now also used routinely for C. hominis detection. Therefore C. cuniculus oocysts can be detected by methods already in routine use in water and clinical testing laboratories.

To further assess the host range of C. cuniculus and compare it to C. hominis, the CRU researchers conducted infection tests in neonatal mice, weanling rabbits, immunosuppressed adult mice and immunosuppressed Mongolian gerbils. C. cuniculus oocysts were also tested for infectivity in HCT-8 cell culture (a human cell line used for culture of C. hominis). Both C. cuniculus and C. hominis failed to infect neonatal mice. C. cuniculus readily infected weanling rabbits and the animals began shedding moderate numbers of oocysts 4 to 7 days after inoculation and continued until 14 days after infection. In contrast, only 1 of 4 weanling rabbits was infected by C. hominis, and oocysts were shed in low numbers only on Day 17. Both C. cuniculus and C. hominis were able to infect immunosuppressed Mongolian gerbils but animals infected with C. cuniculus began shedding high densities of oocysts significantly earlier than those infected with C. hominis. Immunosuppressed adult mice were infected by both types of Cryptosporidium and a very marked difference in shedding times was evident. Animals infected with C. cuniculus began shedding oocysts after 3 to 5 days, while those infected with C. hominis began shedding only after 10 days. Oocyst shedding density was also higher for C. cuniculus. Histological examination of the small intestine from rabbits, gerbils and adult mice shedding C. cuniculus showed features consistent with Cryptosporidium infection. In the cell culture experiment, endogenous replicating stages of C. cuniculus were readily detectable, indicating this model system is suitable for study of this genotype. Overall, these results show that despite their apparent close genetic relatedness, C. cuniculus and C. hominis have distinct biological differences in host range and replication properties.

To assess the contribution of C. cuniculus to symptomatic cryptosporidiosis in humans, the researchers examined 3,030 samples of archived DNA which had been extracted from oocysts in faecal specimens from people with diarrhoeal disease (1). The specimens originated from sporadic cases of cryptosporidiosis occurring in England, Scotland and Wales between January 2007 and December 2008, and had been submitted for routine testing as part of normal medical practice. This time interval included the period of the waterborne outbreak (July-August 2008) but the isolates tested here were not part of the outbreak investigation. Isolates received outside the outbreak period had been routinely screened by PCR-RFLP Rsa1 analysis of the COWP locus, but as noted above, this analysis is not able to distinguish C. cuniculus from the closely related C. hominis. These stored DNA extracts were tested again by single-round small subunit (SSU) rRNA PCR-RFLP using SspI, which generates a unique pattern for C. cuniculus. Specimens received during the outbreak period were tested by a more labour intensive method which was able to differentiate a larger number of species/genotypes. The identity of presumptive C. cuniculus isolates was confirmed by sequencing segments of the SSU rRNA gene and glycoprotein (GP60) gene.

Among the 3,030 specimens tested, only 37 (1.2%) contained C. cuniculus. The most commonly detected species was C. parvum (1,506 isolates, 49.7%), followed closely by C. hominis (1,383 isolates, 45.6%). Others identified were C. meleagridis (26 isolates), C. felis (8 isolates), the cervine (deer) genotype (8 isolates), novel or unidentified genotypes (5 isolates), and the C. hominis monkey genotype (1 isolate). Co-infection with C. hominis and C. parvum was seen in 5 samples, and 88 samples failed to amplify with the PCR primers used. The isolates of C. cuniculus occurred in both years (23 in 2007, 14 in
2008), and in patients residing in England (24), Wales (1) and Scotland (12). None of the sporadic C. cuniculus cases resided in the area affected by the waterborne outbreak. The more detailed genotyping method used for the outbreak did not show a higher rate of “unusual” genotypes than the routine method except for the C. cuniculus isolates.

Analysis of the characteristics of sporadic cases showed significant differences in the age range of C. cuniculus cases in comparison to C. hominis and C. parvum cases. C. cuniculus cases (range 1–74 years; mean 29 years; median 31 years) were more evenly distributed across all age groups, while C. hominis (range 0–83 years; mean 19 years; median 13 years) and C. parvum cases (range 0–86 years; mean 17 years; median 29 years) were less frequent in older age groups. C. cuniculus occurred most frequently in the summer and autumn; a pattern similar to C. hominis, but different from C. parvum which has peak occurrence in spring. Two of the 37 cases with C. cuniculus infection had travelled outside the UK during the presumed incubation period for their illness (14 days prior to onset of symptoms). Information on occupational and environmental exposures during the incubation period was available for only 14 cases. One case reported direct contact with a pet rabbit, two others reported outdoor activity (playing golf, sitting on grass) which might have exposed them to C. cuniculus oocysts in the environment. None reported visiting the area affected by the waterborne outbreak or having any contact with people from the outbreak area. Two people reported household contact with others suffering from diarrhoeal illness, and one person was known to be immunosuppressed (kidney transplant patient).

The clinical details recorded for sporadic cases were insufficient to allow comparison of symptom characteristics or severity between people infected with C. cuniculus and those infected with C. hominis or C. parvum. However, due to the more detailed investigation undertaken in association with the waterborne outbreak, clinical details were available for 22 of the 23 outbreak cases. All of these cases reported suffering from watery diarrhoea, which one person described as ‘moderate’ and the rest as ‘severe’. The median duration of diarrhoea was 13 days (range 2 to 39 days). Four people also had vomiting and 14 reported nausea. Abdominal cramps and/or abdominal pain were reported by the majority of cases. The youngest case was 10 years old and the oldest 60 years old (median 29 years). Cases reported consuming a median of 1.8 litres of unfiltered, unboiled tap water per day prior to their infection; considerably higher than the average of 0.78 litres per day seasonal estimate from the most recent National Tap Water Consumption Study undertaken by the UK Drinking Water Inspectorate. Based on Monte Carlo modelling of oocyst concentrations delivered to consumers in different parts of the drinking water distribution system over the 5-day period of contamination, the mean incubation period before onset of symptoms was estimated at 6.8 days with an 80% credible interval of 2 to 11 days (assuming that two cases with symptom onset 17 and 18 days after the boil water notice were secondary and not primary cases). The majority of cases (15/22) reported a history of prior medical conditions, although some of these did not appear to be plausibly related to vulnerability to Cryptosporidium infection. However, the researchers noted that 10 cases reported bowel conditions (e.g. reflux, indigestion, prior surgery) that may have been of relevance.

The CRU research team also carried out a risk assessment to investigate whether the infectivity/virulence characteristics of the C. cuniculus outbreak strain were likely to be significantly different from those of other Cryptosporidium isolates that have previously been used to assess human health risks from drinking water. This was done by using data from the C. cuniculus Pitsford outbreak and a C. parvum outbreak which occurred in the town of Clitheroe in 2000. The daily known (Pitsford) or modelled (Clitheroe) oocyst concentration data from the two outbreaks was used in Quantitative Microbial Risk Assessment to predict the proportion of the population likely to have been infected in each outbreak. This prediction was then compared to the reported attack rate (number of exposed people identified as cases in the outbreaks) to determine the ratio of the two numbers. This ratio is expected to be small as many infected individuals may be asymptomatic and, even in a publicised outbreak, it is
likely that only a small minority of people who experience gastroenteritis symptoms will seek medical care and have a laboratory-confirmed diagnosis made. On this basis, the ratio should provide an indication of any significant differences in the infectivity/virulence properties of the two Cryptosporidium strains, assuming the two populations had equal susceptibility to infection prior to the outbreak and no significant differences in water consumption. Given the low proportion of human sporadic cases that are attributable to C. cuniculus, it is unlikely that many people in the Pitsford area would have had existing immunity to this strain. In the case of Clitheroe, the researchers noted that prior to the outbreak, this town had very low rates of reporting of sporadic cryptosporidiosis cases, so the assumption of low levels of immunity in the exposed population is also reasonable.

Drinking water intake was modelled as a Poisson distribution assuming a mean of 533 ml per day, and dose response parameters from published Cryptosporidium risk assessments were used. The two outbreaks had substantial differences in exposure, with peak oocyst concentrations in the Clitheroe outbreak documented as being 40 times higher than the Pitsford outbreak. The period of exposure was also longer for Clitheroe (15 days) in comparison to Pitsford (4 days). The calculated attack rate for the Clitheroe outbreak was 29.6 per 10,000 people (95%CI 21.5 to 37.7) while for Pitsford it was 0.81 per 10,000 people (95%CI 0.5 - 1.2). However, the modelling suggested that the probability that an infected person was recorded as being an outbreak case was not significantly different between the two outbreaks (0.35% for the Clitheroe outbreak and 0.24% for the Pitsford outbreak). The researchers concluded that it was unlikely that the Pitsford outbreak strain (C. cuniculus) had significantly different infectivity/virulence characteristics from the Clitheroe outbreak strain (C. parvum). Therefore, in the absence of human feeding studies on C. cuniculus, it is reasonable to apply the current Cryptosporidium dose-response model in QMRA modelling for this organism.

Subsequent to completion of the CRU literature review, an Australian study was published which reported a survey of 176 rabbit droppings from four areas in the state of Victoria. Cryptosporidium oocysts were detected in 12 samples (6.8%), and were confirmed to be C. cuniculus by molecular analysis of the SSU rRNA and glycoprotein gp60 loci (5). In addition, genetic analysis of 310 faecal specimens from sporadic human cryptosporidiosis cases occurring in France from 2006 to 2009 identified one C. cuniculus isolate (6). This isolate originated from a person with HIV infection but no information was available on other risk factors such as contact with animals or other people with gastroenteritis symptoms.

Overall, this body of research has shown that C. cuniculus from rabbits currently makes up a minor fraction of human cases of illness, but has the potential to cause waterborne outbreaks given the right circumstances. The potential for rabbits to contribute to water contamination must therefore be considered in water quality management strategies. Information is needed on the density of oocysts produced per gram of rabbit faeces and the weight of faeces produced per infected rabbit per day in order to assess the relative importance of rabbits compared to other catchment animals which may also be host to human-infectious Cryptosporidium strains. The discovery of this ‘new’ source of risk does not invalidate past Cryptosporidium water testing results or risk assessments based on such results as C. cuniculus oocysts would have been detected by currently used techniques, but probably misclassified as C. hominis.

2) Reported in Health Stream Issues 51 and 52.
Tularemia Linked to Wells in Norway

Investigators in Norway investigating an upsurge in cases of tularemia in early 2011 have linked the disease to consumption of water from private drinking water wells and streams. The disease, caused by infection with the bacterium *Francisella tularensis*, is rare but can be life-threatening if not recognised and treated promptly with appropriate antibiotics. The bacterium can infect a number of animal species including rabbits, hares and rodents, and tularemia is endemic in North America and parts of Europe and Asia. The predominant mode of transmission to humans is via bites from ticks or flies which have previously fed on infected animals, but transmission can also occur via ingestion or inhalation of bacterial cells from infected animals or carcasses. The disease can manifest in different clinical forms depending on the initial mode of infection. The causative organism has been reported to survive for months in cold water, and outbreaks attributed to ingestion of contaminated water have been reported previously. Tularemia is considered to be a potential biological weapon due to its low infectious dose and ability to infect via the airborne route. It is a notifiable disease in most developed countries.

The recent investigation was triggered by a sudden increase in reported cases from three counties in central Norway. A total of 39 cases were reported from this area during January-March 2011, compared to four and eight cases respectively for 2009 and 2010. Preliminary enquiries showed that cases occurred in 13 municipalities, making it unlikely that a single exposure source was responsible. Information from the patients showed that 34 of the 39 had consumed water from private wells or streams. Seven cases shared a single water source but a further two cases shared a common well, but the remaining 25 appear to have occurred independently. *Francisella tularensis* was detected by PCR in water samples from five wells (the number of wells or volume of water tested was not stated). The majority of cases (31/39) exhibited clinical symptoms of fever and pharyngitis or swollen lymph glands in the neck, which is consistent with infection via the ingestion route.

News Items

Rivers, Nutrients and Cholera

Researchers from the US have discovered a previously unknown relationship between nutrient discharge from rivers and blooms of coastal phytoplankton that may lead to increased risks of cholera outbreaks. It has been generally found that phytoplankton numbers decrease when sea temperatures rise, but in the Bay of Bengal the reverse relationship has been observed. The researchers found that phytoplankton numbers decrease when sea temperatures rise, but in the Bay of Bengal the reverse relationship has been observed. The researchers found that phytoplankton numbers were closely related to large outflows from rivers, and suggest that rising nutrient levels rather than temperature may be the triggering factor for blooms in coastal areas. The phytoplankton are consumed by zooplankton which may serve as hosts for the cholera bacteria *Vibrio cholerae*. The persistence of the organism in this environmental reservoir adds to the difficulty of controlling cholera outbreaks and achieving elimination of the pathogen from developing countries. Similar relationships between river outflows and phytoplankton blooms were seen when data for other major river systems in Africa and...
South America were analysed. This finding suggests that the apparent relationship between sea surface temperature and cholera risks may need to be re-evaluated.

**Water Contamination in Berlin**
Part of the German capital Berlin was subject to a boil water notice for several days in late July after coliform bacteria were detected in the water supply. The city of 3.4 million inhabitants is served by groundwater drawn from around 800 wells and distributed via nine major water works. The water is aerated and sand filtered to remove excess manganese and iron, but is usually distributed without disinfection. Routine monitoring detected coliform bacteria in the distribution system of Spandau district on the western edge of the city on 27 July. A boil water notice was issued for about 130,000 residents in the affected area, while precautionary chlorination of the water supply to the area was established. The resultant investigation failed to pinpoint a specific source for the contamination and it was concluded that high rainfall in July (about four times average levels) had led to saturation of the soil and ingress of contamination. A number of wells were also found to have structural faults which needed repair. At present, chlorination is being maintained for this section of the water supply.

**Shellfish Warning for Christchurch**
Residents and visitors in the Christchurch area of New Zealand have been warned not to consume shellfish from the Avon and Heathcote rivers or estuary after “very high levels” of norovirus were detected in shellfish recently. Sewerage systems in the city and the major sewage treatment works were badly damaged in major earthquakes in February and June this year. As a result, local waters have been subject to contamination from untreated and semi-treated sewage. Work to repair the damaged water and wastewater systems is expected to take up to two years, and Christchurch will have summer water restrictions imposed for the first time in 13 years as water supply capacity is still below normal levels. In addition to the damage suffered by public wells, many homeowners and businesses with private groundwater supplies are now facing deterioration of water quality from previously satisfactory sources.

**From the Literature**

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<td>Summaries of these additional articles are available in the PDF version of Health Stream on the WQRA web page:</td>
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<td><strong><a href="http://www.wqra.com.au">www.wqra.com.au</a></strong></td>
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<td>Lead in school drinking water: Canada can and should address this important ongoing exposure source. Barn P and Kosatsky T. (2011) Canadian Journal of Public Health, 102(2); 118-121.</td>
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<tr>
<td>Dissemination of drinking water contamination data to consumers: A systematic review of impact on consumer behaviors. Lucas PI, et al. (2011) PloS one, 6(6); e21098.</td>
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Arsenic exposure from drinking water and mortality from cardiovascular disease in Bangladesh: Prospective cohort study.

Arsenic has been classified by the International Agency for Research on Cancer as a group 1 human carcinogen, however evidence of other health effects including cardiovascular effects has not been well established. Studies that examine the potential interaction between arsenic exposure and cardiovascular disease and the interaction with cigarette smoking are lacking. It is estimated in Bangladesh that 57 million people have been chronically exposed to groundwater with arsenic concentrations exceeding the WHO standard. This study was undertaken in Araihazar, Bangladesh and examined whether exposure to arsenic, measured in both water and urine, was associated with mortality from cardiovascular disease. Also examined was whether cigarette smoking increases the susceptibility to the cardiovascular effects of arsenic exposure.

Between October 2000 and May 2002, 11,746 men and women were recruited for an ongoing prospective cohort study. To be eligible, participants needed to be married and aged between 18-75; living in the study area for a least five years prior to recruitment; and a primary user of one of the 5,966 tube wells (index wells) for at least three years. Information was collected at baseline and follow-up visits on demographic and lifestyle variables using a standardised questionnaire. Blood pressure was measured by trained clinicians. Water samples and their geographical coordinates were collected for the 5,966 contiguous wells in a defined area of 25 km².

This present study included data from the first (September 2002 to May 2004), second (June 2004 to August 2006) and third (January 2007 to March 2009) follow-ups. Also a field clinic was established for cohort participants for follow-up between their biennial visits. Causes of deaths were coded according to the WHO classification and ICD-10. The water samples from the tube wells were tested for total arsenic concentration. Using baseline data, a time weighted arsenic concentration was derived as a function of drinking durations and well arsenic concentrations. Spot urine samples were collected from 11,224 (95.6%) of 11,746 participants interviewed at baseline, 11,109 (98.1%) of 11,323 at the first follow-up, and 10,726 (98.1%) of 10,934 at the second follow-up. Total urinary arsenic concentration was measured. Urinary creatinine was also analysed. Changes in urinary arsenic between visits were calculated using urinary creatinine adjusted arsenic. Dietary intakes were measured at baseline using a semiquantitative food frequency questionnaire.

The follow-up period included 77,252 person years of observation. There were 460 deaths of which 198 were from diseases of circulatory system (ICD-10 codes 100-199) and these deaths accounted for 43% of total mortality in the population. An increased risk of mortality from diseases of the circulatory system was found in people with high concentrations of well arsenic. The risk became statistically significant for the highest quartile of arsenic exposure. The mortality rate for cardiovascular disease was 214.3 per 100,000 person years in people drinking water containing <12.0 µg/L arsenic compared with 271.1 per 100,000 person years in people drinking water with ≥12.0 µg/L arsenic. Participants exposed to well water with >148 µg/L (mean 265.7 µg/L) of arsenic were 1.47 (95% CI, 0.99 to 2.18) times more likely to die from diseases of the circulatory system compared with those who were exposed to <12 µg/L. There was an increased risk of mortality from ischaemic heart disease and other heart disease in relation to high concentrations of well arsenic, and a dose response relationship was still apparent after adjustment for BMI, smoking status, educational attainment and changes in arsenic concentration between visits adjusted for urinary creatinine and also for age and sex. The hazard ratio was 1.29 (1.10 to 1.52) for a 1 SD increase in well arsenic concentration (115 µg/L). A similar association was found between baseline well arsenic mortality from
ischaemic heart disease; participants with >148 µg/L of arsenic in well water were 1.94 (0.99 to 3.84) times more likely to die from ischaemic heart disease compared with those with <12 µg/L. The hazard ratio was 1.25 (1.03 to 1.52) for a 1 SD increase in well arsenic concentration. However there was no association observed between well arsenic levels and mortality from cerebrovascular disease.

The risk of dying from ischaemic heart disease and other heart disease associated with moderate (25.3-114 µg/L, mean 63.5 µg/L) or high levels of arsenic exposure (>114 µg/L, mean 228.8 µg/L) was consistently higher in those who had ever smoked and especially in current smokers at baseline compared with those who had never smoked. The joint effect of moderate or high levels of arsenic exposure and ever smoking was greater than the sum of their individual effects. Ever smokers were further classified in to past and current smokers and the synergistic effect between moderate or high level of arsenic exposure and current smoking was stronger than for past smokers.

This prospective cohort study showed that exposure to arsenic from drinking well water was associated with an increased risk of cardiovascular disease, in particular ischaemic heart disease and other heart disease. On the basis of the study estimates, 28.9% (1.4% to 60.0%) of deaths from heart disease in this population can be attributed to arsenic concentrations over 12 µg/L in well water. A dose-response relationship was found between arsenic exposure and mortality from cardiovascular disease, especially heart disease and at much lower levels of arsenic exposure than previously reported. A synergistic effect on mortality from ischemic heart disease and other heart disease was apparent between arsenic exposure and cigarette smoking even when arsenic exposure was moderate.

Comment The authors note that previous studies on this topic assessing arsenic exposure on a regional basis have given mixed results but the use of data from individual wells in this study may have provided better characterisation of exposures. The strong interaction between smoking and arsenic means that the adverse public health impact of arsenic exposure may be magnified even at arsenic exposure levels which are considered moderate in Bangladesh.

Chromium

Oral ingestion of hexavalent chromium through drinking water and cancer mortality in an industrial area of Greece - An ecological study.

Hexavalent chromium Cr(VI) is a known carcinogen when inhaled however there is significant debate on the carcinogenicity of hexavalent chromium when it is orally ingested. A recent publication using data from the National Toxicology Program of the US National Institutes of Health, identified hexavalent chromium as ‘likely to be a carcinogen to humans’ with an estimate of the cancer potency to humans equal to 0.5 (mg/kg/day)\(^{-1}\). On the basis of previous ecologic and animals studies, it could be hypothesized that several organs may be targets of chromium carcinogenicity including the liver, kidney, bladder, gastrointestinal tract, the hematopoietic system and even bone. An ecological mortality study was conducted in an industrial area of Greece where the water consumed by the population was contaminated with hexavalent chromium (maximum levels ranging between 41 and 156 µg/l in 2007-2009 and presumed exposure for at least 20 years). The aim of the study was to examine the cancer mortality in this area of Greece which has historically consumed CR(VI)-contaminated water.

The study area was located in Oinofita municipality which is situated 50 km north of Athens, and comprised of four villages that were initially rural but became an industrial area in the early 1970s. In 1969, permission was given for disposal of processed liquid industrial waste into the Asopos river, which runs through Oinofita. In 2009, there were about 700 industries operating in the Oinofita area and about 500 of these generated liquid industrial waste. During the period July 2007 through June 2008, hexavalent chromium measurements in different sites
of the public drinking water supply of Oinofita municipality ranged from 8.3 µg/l to 51 µg/l. A study during the period November to February 2008 found 35 out of 87 samples taken from different wells in the same area to have Cr(VI) levels above 10 µg/l with a maximum of 156 µg/l. Another study during the period September 2008 to December 2008 found Cr(VI) levels ranging from 41 to 53 µg/l in three samples taken from the public drinking water supply of Oinofita. In early 2009 the main drinking water source was changed, and more recent measurements made by the Oinofita municipality (June 2009-July 2010) recorded Cr(VI) levels of <0.01-1.53 µg/l.

Using municipality records, 5842 individuals were identified who met the following criteria: a) being a legally registered citizen of the municipality at any time during the follow up period (1/1/1999 – 31/12/2009) and b) being registered as a permanent resident of Oinofita in the municipality records. Death certificates and local burial records were matched to the municipal records. Gender, age (in five-year age groups) and calendar year mortality ratios (SMRs) were calculated for all deaths, cancer deaths, and specific cancer types for Oinofita residents over the follow up period. The expected number of deaths was calculated based on mortality statistics for the entire Voioitia prefecture, in which Oinofita municipality is located.

There were 474 deaths identified during the 11 year period, of which 118 were cancer related. The all cause SMR for the Oinofita municipality were similar to that of the prefecture of Voioitia (SMR = 98, 95% CI 89-107). The SMR for all cancer deaths over all years was slightly increased but not statistically significant (SMR = 114, 95% CI 94-136). However, SMRs were significantly elevated for several individual types of cancer. For primary liver cancer, the observed deaths were eleven-fold higher than the expected number of deaths (SMR 1104, 95% CI 405-2403, p < 0.001) and were statistically significant among both males and females. Observed deaths associated with kidney and other genitourinary organ cancers (six deaths) were more than three-fold higher than expected in women (SMR 368, 95% CI 119-858, p = 0.025). The SMR for lung cancer was also statistically significantly elevated (SMR 145, 95% CI 101-203, p = 0.047). Elevated SMRs were also found for several other cancer sites but did not reach statistical significance. There was no evidence of a linear trend after grouping the period specific SMRs into 3 time intervals, i.e. 1999-2002, 2003-2006, 2007-2009. However for the year 2009 there was a statistically significant SMR of 193 (95% CI 114-304, p=0.015) for all cancer deaths. It was noted that three out of the six deaths associated with primary liver cancer and two out of the five deaths associated with female kidney and other genitourinary organ cancers came from the small village of Agios Thomas (with only 1090 legally registered permanent residents). The highest concentration of Cr(VI) (156 µg/l) was measured in 2008 in a well close to this village.

The results found in this study raise concerns as to the possibility of higher mortality rates from primary liver and lung cancers in both males and females as well as urologic cancers among women, although they are based on small numbers. The results also suggest the possibility of higher risks of other epithelial and gastrointestinal cancers. The findings here are consistent with previous epidemiological and animal studies indicating carcinogenesis after consumption of drinking water contaminated with Cr(VI). Further studies are required to explore this possible causal link because of the widespread health implications of such contamination. Evidence is needed to establish guidelines to prevent this form of contamination and to formulate public health recommendations.

Comment This study was unable to examine the influence of risk factors such as smoking or occupational exposures (which may for some people have included hexavalent chromium given the widespread generation by local industries). The starting date for the study was chosen for practical reasons to coincide with commencement of systematic storage for (and corresponding ability to retrieve) death certificates. The authors note that given the long latency period of many cancers, further follow up may reveal higher levels of risk in this population.
Disinfection Byproducts

Individual exposures to drinking water trihalomethanes, low birth weight and small for gestational age risk: A prospective Kaunas cohort study.


There have been many recent epidemiological studies examining the association between exposure to disinfection by-products (DBPs), as measured by trihalomethanes (THMs), in drinking water and adverse reproductive or developmental effects. Epidemiological studies have mainly found small increases in risk for low birth weight (LBW) at term or small for gestational age (SGA) or have shown mixed results, however the evidence is still inconsistent and inconclusive, in particular for various exposure routes. This present study evaluated the effect of maternal THM dose on LBW, SGA and birth weight (BW) in singleton births. This study used individual exposure assessment data from a prospective cohort study and controlled for many possible confounding variables.

A prospective cohort study was conducted in Kaunas city, Lithuania where all pregnant women living in Kaunas city between 2007 and 2009 were invited to join the cohort when they visited a General Practitioner. There were 4,161 pregnant women who participated in the study. The first interview was completed during the first trimester with a median gestational age of 8 weeks. The interview collected information on demographics, residence and job characteristics, chronic diseases and reproductive history, including date of last menstrual period and previous preterm delivery. Women also reported their age, educational level, marital status, smoking, alcohol consumption, blood pressure, body mass index and other potential risk factors for LBW. Women were examined by ultrasound to determine the gestational age of the foetus. A water consumption and water use habits questionnaire was administered during the study. Consumption was ascertained for cold tap water or drinks made from cold tap water, boiled tap water (tea, coffee and other) and bottled water, used at home, at work and other. Also, the number of showers, baths, swimming pool attendances, and their average length was ascertained. Pregnancy outcomes were obtained from medical records.

The Kaunas city municipal drinking water is supplied by four water treatment plants. The four plants disinfect groundwater with sodium hypochlorite and produce different concentrations of THMs in finished water. One site supplied finished water with higher levels of THMs and the other three plants supplied finished water with lower levels of all THMs. Water samples were collected four times per year over the 3-year study period in the morning in three locations: close to the treatment plant, at 5 km, and at 10 km or more from every treatment plant. There were a total of 85 water samples collected from 12 monitoring sites in four water supply zones for THM analysis. Samples were analysed for specific values for the four regulated THMs (chloroform, bromoform, bromodichloromethane and dibromochloromethane). Mean quarterly THM concentrations for water zones were calculated. Tap water THM concentration, derived as an average of quarterly sample values over the time that the pregnancy occurred from all sampling sites located in the each distribution system, were used along with geocoded maternal address at birth to assign the individual women a residential exposure index. Every subject’s residential exposure index was combined with water-use questionnaire data to assess individual exposure through ingestion of THMs. Dermal absorption and inhalation were addressed by considering showering and bathing alone and combined with ingestion. The average daily uptake of THM internal dose (level of THMs in the blood stream) was estimated for each woman’s entire pregnancy average and for the three trimesters.

Regression analysis was conducted to evaluate the relationship between internal THM dose and birth outcomes, adjusting for family status, education, smoking, alcohol consumption, body mass index, blood pressure, ethnic group, previous preterm, infant gender and birth year.
The mean total THM level in water at the three low THM sites was 1.3 µg/L, and at the high level site was 21.9 µg/L. Chloroform constituted about 80% of the total THMs by mass. Participation in the study was high, with 79% of women who were approached agreeing to participate. Uptake of total THM (TTHM) via ingestion was found to contribute 8% to the internal dose, showering and bathing were found to be the main contributors and made up 92% of the total internal dose. The individual total uptake of TTHMs ranged between 0.0025 and 2.40 mg/d. There was a strong correlation between TTHM uptake across all three trimesters for individual women, reflecting low seasonal variation in THM levels in water supplies.

Exposure to TTHMs (when classified by tertiles) was associated with an increased risk for LBW and a reduction in BW (when treated as a continuous variable). After adjustment for potential confounders, a statistically significant increased risk with higher dose levels (second and third tertiles) of TTHMs during the three individual trimesters and the entire pregnancy was found. During the entire pregnancy, the odds ratios for LBW were 1.77, (95% CI 0.95-3.30); and 2.13, (95% CI 1.17-3.87), respectively, for second and third tertiles compared to the first tertile. The LBW risk (OR) found per 0.1 µg/d increase in TTHMs was 1.08, (95% CI 1.00-1.16) and 1.07, (95% CI 1.00-1.15) and the decrease in BW was 49.3 g (-146.3 to -1.5) and 47.2 g (-92.7 to -1.6) during the entire pregnancy and third trimester.

When exposure to individual THMs was assessed, chloroform showed similar patterns to TTHMS. For bromodichloromethane, statistically significant increases in LBW risk for the third tertile compared to the first tertile for the third trimester were found (OR 1.80, 95% CI 1.00-1.05). For bromodichloromethane internal dose as a continuous variable, an elevated risk in LBW for the entire pregnancy, first and third trimester was found (ORs 1.04-1.05 for an increase of every 0.01 µg/d). Dibromochloromethane internal dose results were found to be statistically significant for entire pregnancy and third trimester (OR 2.25, 95% CI 1.00-6.36 and OR 2.24, 95% CI 1.03-5.66, respectively). No significant reduction in BW as a continuous variable was found. Some increases in ORs for SGA in relation to elevated internal doses of TTHMs, chloroform and bromodichloromethane were found, however the results were not statistically significant. For dibromochloromethane, ORs for SGA were generally lower than 1.0, and were not statistically significant. (No information is presented on bromoform levels in water or any analysis regarding its association with birth outcomes).

This study shows some epidemiological evidence for a dose-response relationship between THM internal dose exposure and LBW. This study used individual internal dose assessment based on residential THM levels, detailed water use behaviours and exposure during pregnancy which is an improvement on previous exposure assessments. This study also followed women prospectively and they did not move house during pregnancy. The study suggests that internal dose in pregnancy varies substantially across individuals and depends on both water THM levels and water use habits. Further research on the effects of DBPs and birth outcomes needs to focus on the use of integrated internal dose and individual susceptibility to DBPs.

**Gadolinium**

Gadolinium (Gd) is a silvery-white malleable and ductile rare-earth element (REE). Chelated forms of this element have been used since 1988 as contrast agents in clinical and diagnostic magnetic resonance imaging (MRI). These agents are used in relatively high doses and are rapidly excreted in the urine of patients. Gd contrast agents (Gd-CA) have been found in hospital effluent and in urban waste water treatment plants (WWTP). High concentrations of Gd in the environment were first reported in rivers in Germany in 1996. Since then large positive Gd anomalies of varying size have also been reported for rivers in Europe, Asia, North America and Australia. These Gd anomalies are considered to be of anthropogenic origin and are likely to be related to medical usage.

**Anthropogenic gadolinium as a microcontaminant in tap water used as drinking water in urban areas and megacities.**

anthropogenic origin as large excesses of individual REE are not known to occur by natural processes in pristine environments. These Gd compounds are highly stable unreactive compounds and have long half-lives and are not removed in wastewater treatment plants (WWTP). Even though anthropogenic Gd has been widely reported in surface and ground water, evidence of anthropogenic Gd in tap water is scare. This study examined the extent to which anthropogenic Gd in surface and ground water can be traced in municipal tap water that is distributed as drinking water.

There were 23 tap water samples investigated for REE and barium (Ba), rubidium (Rb) strontium (Sr) and uranium (U) from different districts of the City of Berlin, together with a shallow ground water sample from the eastern part of Berlin. The Havel River (which receives WWTP effluent from Berlin) was also sampled for comparison with published data from the mid-1990s. Water from each tap was run for at least 10 min before samples were taken. Samples were filtered and acidified to pH 1.8-2.0. Samples were pre-concentrated before measurement with inductively coupled plasma mass spectrometry (ICPMS). A positive anthropogenic Gd anomaly was defined as the ratio above unity of GdSN/Gd*SN where GdSN is the shale normalised total measure Gd concentration and Gd*SN is the shale normalised background concentration.

The median U concentration in the tap water samples was 0.94 nmol/L (0.22 µg/L) and concentrations were much lower than the current guideline value of 63 nmol/L (15 µg/L), suggested by the World Health Organization. Samples from the western districts of Berlin showed higher U concentrations (median 0.86 nmol/L or 0.20 µg/L) than those from the eastern districts (0.86 nmol/L or 0.20 µg/L). Median dissolved concentrations of Ba, Rb and Sr were 0.45 µmol/L (0.06 mg/L), 23.5 nmol/L (2.01 mg/L) and 2.31 µmol/L (0.20 mg/L), respectively. These values were well below any drinking water limits. The total dissolved REE content had a median of 50.1 pmol/L (7.94 ng/L) and ranged from 26 pmol/L (4.0 ng/L) to 168 pmol/L (26.3 ng/L). These values were low compared with the limited amount of data available worldwide.

Tap water samples from the eastern districts of Berlin showed little to no anthropogenic Gd. In western Berlin, tap water anthropogenic Gd concentrations ranged from 5.83 pmol/L (0.92 ng/L) to 112 pmol/L (17.6 ng/L), on top of a geogenic background of 1.61 pmol/L (0.25 ng/L) and 3.42 pmol/L (0.54 ng/L), respectively. The samples from the eastern districts of Berlin showed a median Gd anomaly of 1.49 while those from the western districts have a median of 8.92, the latter showed that measured Gd concentrations are on average one order of magnitude above geogenic levels. The maximum anthropogenic Gd concentration was found in a sample from Reichstag which is the location of the German parliament. The strong regional differences are most likely from the specific historical situation of Berlin, where before the re-unification of Germany in 1990, different water management schemes were implemented on either side of the Berlin Wall. In contrast to East Berlin, West Berlin used natural and induced bank filtration to keep groundwater levels constant. Therefore, drinking water resources in the western part of Berlin are more strongly affected by anthropogenic Gd than those in the eastern part. Today, about 70% of all drinking water in Berlin relies on natural and induced bank filtration.

The City of Berlin and its surrounding area have close to 4 million inhabitants, each using on average 125 L of water per day. This leads to a large strain on the drinking water supplies of the city and therefore bank filtration will in time play an even more important role in water management. Use of Gd-CA for MRI and other applications will probably increase in the future and so the anthropogenic Gd content in surface and tap water can be expected to rise further. Although Gd-based contrast agents can cause adverse effects in the human body, Gd toxicity should not be a problem at the concentrations found in Berlin tap water. At current levels, a person would have to drink 100 million L of tap water to match exposure levels reached during a single MRI application. The presence of anthropogenic Gd in tap water is not restricted to the City of Berlin, the City of London faces similar challenges to Berlin with the River Thames and tap water in London also carrying anthropogenic Gd.
It can be expected that microcontaminants in surface water, such as contrast agents and pharmaceuticals will eventually be transported into the drinking water that is distributed in urban areas that derive their freshwater from unconfined aquifers or rely on induced bank filtration for groundwater recharge. This will be most evident in megacities with highly evolved health care systems where freshwater supplies are limited and per capita consumption of pharmaceuticals and contrast agent is high. There are numerous pharmaceuticals that can be expected to show similar environmental behavior as Gd-CA due to their high stability, water solubility and ability to pass unaffected or with little attenuation through WWTPs. Testing for anthropogenic Gd anomalies may be a useful way of screening water samples for potential presence of pharmaceuticals. Measuring REE may be a fast and cost-effective way of screening large sample sets in a short period of time.

**Lithium**

**Lithium in drinking water and suicide mortality.**

Lithium has mood-stabilising effects and is used therapeutically to treat bipolar disorder (previously termed manic-depression) and some other psychiatric disorders. Such treatments have been documented to reduce suicide risks. Although the effects of therapeutic doses of lithium are well established, there is little known about the extent to which intake of natural lithium may influence mental health or suicide mortality. A recent report from Japan found an inverse relationship between lithium levels in tap water and suicide mortality in Oita prefecture. This report has been criticised for being based on unreliable lithium measures and for omitting socioeconomic confounders such as poverty and economic issues. This current study extended the design of the Japanese study and used a large data source of lithium levels in drinking water to investigate the association between local lithium levels in drinking water and suicide mortality in Austria, adjusting for regional socioeconomic conditions and the availability of mental health service providers.

The official Austrian mortality database for suicides in 17 age groups for males and females for 99 Austrian districts and for each year from 2005-2009 was provided by Statistics Austria. Comprehensive data on population density, average income per capita and the proportion of Roman Catholics were obtained from the Austrian population census of 2001. Unemployment rates were also obtained and were averaged for the available years 2005-2008. The density of general practitioners and psychiatrists per 10,000 population for each district were available for 2007. The density of psychotherapists per 100,000 was available for 2005.

Standardised mortality ratios (SMRs) were calculated for suicide for each district by using the gender and age composition of the general population as a standard. Also the suicide rates per 100,000 for each district were calculated to allow discussion of estimated effects. There were 6,460 water samples from drinking water supplies from all 99 districts collected between 2005 and autumn 2010 and these were analysed for lithium by inductively coupled plasma optical emission spectrometry. Lithium levels were averaged per district. Multivariate regression models were adjusted for well-known socioeconomic factors that influence suicide mortality in Austria (population density, per capita income, proportion of Roman Catholics, availability of mental health service providers). Sensitivity analyses and weighted least squares regression were used to test the robustness of the results.

The mean lithium level in Austrian drinking water was 0.0113 mg/l (s.d. = 0.027). The highest single lithium level was 1.3 mg/l found in Graz-vicinity and the district with the highest mean level was Mistelbach (0.0823 mg/l). The distribution of lithium levels was highly skewed, with only 7 districts having levels above 0.020 mg/l. Suicide mortality showed a significant correlation with mean lithium levels per district, population density, per capita income, the proportion of Roman Catholics as well as the density of psychiatrists, psychotherapists and GPs. Unemployment did not correlate with
suicide mortality. Sensitivity analyses of the univariate models did not challenge the robustness of the findings. Also, adjustment for well-known socioeconomic confounders did not affect the association with lithium concentrations in drinking water. In the crude multivariate model, an increase in lithium concentration in drinking water of 0.01 mg/l was associated with a decrease in the suicide rate of 1.4 per 100,000 or a 7.2% reduction in the SMR for suicide. Lithium was still a significant predictor of suicide SMR in the final weighted multivariate model although statistical significance was marginal. Regional lithium concentration explained 17% of variance in suicide mortality in the crude model and 3.9% in the adjusted, weighted model.

This study provides strong evidence that geographic regions with higher natural lithium concentrations in drinking water are associated with lower suicide rates. There is now evidence from Texas, Oita prefecture, Japan and Austria of the beneficial effects of lithium in drinking water on suicide mortality. However, currently there is not enough known about the effects of natural lithium on the prevalence of neurodevelopmental disorders to consider artificially increasing its level in drinking water as a method of universally preventing suicide. The true effects of chronic low-lithium intake on health and suicide need to be investigated further.

Comment Therapeutic doses of lithium are usually in the range of 600 to 2,400 mg per person per day. The authors note they could not assess lithium intake from bottled mineral water (which may have high levels) or food. There is also some evidence that lithium can be absorbed via the skin, therefore showering or bathing habits may contribute to variations in exposure.

Manganese (Mn) is an essential nutrient although in excess it can be a potent neurotoxicant. Manganese is commonly found in ground water however the risks associated with this route of exposure are mostly unknown. Manganese in not regulated in drinking water in the United States or Canada. There have been no epidemiological studies to date that have examined possible neurotoxic effects of manganese concentrations common in North American aquifers. This study assessed the relationship between exposure to manganese from drinking water and IQ in school-age children living in communities relying on groundwater. Also the relationship between hair manganese concentration (MnH) and estimated manganese intakes from water consumption and from diet were examined.

A cross-sectional study was conducted in southern Quebec, Canada between June 2007 and June 2009. Eight municipalities were selected in order to give a range of manganese concentrations in water (MnW). There were 362 children (age 6-13) from 251 families who participated in the study that had lived in the same house for > 3 months. Hair samples were collected from each child, washed and measured for concentrations of manganese, lead (Pb), iron (Fe), arsenic (As), zinc (Zn), and copper (Cu) by inductively coupled plasma-mass spectrometry (ICP-MS). There were 302 children included in the hair analyses and 362 in the other analyses. During a home visit, parents were interviewed about the source of the domestic tap water (private well/public well), residential history and changes to domestic water treatments. A water sample was collected from the kitchen tap and a second sample was collected when there was a point-of-use filter attached to the tap. The metals Mn, Pb, Fe, As, Zn and Cu were measured in tap water by ICP-MS. For a subsample of 20 families, tap water was sampled on three occasions over a 1-year period to examine time-dependent variability.

During the home visit, a semi-quantitative food frequency questionnaire was administered to the parent and the child to assess manganese intake from the diet and water consumption. General cognitive abilities were assessed using the Wechsler Abbreviated Scale of Intelligence (WASI) which yields a Verbal

Intellectual impairment in school-age children exposed to manganese from drinking water.
IQ score, a Performance IQ score and a Full Scale IQ score. Information was collected from the mother on factors that might confound the association between manganese exposure and cognitive abilities of the child, such as socio-economic status indicators, parity and alcohol and tobacco consumption during the pregnancy. Maternal nonverbal intelligence and maternal symptoms of depression were also assessed.

Changes in IQ were examined in relation to four manganese exposure metrics: MnW, MnH, manganese intake from water consumption and dietary manganese intake. The change in IQ (β) associated with a 10-fold increase in manganese exposure indicators was examined with adjustment for two sets of covariates. The first set of covariates (model A) included several socioeconomic indicators. The second set of covariates (model B) included the same variables as model A, as well as variables significantly associated with IQ or MnW, to reduce the unexplained variance.

Tap MnW was found to range from 1 to 2,700 µg/L, with an arithmetic mean of 98 µg/L and a geometric mean of 20 µg/L. Home tap water sources were almost equally divided between public well water (53%) and private well water (47%). The median of estimated manganese intakes from direct consumption of water (1.6 µg/kg/month) were similar to the median of intakes from water incorporated into food preparations (1.9 µg/kg/month). Estimated dietary manganese intakes were much higher than the intakes from water consumption, with a median of 2,335 µg/kg/month. MnH was significantly associated with manganese intake from water consumption (p < 0.001) but not with dietary intake (p = 0.76). Estimated dietary manganese intake was not significantly associated with IQ scores in unadjusted or adjusted analyses. Higher MnW was significantly associated with lower IQ scores in both model A [β = -3.7 (95% CI, -6.5 to -0.8)] and model B [β = -3.3 (95% CI, -6.1 to -0.5)]. MnH was also associated with lower Performance and Verbal IQ scores, although this was not statistically significant except for Verbal IQ in model A [β = -3.1 (95% CI, -5.9 to -0.3)]. Children in the highest MnW quintile (median, 216 µg/L) scored 6.2 points below those in the lowest quintile (median, 1 µg/L). For estimated manganese intake from water ingestion, those children in the lowest quintile had the highest IQ scores and those in the highest quintile had the lowest scores, however point estimates in the middle quintiles did not show a consistent trend. For MnH, IQ scores decreased only slightly between children in the lowest quintile and middle quintiles, and there was a steeper decrease for children in the highest quintile. There was no association between dietary manganese intake and IQ scores.

Higher MnH was associated with lower Full Scale IQ scores, both in model A [β = -3.7 (95% CI, -6.5 to -0.8)] and in model B [β = -3.3 (95% CI, -6.1 to -0.5)]. MnH was also associated with lower Performance and Verbal IQ scores, although this was not statistically significant except for Verbal IQ in model A [β = -3.1 (95% CI, -5.9 to -0.3)]. Children in the highest MnW quintile (median, 216 µg/L) scored 6.2 points below those in the lowest quintile (median, 1 µg/L). For estimated manganese intake from water ingestion, those children in the lowest quintile had the highest IQ scores and those in the highest quintile had the lowest scores, however point estimates in the middle quintiles did not show a consistent trend. For MnH, IQ scores decreased only slightly between children in the lowest quintile and middle quintiles, and there was a steeper decrease for children in the highest quintile. There was no association between dietary manganese intake and IQ scores.

This study showed that low-level, chronic manganese intake from water ingestion but not from diet, was significantly associated with elevated MnH. These finding suggest that manganese from drinking water is metabolised differently than that from diet and can lead to overload upon exposure from water and subsequent neurotoxic effects expressed by intellectual impairments in children. As manganese occurs commonly in drinking water and the effects seen in this study were at low MnW levels, it is proposed that the guidelines for safe manganese in water should be revisited. Further studies in other populations are needed and studies employing a prospective design would provide a stronger basis for examining the influence of exposure duration and timing (i.e., critical development periods) on manganese neurotoxic effects.

Comment The health guideline for manganese in the Australian Drinking Water Guidelines is 0.5 mg/L (500 µg/L), however the aesthetic guideline is 0.1 mg/L (100 µg/L) based on staining of fixtures and taste issues. Levels above 0.02 mg/L can cause ‘dirty water’ problems for customers, and water suppliers generally treat high Mn source waters to reduce concentrations well below the aesthetic guideline value.
Perfluorocarbons

Implications of early menopause in women exposed to perfluorocarbons.

The perfluorocarbons (PFC) perfluorooctanoate (PFOA) and perfluorooctane sulfonate (PFOS) are man-made chemicals used in a variety of household products. These chemicals have a long half-life and surveys have shown their presence in human blood and internal organs appears to be ubiquitous. PFCs have been associated with multiple physiological and health outcomes in human and animal studies. Animal studies have provided strong evidence of endocrine-disrupting effects of PFC however evidence in humans is scarce. This current study was conducted to investigate menopausal status and estradiol concentrations in women exposed to PFCs.

The C8 Health Project was established as a result of a legal class action relating to contamination of drinking water supplies by PFCs in the vicinity of an industrial plant. The project collected data on 69,030 adults and children from six public water districts contaminated by PFOA from the Dupont Washington Works Plant near Parkersburg, West Virginia, between August 2005 and August 2006. The project is designed to collect information on a wide range of health parameters and conditions, with no a priori hypotheses regarding adverse effects of PFOA.

This present analysis included 25,957 women from this project who were aged 18-65 years. Serum levels of PFOA and PFOS were in blood samples were analysed, and self-reported hormone use and occurrence of menopause was determined for study participants. Serum estradiol was also assessed to investigate whether it varied with PFC levels. The odds of having experienced menopause were calculated with logistic regression using quintiles of log transformed PFC with the lowest quintile as the reference and excluding women who had a hysterectomy. Odds were adjusted for smoking, age (within grouping), BMI, alcohol consumption (yes/no) and whether or not they had a regular exercise program. For estradiol analysis, regressions were calculated using the same quintiles and covariates, excluding pregnant women and women with a full hysterectomy as well as women taking hormones and fertility drugs or selective estrogen receptor modulators.

The adjusted odds of having experienced menopause in the oldest group of women (> 51 ≤ 65 years) exposed to PFOS showed a monotonic increase with all quintiles being significantly higher in relation to the lowest. For women in the perimenopausal years (>42 to ≤ 51 years of age), there was no monotonic increase by quintile, but the highest three quintiles were significantly higher than the lowest. The pattern for PFOA was similar but not monotonic in the oldest group of women. All of the quintiles were significantly higher than the lowest. For the perimenopausal age group, the top three quintiles were significantly higher compared with the lowest.

In the adjusted analysis, PFOA was not associated with serum estradiol concentrations in any group. PFOS however, was negatively associated with estradiol concentrations in all groups but only significantly in the perimenopausal (β = -3.65; P < 0.0001) and menopausal age groups (β = -0.83; P = 0.007). The mean PFC concentration in women with and without hysterectomy was compared in the 40-55 year age group to see whether hysterectomy made a difference. In women with a hysterectomy both PFOS and PFOA were significantly higher (P < 0.0001).

This large study showed that after controlling for age within the group, women of perimenopausal age in this population were more likely to have experienced menopause if they had high serum concentrations of PFOS and PFOA compared to those with lower levels. The mechanism explaining the increased risk of menopause within this group of women with high levels of PFOS and PFOA is still not clearly understood, although a reduction of endogenous estrogen in women exposed to PFOS is possible. Animal studies have shown that PFOA demonstrates estrogen-like properties, causing degeneration of ovaries in PFOA-exposed females. The authors note
that the cross-sectional nature of the study does not permit the time relationship between PFC exposure and menopause to be determined. It could be argued, for example, that cessation of menstrual bleeding at menopause causes increased PFC levels as some chemical is normally lost in the menses. The finding of higher mean PFC levels in women with hysterectomies would support this explanation. However, this hypothesis is not consistent with the inverse relationship between estradiol and PFOS. Further research is required to understand the associations found here.

POU Treatment

Purification of household water using a novel mixture reduces diarrhoeal disease in Matlab, Bangladesh.

In Bangladesh, one of the major causes of waterborne disease is contaminated surface water which is used for many household purposes such as washing utensils, bathing, washing vegetables as well as for drinking. Also in Bangladesh many of the tube wells are contaminated with arsenic and therefore the options for obtaining safe drinking water are limited. The use of point-of-use water treatment such as household based chlorination has been found to be an effective intervention to prevent diarrhoeal diseases. This pilot study was conducted to determine the acceptability and effectiveness of treatment of household water with a recently developed surface water purifying mixture, in combination with training on the use of the mixture to prevent diarrhoeal diseases in the rural area of Matlab, Bangladesh. A mixture of alum potash, bleaching powder (calcium hypochlorite) and lime was developed to decontaminate surface water. Alum potash was included as a flocculent, bleaching powder provided the disinfectant in the mixture, and lime was included to adjust the pH. The proportion of the mixture of alum:lime:bleach was 9:3:2. The mixture provided a chlorine residual in water after primary disinfection and was inexpensive (less than US 1 cent per use).

The pilot field trial was conducted from May 2006 to April 2007 in Matlab. There were 420 families from 15 villages in the Matlab area randomly selected for the study. The villages were divided into 10 household clusters and 42 families from each cluster who used surface water for some purpose in the house, each with a child under 5 years of age, were approached to participate in the study. A field worker visited each family in a cluster at 15-day intervals to provide health messages and provide a supply of the water purification mixture (named Siraj Mixture). All the ingredients in the mixture were familiar to the families. Five clusters were also provided with H2S kits to demonstrate the presence of bacterial contamination in the surface water and show its absence after purification with the mixture.

Mothers in the families were instructed to collect 15 l of surface water in a pitcher and shown how to add the purifying mixture and mix it with the water. After 30 min they were shown how to pour the treated water into a separate covered water container, leaving the sludge behind. Data were collected via periodic questionnaires on the sources of household water as well as knowledge and attitudes regarding safe water, water storage, shifting from arsenic-contaminated and arsenic-free tube well water to mixture-treated water for drinking, etc. Field workers also collected information about water use from tube wells and surface water via questionnaires. Data were obtained from records of the International Centre of Diarrhoeal Disease Research, Bangladesh hospital in Matlab of episodes of diarrhoeal disease in the study families. It was possible to link any patient from the intervention villages with hospital treatment data according to their unique identification number. For comparison with the intervention families, hospital data was collected for diarrhoea cases treated at the hospital from 1613 control families from the same villages who were not provided with the water purification mixture.

During the study period, only one patient (who contracted cholera when he was away from home) from the 420 intervention families was treated for diarrhoea at the Matlab Hospital, whereas 83 patients from the 1613 control families received diarrhoea treatment. During the year prior to the intervention
(May 2005 to April 2006), 10 diarrhoea patients were treated at the Hospital from among the intervention families and 71 from among the control families. Many families shifted from tube well water to surface water treated with the mixture without encouragement from the field workers. Of the 399 families who were using tube well water as the source of their drinking water, 29% and 11% of the families who were using drinking water from arsenic-contaminated and arsenic-free tube wells, respectively shifted to drinking surface water treated with the mixture after 52 weeks. There were no differences found between the families who were given the H₂S kits and those who were not with regard to diarrhoea rates for those seeking treatment at Matlab Hospital or with regard to source of water switching.

This study showed a major reduction in the number of episodes of diarrhoea for which treatment was sought at the Matlab Hospital among families who were provided with the water purification mixture. The mixture was found to be convenient to use and to be acceptable to the villagers in Bangladesh and was also inexpensive. This mixture could also play an important role in providing safe water during natural disasters such as floods and cyclones when surface water becomes highly contaminated and thus reduce diarrhoeal disease in such situations. Further studies are required to determine whether the mixture can be scaled up in larger populations using a more convenient formulation along with the support of a health education program.

Comment This intervention appears to have produced a large decrease in severe diarrhoea cases, although no statistical comparison is presented. The authors note that the H₂S kits were provided to encourage use of the disinfection mixture by enabling householders to see positive test result before treatment and negative result after treatment. However the greatly improved clarity of treated water was probably regarded by householders as sufficient evidence of benefit even without use of the test kit. Compliance with use of the kit, and test results were not reported.

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Pam Hayes  
Epidemiology and Preventive Medicine  
Monash University - SPHPM  
Alfred Hospital, Melbourne VIC 3004  
AUSTRALIA

Phone +61 (0)3 9903 0571  
Fax +61 (0)3 9903 0556  
Email pam.hayes@monash.edu

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pam.hayes@monash.edu

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Arsenic

Urine arsenic concentration and obstructive pulmonary disease in the U.S. population.

There is an emerging body of evidence that suggests that exposure to inorganic As may lead to non-malignant respiratory conditions such as chronic cough and bronchiectasis as well as the already documented risk of lung cancer. There is debate as to whether chronic low-level arsenic exposure such as is common in the United States, might result in chronic disease. This study was conducted to investigate the association between urinary arsenic concentration and the prevalence of asthma, chronic bronchitis, emphysema diagnoses and respiratory symptoms.

The study population came from the US National Health and Nutrition Examination Survey (NHANES) combined 2003-2006 cohorts. Urinary arsenic concentration were analysed in 5365 survey participants aged 6 years and older. There were 236 participants that were excluded due to incomplete arsenic speciation data. This study was restricted to participants 20 years and older, as paediatric asthma has different etiologies from chronic respiratory disease and children have less chronic exposures than adults. Those who had consumed at least 1 serving of fish in the past 24 h were excluded to reduce the influence of organic arsenic found in fish on measured total urine arsenic concentration. Two participants were excluded with measured total arsenic concentrations 10 times the 99th percentile and therefore the final analysis consisted of 2687 participants.

Spot urine samples were obtained at the time of physical examinations. Total urine arsenic levels were measured and speciated. Urine creatinine concentration was also measured. Information on demographics and other covariates was collected as part of NHANES. Information collected included gender, age, race/ethnicity and level of education, smoking history, body mass index, and seafood consumption based on 24h dietary recall interview and from serum Hg concentrations.

Total arsenic was the exposure of interest and two different methods were used to adjust for the presence of organic arsenic. Linear regression (adjusting for gender, age, race/ethnicity, education, BMI, cotinine and urinary creatinine) was performed on log-transformed total and estimated inorganic arsenic to determine the ratio of geometric mean arsenic concentrations in participants with respiratory disease to participants without. Logistic regression models compared urinary arsenic adjusted for gender, age, race/ethnicity, education, BMI, smoking status, continuous serum Hg and serum cotinine category and urinary creatinine with diagnoses of asthma, chronic bronchitis, emphysema and respiratory symptoms, comparing participants above the 80th percentile of total and estimated inorganic arsenic concentrations with those below the 20th percentile.

Arsenic concentrations were not significantly different between participants with and without a diagnosis of asthma, emphysema or chronic bronchitis. Linear regression was performed and for asthmatics versus non-asthmatics, the ratio of total arsenic geometric mean was 0.92 (0.82, 1.02). For chronic bronchitis the ratio was 1.06 (0.99, 1.12) and for emphysema it was 0.95 (0.80, 1.02). Logistic regression showed that participants with greater than the 80th (>17.23 µg/L) percentile total arsenic had a crude odds ratio of 0.85 (95% CI: 0.59, 1.23) for having asthma when compared to participants with less than the 20th (<3.52 µg/L) percentile. When potential confounders were added into the model, the adjusted odds ratio was 0.71 (0.41, 1.24). Adjusting for organic arsenic and fish consumption increased the odds ratio to 1.27 (0.51, 3.12). The adjusted odds ratio for estimated inorganic arsenic was 0.79 (0.43, 1.46). Similar trends were found when assessing odds for having chronic bronchitis and emphysema, comparing participants with the lowest quintile of exposure to those with the highest. Adjusted odds ratios for having respiratory symptoms were assessed in the same way and were also below 1.
These results show no significant association between asthma, emphysema and chronic bronchitis, with urinary arsenic levels found in the general U.S. population. Additional analysis of chronic cough, phlegm production and wheezing did not show consistently significant associations after adjusting for organic arsenic. Much higher arsenic exposures in other regions of the world may influence the development of pulmonary disease and respiratory symptoms, however in this minimally exposed U.S. population no evidence of an association was found.

Sustainable use of arsenic-removing sand filters in Vietnam: Psychological and social factors.

Vietnam is one of many countries where chronic exposure to high levels of arsenic in groundwater is a significant public health problem. Recorded levels of arsenic in groundwater sometimes exceed 1000 µg/L. Household sand filters are a good option for arsenic removal in rural Vietnam. These filters are simple to operate and remove about 80% of arsenic from groundwater containing ≥ 1 mg/L of dissolved iron or an iron/arsenic ratio of ≥ 50 (high arsenic and high iron content commonly occur together in groundwater). The filters have low operational costs, do not require chemicals and the construction materials are locally available. Past studies have shown that after two years, drinking sand-filtered water reduces the body burden of arsenic (as measured by As in hair samples) sufficiently so that arsenic-associated skin problems should not develop. Iron is also removed by these filters, producing an improvement in the taste and colour of water that is perceptible to users. This present study examines the effects of psychological factors on the sustainable use of arsenic-removing sand filters in Vietnam posing two questions: (1) to what extent do the different psychological factors explain the different key behaviours of sustainable use, and (2) what can be done to promote the sustainable use of sand filters in Vietnam.

Face-to-face interviews were conducted in spring 2007. The survey was carried out in four villages in the former province of Ha Tay, near Hanoi. The villages were selected on the basis of high mean arsenic concentration in the groundwater and the number of sand filters in the village. The questionnaires contained a mixture of open and closed questions for measuring psychological factors related to a set of interrelated key behaviours: firstly users must decide to choose a sand filter instead of other alternatives for investing effort and money, and then they must acquire, use and maintain the sand filter properly. Specific questions were designed to quantify user perceptions regarding benefits and costs, difficulties and problems, knowledge and memory, affective and normative evaluations, social networks and details on decision-making and acquisition. Interviewees were also asked about what purchase or activity they might do instead of buying or building a sand filter (competing behaviour). Data was analysed with binomial logistic and linear regression models.

Data from 319 households were gathered. Of these, 162 had an arsenic-removing sand filter and 157 did not. In some villages almost everyone used a sand filter while in other villages there were just a few users. Having a sand filter was strongly related to having a groundwater tubewell. Taste was important or very important for 70% of the interviewees and the perceived health effect of the sand filter was one of the most important benefits mentioned with health issues seen as important or very important by 76% of interviewees. An unexpected advantage of the sand filters mentioned by 48% of all interviewees was that the sand filters can clean a large amount of water, not only for drinking but also for bathing, doing laundry and other purposes. Interviewees did not know much about the arsenic problems and motivation for installing sand filters seem to mainly relate to removing the iron dissolved in groundwater and not to removing arsenic. The most important problems with the sand filters were the inflexibility of the device (49 mentions of problems with space requirement, weight, or immobility) and practical problems (35 mentions of problems with pumping, like power outages, slow water drainage, or lack of knowledge of how to repair the filters). Practical problems with maintenance were mentioned 31 times.
The regression analyses investigated the three key behaviours (decision, acquisition, and maintenance) in relation to benefits, costs, social influences, affective influences, difficulties, knowledge and memory. In relation to benefits, user perceptions of positive health effects were related to all three key behaviours. For the decision, this relationship depends on the importance of health issues. For acquisition, the relationship is negative. This may be because persons who have a sand filter consider their water as healthier than that of person without filters. Conversely, those without filters expect a large improvement in the healthiness of their water if they were to install a filter. Another important benefit of sand filters was the improvement in the taste of the water. For the decision, the improvement in taste due to the sand filter is crucial, while for maintenance, the current taste of the water is more important. No significant effect of taste was found on acquisition of sand filters. The availability of large quantities of clean water had significant effects on the decision and acquisition of sand filters. No effect was seen for maintenance which does not increase the amount of water available for use.

Monetary costs had negative effects on the decision and the acquisition of sand filters. Some households decided to build the sand filter on their own, and the time and effort required to build a filter had a negative effect on acquisition. However, the physical effort needed to build a filter was positively related to the decision. Physical effort for maintenance was also positively related to maintenance. Poorer households did not abstain from competing behaviours in order to acquire a sand filter. If households could afford both, they acquired a sand filter; if not, only the competing behaviour was implemented.

Social influences were significant for all three key behaviours. The descriptive norms (i.e., what people think, how many other persons perform a certain behaviour) for having sand filters were strongly related to decision and acquisition. Maintenance was not related to descriptive norms regarding the sand filter, but (negatively) to the descriptive norm of performing the competing behaviour. Affective influences were important for all three key behaviours. Decision and acquisition were related to whether building a sand-filter would be enjoyable. Maintenance was related to being committed to perform maintenance within 3 months and the confidence of the persons that they will perform the maintenance.

None of the questions assessing the difficulties of performing the behaviours had significant effects. Knowledge about water-related problems other than arsenic was related to acquisition, but not to the other key behaviours. Memory processes (i.e., forgetting to perform a behaviour) are of relevance in regard to repeated behaviours. In the case of maintenance, forgetting was not an issue because of natural reminders, i.e., the colour of the water was used as an indicator.

In this study psychological and social factors explained significant variance in the key behaviours relating to sand filters. Based on this information, campaigns can be designed to promote the innovation by highlighting the advantages of improved healthiness and taste, as well as the availability of large quantities of clean water for washing, laundry, etc. Costs may be a problem in poorer areas and strategies are needed to change the situation where sand filters are only considered if there is enough money left after purchasing other goods. Promotion of filters as desirable and common to have, use and maintain is important to encourage uptake. Attention to practical issues is needed to choose the appropriate site for filters. Also increased knowledge of the health problems related to elevated arsenic in groundwater might facilitate increased use and maintenance.

Comment The presence of high levels of iron in water is noticeable due to staining of fixtures and laundry, and unpleasant taste. However, high levels of arsenic are not perceptible to the senses, and adverse health effects generally require a decade of exposure to become apparent, so there is no immediate signal to users of problems with water quality. As noted by the authors, the tangible aesthetic benefits of iron reduction may be a stronger motivation for uptake of sand filters than the long term (and poorly appreciated) health risks from arsenic.
Exposure to brominated trihalomethanes in drinking water and reproductive outcomes.


A recent meta-analysis suggests that exposure to disinfection by-products (DBPs) during pregnancy is associated with a small, positive association between trihalomethanes (THMs) concentrations in drinking water and term low birth weight (TLBW), small for gestation age (SGA) and intrauterine growth restriction (IUGR). The effect of low levels of exposure however remains unexplored. Experimental studies have shown that high volatility and dermal permeability of trihalomethanes may result in exposure through routes other than ingestion. This study aimed to improve on the exposure assessment of previous studies by determining levels of DBPs in samples of the public water systems from the prefecture of Heraklion in Crete, Greece, and by calculating the residential time-specific DBP exposure for each participant and evaluating the exposure to DBPs via different exposure routes (ingestion, inhalation and dermal absorption). This approach was used to investigate the association between exposure to residential and all routes uptake time-specific THMs and reproductive outcomes in the mother-child cohort of pregnant women who were residents of the prefecture of Heraklion, Crete (Rhea study).

All women who became pregnant from February 2007 to February 2008 were invited to participate in the study. Exposures were assessed through three questionnaires administered during pregnancy, with the first interview occurring at about 3 months gestation. The questionnaires collected information which included sociodemographic characteristics, smoking habits, occupational, residential, familial and medical histories. Information on water-related habits included: drinking water source (tap/bottle/spring water) at home and other places; average daily consumption of water; average frequency and duration for showering and bathing; swimming pool attendance; type of water used to cook; use of filter both for drinking and cooking water; usual method of dishwashing; use of gloves for dishwashing by hand; and frequency and duration of dishwashing per day. A Food Frequency Questionnaire was also administered which provided information on water-based fluids consumption (coffee, tea, other herbs). In the third trimester questionnaire information was also collected on average daily consumption of water during the third trimester of pregnancy. A final interview was performed after birth and requested information on birth outcomes including low birth weight (LBW), SGA and preterm delivery (PD).

A total of 1359 pregnant women were included in the final analysis out of 2221 approached. There were 18 water sampling points selected (12 in urban areas and six in rural areas) which covered geographically the residences of pregnant women in the Rhea cohort. Women were visited four times at home to collect tap water samples (72 tap water samples in total). The main water source in Crete is groundwater, while chlorination is the main method of disinfecting drinking water. Samples were analysed for major DBPs including trihalomethanes. All women were assigned to a water supply zone based on their address at the time of the first major interview. Women were grouped in to three exposure categories (low, medium, high) based on the residential water supply zone they were assigned to and the brominated THM concentrations in each zone. Residential time-specific THM and brominated THM levels were calculated. Individual levels of total THMs and brominated THMS were modelled using Generalised Additive Models (GAMs) for trimester-specific residential and all routes exposure.

THM concentrations were found to be low and there was a high proportion of brominated compounds, in particular bromoform. The mean concentration for total THMs was 3.71 µg/l (±5.75) for all sampling sites with a range from 0.004 µg/l to 26 µg/l. The mean bromoform concentration over all sites was 2.83 ±4.57 and it followed the same pattern as THMs. Levels of chloroform, bromodichloromethane and chlorodibromomethane were low. Nine haloacetic acids were tested by gas chromatography.
but there were no positive detections. In general, the pregnant women reported a high consumption of bottled water at home (76%), while an additional 33% of those who consumed tap water reported the use of a filter. The majority of the study population reported consumption of bottled water in places other than at home (96%). There were 82% of women who used tap water to cook while only 11% of these reported the use of a filter. Around a third of women (34%) reported water consumption of more than 1.5 l/day and this was even higher for third trimester (38%). More than half of the women (59%) washed dishes by hand. Nearly all women (94%) took showers rather than baths. The mean frequency for showering and bathing was 6 and 3 times per week, respectively, while the mean duration for showering was 6 min and for bathing 15 min. Only 2% attended a swimming pool. Consumption of coffee and tea/herb infusions was low (mean 56 and 19 g/day respectively).

Preterm delivery (PD) and low birth weight (LBW) were associated but not statistically significantly with residential third trimester exposure to brominated THMs (adjusted OR 1.2, 95% CI 0.8 to 2.0 and adjusted OR 1.1, 95% CI 0.6 to 2.2, respectively) when comparing the higher with the lowest tertile of exposure. No statistically significant results were found for residential exposure during the third trimester and pregnancy average for SGA based on weight (adjusted OR 1.1, 95% CI 0.6, 2.1 and 1.1 95% CI 0.6, 2.2, respectively). An excess risk was estimated for SGA based on length (SGAlength) and residential exposure during the first (adjusted OR 1.3, 95% CI 0.5 to 3.2) and third (adjusted OR 1.2, 95% CI 0.5 to 2.7) pregnancy trimesters between the higher and the lowest tertile of exposure. The highest tertile of all routes exposure was associated with a higher risk of SGAlength for first trimester (adjusted OR 1.5, 95% CI 0.6 to 3.7), third trimester (adjusted OR 1.1, 95% CI 0.5 to 2.6) and average pregnancy (adjusted OR 1.3, 95% CI 0.5 to 3.2) exposure.

This study applied comprehensive models for the assessment of exposure and uptake of THMs in pregnant women and found no evidence for significantly increased risks of LBW, SGA and PD at the relatively low level exposure to THMs and particularly brominated THMs found in this Cretan drinking water.

Comment Recent evidence suggests brominated disinfection byproducts may be more toxic than their chlorinated counterparts. The toxicity of brominated THMs is unlikely to be sufficient to cause adverse effects at concentrations seen in drinking water, but they may act as indicators of the levels of other, as yet uncharacterised, brominated DBPs.

Indicator Organisms

Are microbial indicators and pathogens correlated? A statistical analysis of 40 years of research.

Indicator organisms are used to assess the public health risk of waterborne pathogens in recreational water, to highlight periods of challenge to drinking water treatment plants and to determine the effectiveness of treatment and the quality of distributed water. The efficacy of using indicator organism to indicate pathogen risk has been questioned as the absence of indicators in water does not ensure the absence of pathogens and their presence does not always indicate a public health risk. Many studies have tried to identify the most suitable indicators to signal the presence of pathogens based upon statistical correlations and the results have been conflicting. This study aimed to investigate the relationship between microbial indicators and pathogens in a variety of water environments (river, lake, reservoir, pond, estuary, coastal and marine waters and wastewater) by conducting an extensive review of past data.

Data were collected from the literature published in scientific journals on the relationship between indicators and pathogens for the period 1970-2009. Groundwaters, treated drinking waters and waters from drinking distribution systems were not considered because of the relatively low frequency of pathogen detection. When cases of interest were found, the specific types of indicators and pathogens were recorded along with their relationship
(significantly correlated or not), geographic location, the method used for pathogen detection and enumeration, water type, the statistical method used for correlation analysis, the year of publication, the number of samples collected, the percentage of samples positive for pathogens and the total number of positive pathogen samples. There were 540 independent indicator-pathogen pairs found in the literature. The association between indicators and pathogens was examined using a logistic regression model. A geographic information system (GIS) was used to analyse the potential geographic variation of indicator-pathogen relationships.

Of the 540 cases in the pathogen-indicator dataset, 223 cases showed that indicators and pathogens were correlated and 317 cases showed they were uncorrelated. The most frequently used indicators were faecal coliforms (126 cases or 23.3%), total coliforms (95 cases or 17.6%), faecal streptococci (55 cases or 10.2%), enterococci (46 cases, or 8.5%), C. perfringens (43 cases or 8%), F-specific coliphages (including F-RNA coliphages, 40 cases or 7.4%), E. coli (40 cases or 7.4%), and somatic coliphages (30 cases or 5.6%). The most frequently studied pathogens were Cryptosporidium (92 cases or 17%), Salmonella (92 cases or 17%), enteroviruses (63 cases or 11.7%), Giardia (59 cases or 10.9%), Vibrios (53 cases or 9.8%) and adenoviruses (23 cases or 4.3%).

All of the indicators with the exception of coliphages had a greater number of uncorrelated cases than correlated cases. There was no single indicator that was most likely to be correlated with pathogens, however, coliphages, F-specific coliphages, C. perfringens, faecal streptococci and total coliforms were more likely that the other indicators to be correlation with pathogens. E. coli and enterococci, two frequently used indicators, did not show any greater likelihood of correlating with pathogens than other indicators. However the presence of E. coli and enterococci in water generally indicates faecal contamination and therefore a health risk, regardless of whether or not specific pathogens are observed. For all the significantly linearly correlated cases (n=168), the average r value for indicator-pathogen correlations was 0.554 with a standard deviation of ± 0.286.

The water types were reclassified into fresh water, brackish and saline water and wastewater. Of the 540 cases, 230 were from fresh waters, 205 from brackish or saline water and 105 cases from wastewaters. The number of correlated cases was larger than the number of uncorrelated cases in brackish and saline waters but smaller in fresh water and wastewater. In wastewater, the number of uncorrelated cases was four times the number of correlated cases. Logistical analysis showed that the correlation between indicators and pathogens is significantly higher in brackish and saline water than in other types of water (OR = 2, p < 0.001). There was significantly less possibility of correlation in wastewater (OR = 0.29, p < 0.001). The correlation between indicators and pathogens was not significant in fresh water (OR = 1.03, p= 0.857).

In the logistic regression model, the most important factor was found to be the number of samples positive for the given pathogen (p < 0.001). Indicators were more likely to correlate with pathogens if more than 13 samples were positive for pathogens. The logistical regression analysis also showed that the conventional detection methods had a greater likelihood of demonstrating correlation between indicators and pathogens than other methods (OR=2.36, p < 0.001). Molecular methods were less likely to result in correlated cases than other detection methods (OR = 0.75, p = 0.181). Immunoassays had no effect on whether cases were correlated or uncorrelated (OR = 0.75, p = 0.181).

Multivariate analyses of the data showed that the type of statistical method used for data analysis influenced whether or not pathogens and indicators were reported as correlated. Studies that used the Wilcoxon-Mann-Whitney test, resulted in significantly higher reporting of correlations between indicators and pathogens (p = 0.011). For studies where the number of samples positive for pathogens was > 30, linear regression showed significantly greater numbers of correlated than uncorrelated cases (p = 0.0373).

The geographic distribution of cases of pathogen-indicator correlation studies showed that the studied areas were mostly distributed in North America and Europe with very few studies in South America, Asia
and Africa. This unbalanced distribution reflects the current economic and scientific status with most studies conducted in developed countries. The highest number of correlated cases was found in Europe, especially southern and western Europe. There were few correlated cases found in the west coast or south coast of the United States. The highest percentages of correlated cases was found in South America and Oceania (60%, n=5, 55%, n=22, respectively). The results suggest that geographic variation influenced the relationship between indicator organisms and pathogens. The economic situation at a given geographic location may influence the stringency, frequency and monitoring design for indications and pathogens in environmental waters.

This analysis shows that indicator organisms were possibly correlated with pathogens if sufficient data were available, although the presence of indicator organisms cannot guarantee the presence of pathogen contamination for a given water sample. However, long-term monitoring of indicator organisms provides a reliable indication of the potential degree of pathogenic contamination of a specific water body and therefore an assessment of potential and relative risk. For monitoring and assessing water quality for microbiological contaminants, an approach that includes indicators of recent water contamination such as *E. coli* along with indicators of longer term contamination such as *C. perfringens* would be most suitable. As non-enteric indicators were more frequently associated with pathogens, it is recommended that total or faecal coliforms be included in monitoring programs, particularly for water with low levels of faecal contamination. Much of the debate with regards to indicator and pathogen correlation is the result of studies with insufficient data for assessing such correlations. Therefore there is a need for large site-specific monitoring efforts to more accurately describe local public health risks.

Comment This paper highlights the need for careful design of both indicator and pathogen monitoring programs so that a sufficient level of statistical robustness can be achieved, to ensure that the funds devoted to such programs are well spent. However, the “perfect” indicator organism, that correlates with risks for all categories of pathogens in all waters and under all circumstances, may not exist.

**Iron**

**Iron status of women is associated with the iron concentration of potable groundwater in rural Bangladesh.**


Women of reproductive age have a disproportionately higher prevalence of iron deficiency due to the increased demand for iron associated with menstruation and pregnancy, and also as a result of diets low in bioavailable iron. Across Bangladesh, elevated and variable levels of dissolved iron have been report in groundwater used by over 90% of the population for domestic purposes. Previous studies have found that groundwater iron concentration was positively associated with linear growth of children in Bangladesh. This study investigated the potential impact on iron status of consuming iron from a natural groundwater source in combination with other influencing factors in a population of women living in rural Bangladesh.

This study was conducted in 2008 and included 209 non-pregnant women of reproductive age living in northwestern Bangladesh. Participating women completed surveys in 2008 during two rounds in two different seasons, the first round May to July (dry/early monsoon season) and the second round October to November (post-monsoon). During both rounds, home interviews were conducted and groundwater was collected and analysed from participant-identified tubewells for iron content. During round 1, standard anthropometric procedures were used to measure weight, height and mid-upper arm circumference. Capillary blood was collected in round 2 and tested for plasma ferritin, soluble transferring receptor (TfR), and C-reactive protein (CRP) and body iron was calculated. The haemoglobin (HB) concentration was assessed on the spot at the time of blood sample.
The interviews included a 7-d food frequency questionnaire, a 7-d habitual recall of tea and coffee consumption within 30 min of a meal, and a 30-d recall of nutrient supplement use. Participants were also asked about their rice preparation, including cooking pot material, and consumption and drinking water consumption in the previous 24 h. Participants identified their predominant drinking water source and were asked about their perception of iron level in the water based on a 4-point scale (none, a little, a medium amount, and a lot). At both visits, participants completed a 7-day history of high fever, vomiting, painful urination, dysentery and diarrhoea. During round 1, an interim pregnancy history was obtained and socioeconomic status was updated.

Of the 209 women in the analysis, 65% were between 20 and 30 years of age and 82% had more than 1 child. No participants had iron deficiency anaemia. Plasma ferritin and calculated total body iron were not associated with wasting undernutrition. Recent morbidity was not associated with elevated CRP. There were 7% who were at risk of iron overload, only 1 of who showed signs of elevated CRP. Plasma ferritin was higher among those who consumed dark green leafy vegetables frequently but did not differ for other food groups. Study women consumed a typical Bangladeshi diet high in rice with relatively infrequent intakes of heme-rich meat but frequent fish intake. Participants usually consumed 42 mg/d (range: 0-151) of iron through drinking groundwater alone. Iron status was positively associated with iron intake from drinking groundwater in crude and adjusted analyses. Groundwater iron intake was also positively associated with participants’ perception of iron level in groundwater. Correspondingly, plasma ferritin (µg/L) increased with perceived iron level in groundwater for none, a little, a medium amount and a lot, n = 30, 49, 49 and 78, respectively, excluding those who filtered groundwater: 52 (24,82), 57 (42,84), 69 (39,110), 79 (55,106); P < 0.001.

This study showed that daily iron intake from groundwater in a rural area of northwestern Bangladesh was positively related to plasma ferritin and total body iron. There was a strong, positive, dose-response relationship between natural iron content in groundwater, intake of iron from such sources and iron status of women, with body stores expected to be 0.3 mg/kg higher for every 10-mg increment in daily iron intake from water. Plasma ferritin was estimated to be ~6% higher for the same increment. Local water consumption appears to exert a strong and positive effect on iron status in this population, raising iron nutrition and virtually eliminating iron deficiency without posing a risk of excess iron. These finding suggest that iron intake through water should be considered when evaluating dietary risks associated with iron deficiency.

Comment The authors note that this study was prompted by contradictory observations in a prior study of pregnant women which showed high levels of iron sufficiency (measured by plasma ferritin levels) but also high prevalence of anemia (measured by haemoglobin levels). This paper does not present data on anemia in the study population.

Lead

Lead in school drinking water: Canada can and should address this important ongoing exposure source.


Blood lead levels (BLL) of < 10 µg/dL in children have been linked to persistent deficits in intelligence as well as to neuro-psychiatric disorders including antisocial behaviour. Even small reductions in BLL have been shown to have important population-level health gains. Elevated lead levels in water still exist in Canadian schools. Ontario schools were tested in 2007 and 28% of 3,669 ‘first draw’ 1L samples were above the Canadian drinking water guideline of 10 µg/L, as were 9% of the 3,479 1L samples taken after 30 seconds of flushing. School water systems can contain high lead levels due to leaching from plumbing, including tin-lead solder and brass fittings, within the municipal water distribution system or inside the school building. Two factors that are especially important for school water systems are stagnation and outlet design. The 2004 Canadian Community Health Survey suggests that 70% of children consume water on a daily basis. It is reasonable to assume that some of this water
consumption occurs during school attendance. Therefore, some children may be exposed to lead on a daily basis via their school’s drinking water and in areas where residential water levels may also be elevated this may further contribute to children’s exposure.

Ontario is the only Canadian jurisdiction to establish a regulatory framework to assess lead levels in school drinking water. All Ontario schools must test their water annually and if any sample exceeds an action level of 10 µg/L, the school must implement mitigation measures. Recently changes to the testing requirements have occurred and testing is required every three years for schools that show lead results below 10 µg/L for all samples over a previous 2 years, this allows for the allocation of efforts towards “priority” schools. Outside of Ontario, testing for lead in school drinking water only occurs on a case by case basis, typically initiated by concerned parents or as part of testing of residences and institutions in neighbourhoods where lead is shown to be leaching from the distribution system.

Water sampling frameworks have been developed by Ontario Ministry of the Environment, Health Canada (HC) and the US Environmental Protection Agency (EPA) however each has important limitations. Ontario only requires samples to be collected from a single outlet within a facility. Samples taken from a single outlet may not be representative of the building’s water supply. Also testing of refrigerated water coolers is excluded however refrigerated units in schools can be an important source if lead components are present. Both HC and EPA guidelines promote sampling of outlets within a facility. The EPA guidelines, in particular, describe in-depth diagnostic sampling to determine the source of contamination which can be time-consuming and expensive. Schools need further direction on how to identify “priority” outlets, as well as a simplified approach to sampling “priority” schools.

Testing programs need to emphasize elementary schools as lead exposure is of greater concern among younger children. Schools should be tested if they are older, where lead plumbing is more likely, in neighbourhoods known to have lead service pipes, and in areas where previous residential sampling has found elevated levels or where municipal water is “soft” or of low pH. Testing frequency needs to be based on the level of risk, to avoid burdening local health units and schools boards with lower-yield testing.

There are several mitigation options available to reduce lead exposures through drinking water. Flushing can be time consuming and uses large volumes of water and should only be used for temporary mitigation. Replacement of lead plumbing components represents the ideal approach but it is associated with higher initial costs, however it offers a long-term permanent solution. Other approaches to dealing with lead in drinking water include: altering water chemistry at the municipal treatment level, use of only cold water taps as cold water is associated with less leaching than hot water, using alternative drinking water sources such as bottled water and use of point-of-use filters.

Monitoring in Ontario has shown that schools with elevated water lead levels are not uncommon and therefore all provinces and territories should consider implementing polices to reduce children’s lead exposure in schools. The effectiveness of monitoring and remediation programs needs to be evaluated at the school and provincial levels and the cost-benefit evaluations should consider the costs of remediation versus the direct and indirect cost of unmitigated lead exposure.

**Microsporidia**

**Detection of microsporidia in drinking water, wastewater and recreational rivers.**


Microsporidia are parasites that may cause infection in both vertebrate and invertebrate hosts. Diarrhoea
the main health problem caused by human-related microsporidia. Waterborne transmission of microsporidian spores has not been appropriately addressed in epidemiological studies, due to the small size of spores (1-4 µm). Their presence has rarely been documented in association with waterborne outbreaks and also with recreational and river water. However, it has been recently demonstrated that microsporidian spores of species known to infect humans are present in common waterfowl which have unlimited access to surface waters. Microsporidia have been included in the Contaminant Candidate List of the U.S. Environmental Protection Agency (EPA) because spore identification, removal and inactivation in drinking water is technologically challenging and human microsporidial infections are difficult to treat. This present study examines the presence of microsporidia in different types of water in Spain.

The survey included 38 water samples from 8 drinking water treatment plants (DWTPs), 8 wastewater treatment plants (WWTPs) and 6 water samples from recreational river areas (RRAs) from Galicia (NW Spain). The water treatment carried out in all the DWTPs included coagulation, flocculation and clarification through sedimentation, filtration and disinfection by chlorination. There was no UV treatment nor ozonation carried out in any of the DWTPs. The main processes at the WWTPs included a primary treatment (screening, storage and preconditioning) a secondary treatment (coagulation and flocculation, sedimentation and decantation). Tertiary treatment (UV or ozone) was not conducted. All water sampling was conducted in areas with high cattle and sheep activity, predominantly cattle farming. Samples of 100 L of water were collected from DWTPs, while 50 L samples were collected from WWTPs and RRAs. The samples were filtered to recover parasites, using the IDEXX Filta-Max® system. Microsporidian spores were detected by Weber’s chromotrope-based stain. To determine the microsporidian species, DNA was extracted and PCR inhibitors were removed. PCR amplification using specific primers for Enterocytozoon bieneusi, Encephalitozoon intestinalis, Encephalitozoon cuniculi and Encephalitozoon hellem (the four most common microsporidia infecting humans) was conducted.

Microsporidian spores were identified by staining protocols in 8 (21%) of the 38 water samples (2 from DWTPs, 5 from WWTPs and 1 from an RRA). Seven of the eight positive detections at DWTPs and WWTPs were for influent water samples (raw drinking water or raw sewage). In one of the positive WWTPs microsporidian spores were detected in the final effluent. DNA amplification of positive samples allowed for confirmation of the presence of the microsporidian species E. intestinalis in the water sample from an RRA. No positive samples were found for E. bieneusi, E. cuniculi or E. hellem.

This is most likely the first report of human-pathogenic microsporidia in water samples from Spain. A low contamination by microsporidia in DWTPs was found compared to WWTPs. The contamination detected in the DWTPs was only found in the influent water and not the final effluent suggesting that the treatment used effected its removal. In one of the positive samples from WWTPs, microsporidian spores were detected only in the effluent. Other studies have found human microsporidia in tertiary effluent or in sewage sludge end products or wetland outfalls which could be because these parasites are potentially resistant to disinfection or they could be propagated by dogs, livestock and visiting wildlife. The presence of E. intestinalis in an RRA could be due to wildlife as wild animals, including waterfowl, have unlimited access to surface waters of the area studied. Also both livestock manure and grazing cattle may contribute to contamination of the rivers.

Studies to detect the possible source of the contamination and the viability of these parasites after treatments are necessary, as the water obtained in WWTPs could be discharged into a river or be used for urban, agricultural, industrial, recreational or environmental practices and may therefore constitute a risk to human health. There is a need for the development and standardisation of good laboratory methods for easier and more acute detection of microsporidia in water samples. This would assist in the development of a monitoring program to conduct source-tracking, risk assessment and linked
epidemiological studies to understand these pathogens better.

Perfluorocarbons

Concentrations of PFOS, PFOA and other perfluorinated alkyl acids in Australian drinking water

Perfluorinated alkyl acids (PFAAs) and their anions such as perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) are persistent anthropogenic chemicals which are ubiquitous in the environment. Concerns have been raised regarding their bioaccumulation and possible health effects and therefore understanding routes of human exposure is necessary. Australia does not have a record of local PFAA manufacturing and has a relatively small inventory of PFAAs, however measurements of human serum in Australia suggests a background contamination similar to that found internationally, including countries that are more populous and those with a history of PFAA manufacturing. PFAAs may be resistant to water treatment processes, making drinking water a potential source of human exposure. This study aimed to evaluate the concentrations of PFAAs in drinking water in Australia and use this data to estimate the contribution made by drinking water to previously modelled daily intakes of PFOS and PFOA in the Australian population.

Samples were collected directly from drinking water taps in several batches between August and November 2010 at 34 locations including capital cities and regional centres around Australia. The 62 samples were analysed using a liquid chromatograph coupled to a triple quadrupole mass spectrometer.

PFOS and PFOA were the most commonly detected PFAAs and were quantifiable in 49% and 40% of samples respectively, and were typically found at the highest concentrations of the PFAAs. PFHxS was also detected in 27% of samples and at concentrations generally less than PFOS but higher than PFOA. All samples showed low concentrations of PFAAs, with a greater percentage of non-detects relative to detection. There were three sites in Sydney: Blacktown, Quakers Hill and North Richmond that all had relatively high \( \sum \) PFAAs concentrations, up to 36 ng L\(^{-1} \) in North Richmond and 12 ng L\(^{-1} \) in Quakers Hill. Two samples from regional NSW, Gundagai and Yass also had relatively high concentrations with \( \sum \) PFAAs around 12 ng L\(^{-1} \). Samples collected from Glenuga, SA had an average \( \sum \) PFAAs of 28 ng L\(^{-1} \) due to relatively high concentrations of PFHxS (13 ng L\(^{-1} \)) and PFOA (15 ng L\(^{-1} \)).

The concentrations found in this study were well below the currently available provisional guidelines suggested by the US EPA (500 ng L\(^{-1} \) and 200 ng L\(^{-1} \) for PFOA and PFOS respectively), as well as those set by the German Drinking Water Commission (300 ng L\(^{-1} \) for combined concentrations of PFOS and PFOA) and other international authorities. The concentrations measured in this study were on par with those measured in China, USA and Brazil, corresponding with the lower ranges of concentrations measured in these international studies.

The contribution of drinking water to daily PFOS and PFOA intakes in Australia was estimated. Assuming a daily water consumption rate of 1.4 L d\(^{-1} \) an average body weight of 70 kg and the concentrations of PFOS and PFOA found in this study, an estimated daily intake from drinking water was calculated to ranged from 0 to 11 ng PFOS/day and 0 to 13 ng PFOA/day, with the majority of locations providing estimated intakes between 1 and 3 ng PFOS/day and < 1 ng PFOA/day. The daily water intakes are generally quite small as a percentage of total daily intake (estimated from prior research using modelling based on a serological survey) with an average for both PFOS and PFOA of 2.2%. In the locations where concentrations were higher, these values ranged up to 22% for PFOS and 24% for PFOA.

This study is the first published description of PFAA concentrations in Australian drinking water. The concentrations seen in this study suggest that drinking water is only a minor contributor to the daily intake of these chemicals in the Australian population, although in some locations it may contribute more.
POU Treatment

Assessment of the efficacy of the first water system for emergency hospital use.


In the hospital setting, the control of both waterborne infectious agents and chemicals is crucial to ensure the quality of care that is provided to patients. During emergency situations that result from natural and man-made disasters, safe water must be delivered to maintain patient care. Hospital need to have contingency plans for providing short-term alternative sources of clean water during situations in which reliable municipal water sources are not available. Options for providing clean, safe water include: bottled water, maintenance of a backup well and trucked-in water. There are a number of ‘package’ water treatment devices that have been developed and marketed for locations where potable water sources and piped municipal water is scarce such as in the developing world. One system that is promoted for applications during emergency situations is called First Water. This paper evaluated the First Water Responder B package water treatment device for its ability to reduce the levels of spiked indicators and pathogens in surface water and its appropriateness to be used to provide safe drinking water to hospitals during emergency situations.

Source water was collected on 5 occasions between October and November from Lake Mendota, Madison, Wisconsin and was spiked with representative bacterial and viral indicators (Escherichia coli and MS2 coliphage) and viral and protozoan pathogens (murine [mouse] adenovirus and Cryptosporidium. parvum oocysts). The lake water was selected to be representative of a water source that may be available during a flood or other natural disaster. In each of the 6 treatment tests, 50 L of water was used. There were two challenge levels for analysis: low spike (eg, tens of organisms per 100 mL) and a high spike (eg, hundreds to thousands of organisms per 100 mL). These spike levels were chosen to represent highly protected source water and anthropogenically influenced source waters. A high and low spike was tested in 3 separate tests. All the organisms were spiked together to represent a worst-case scenario. The First Water treatment unit consisted of a 5-µm wound filter, followed by a 0.5-µm nominal pore size carbon block filter and an ultraviolet (UV) unit rated for 10,000 hours of use. Water samples were collected and analysed by enumerating each organism type (spiked and naturally occurring) before and after First Water treatment. Microbial removal efficiencies were compared with Environmental Protection Agency guidelines. To index the experiments so that results could be extrapolated to other water qualities based on literature information, a number of water-quality parameters were tested: pH, specific conductance, turbidity, hardness and total organic carbon (TOC).

Overall, the water quality of the lake water used in this study represented waters within the spectrum found in Wisconsin (pH 8.15 to 8.35, turbidity 0.8 to 4.7 NTU, TOC 5.7 to 6.3 mg/L, hardness 200 to 219 mg/L CaCO₃). E. coli spikes ranged from 2.9 to 1059 colony-forming units (CFU)/100 mL. The inactivation and removal efficiency for E. coli was found to range from >88% to >99.9%. The inactivation and removal efficiency tests for E. coli showed that Tests 1 through 4 may meet the EPA target of 6 log₁₀ reduction goal for bacteria. E. coli were detected in the treated sample in Tests 5 and 6 with 99.7% (2.5 log) and 99.8% (2.8 log) removal, respectively. This shows that the treatment efficiency may decline over time and additional treatment may be needed based on Tests 5 and 6 to achieve the 6log₁₀ reduction goal for bacteria.

MS2 coliphage spikes ranged from 3 plaque-forming units (PFU) to 837 PFU/100 mL. The Responder B unit removed coliphage MS2 from spiked lake water with 78% to 98.6% efficiency, with greater removal efficiencies shown at higher spike concentrations. Active coliphage MS2 was recovered/detected in all the treated samples except in Test 3, in which MS2 was inactivated/removed to below assay detection limits (1 PFU/100 mL). These inactivation/removal efficiencies are below the EPA target of 99.99% for viruses. Based on the results, 5 of the 6 waters treated would therefore not be considered suitable for potable use.
Murine adenovirus spikes ranged from 203 to 8410 most probable number (MPN) of infectious units/100 mL. The inactivation and removal efficiency for murine adenovirus ranged from 83.7% to 94%. These inactivation/removal efficiencies are below the EPA target of 99.99% for virus. Murine adenovirus was detected at concentrations above the assay detection limit in each of the 6 trials except test 1. Based on the results, 5 of the 6 water treated would therefore not be considered suitable for potable use with respect to adenovirus. Additional treatment such as chemical disinfection used in conjunction with First Water treatment should be used during emergency situations.

The Responder B unit removed spiked Cryptosporidium oocysts to below assay detection limits (1 oocysts per litre in Tests 1, 2 and 3 and 4 oocysts per litre in Tests 4, 5 and 6) in 4 of the 6 trials. When oocysts were enumerated in the treated water (Tests 4 and 5), 99.96% removal was achieved. These inactivation/removal efficiencies met the EPA target of 99.9% or 3 log_{10} reductions for Cryptosporidium oocysts. Complete removal was achieved at the lower initial Cryptosporidium densities (52-64 oocysts per litre); however, oocysts were not completely removed using the higher spiking level (788-853 oocysts per litre). As 1 oocyst may be a significant infectious dose for those with compromised immune systems, additional treatment may be necessary to ensure safe water during an emergency situation.

The range of microorganisms removals achieved by the First Water systems (≥78%-99.96% of all of the organisms in all of the test runs) is similar or better than the package water treatment systems tested or promoted for use in developing countries. The infectious dose of the microorganisms evaluated can be low in healthy individuals, and may be lower in those who are immunocompromised, or have a lower health status. It is recommended that chemical disinfection using chlorine or another inactivation process be applied in combination with a treatment similar to First Water in a multiple-barrier approach to provide water of the highest achievable standard for use in hospital emergency situations.

The outcomes of interest were: health outcomes attributable to consumption of contaminated water, knowledge of risk of contamination, source switching, POU water treatment, source water treatment and water quality improvements.

More than 14,000 unique documents were located and six studies met the inclusion criteria for systematic review. Four of the included studies concerning arsenic contamination and two concerned indicators for faecal contamination (E. coli or H_{2}S-producing bacteria). All the participants in the study groups were shown to be at high risk of consuming contaminated water. Four studies were based in Bangladesh (all concerning arsenic contamination),

Public Communication

Dissemination of drinking water contamination data to consumers: A systematic review of impact on consumer behaviors.

Drinking water contamination by chemicals or pathogens is a serious public health threat in developing countries. There are two main routes to improving the quality of consumed water, either improving water quality at the source by better community management or improving water quality in the home through ‘point-of-use’ (POU) treatment. Many safe water interventions may have failed because of the high cost of repeated multiple acts required to maintain high water quality, combined with a low perceived threat. Also in the developing world, water consumers are unlikely to know which sources are contaminated and when POU treatment is necessary. One approach which has emerged is that testing water for contaminants (both chemical and microbiological) and disseminating the results to consumers might promote behaviour change by increasing awareness of the threat and informing communities about the difference in water quality between different sources. A systematic review of the literature was undertaken examining the efficacy of using water quality information dissemination about chemical and microbial contamination to change either household or community water management behaviour. The outcomes of interest were: health outcomes attributable to consumption of contaminated water, knowledge of risk of contamination, source switching, POU water treatment, source water treatment and water quality improvements.
one study was in India and one in Kenya (both microbiological contamination). All of the studies used external groups to test the water and disseminate results and all required behaviour change at the individual rather than community level. The risk of bias in these selected studies was judged as moderate to high in most cases, considering study design, sampling and missing information. Meta-analysis was only conducted on one occasion where sufficient data were available on common outcomes using compatible study designs.

Source switching was measured using self reported proportion of households changing their main water sources. The strongest evidence was for source switching in response to arsenic contamination information with four studies reporting higher rates of switching (26-52%) in households previously drinking from contaminated wells (3 were statistically significant). Although five studies reported rates of switching, a common estimated of effect (Risk Difference (RD)) could only be calculated for two studies, both of which considered arsenic contamination of drinking water in Bangladesh, both with low/moderate risk of bias. The data comparing switching rates between those with safe and unsafe wells at 6-12 month follow-up was pooled and showed a significant difference in rates of switching [RD=0.43, CI 0.40-0.46] which suggests that 43% more of those who were informed that their well was unsafe switched sources compared to those who were told their water source was safe. The strength of evidence provided by the findings is low as the comparison is made between non-equivalent groups; those with unsafe wells may not be similar to those who have safe wells.

The Health Effects of Arsenic Longitudinal Study (HEALS) study was the only study reporting health outcomes from information sharing. A significant reduction of creatinine adjusted urinary arsenic was found among those using unsafe wells at baseline (109 vs 6.2 µ/L, effect size 0.86, 95% CI 0.18, 1.5) in a cohort whose wells had been labelled to identify safe/unsafe levels of arsenic. This represented a Standardised Mean Difference of -0.42 (CI -0.45, -0.35) between groups, favouring those who had been informed their wells were unsafe.

Only one study reported water quality as an outcome, comparing levels of *E. coli* in household water, pre and post intervention only. A significant reduction in *E. coli* in household water after dissemination of source water quality results was reported (mean reduction of 0.6 log cfu/100ml SE = 0.17, n= 1357, p < 0.01), but not following information about household water quality (mean difference 0.11 log cfu/100 ml, SE = 0.18, p>0.1). The two studies of microbiological contamination reported POU treatment as a primary outcome and both reported non-significant increases in point-of-use water treatment. Some studies collected knowledge of the contamination level of their water source as an interim outcome. Where this was reported, increases in knowledge of between 25-78% following intervention were observed however all studies were judged to have a high risk of bias.

This systematic review provides the most comprehensive collation of studies of this type published to date and shows the widespread interested in the use of dissemination of water contamination information to promote behaviour change. This review showed that in large cohort studies of arsenic mitigation programs in Bangladesh, consumers were more likely to change wells if they were informed about which were contaminated with arsenic, however the evidence base is currently unclear as there is no robust comparison data from groups not receiving information. The ability to draw strong conclusions from the data found here is limited by the many gaps in the evidence to date as few studies have used robust control or comparison groups. There is a need for rigorous studies on this topic using common outcome measures.

**Rainwater**

**Quality assessment of rooftop runoff and harvested rainwater from a building catchment.**


This study was undertaken to analyse microbiological and chemical parameters of rainwater, rooftop runoff and stored rainwater according to elapsed time. This study also aimed to provide principal influencing
factors for acceptable quantity and quality through statistical analysis and to recommend guidelines for feasible design.

An auditorium was selected for sample collection in Gangneung on the east coast of South Korea. The roof was galvanized and steeply tilted to drain runoff. The rooftop rainfall runoff flowed into a portable 200 L polyvinyl chloride storage tank via aluminum gutters and a downpipe. Samples were collected from three parts of the auditorium from 40 events in 2009. Rainwater was sampled on several sterilised glass plates for analysis of the initial chemical and microbiological characteristics before runoff. Runoff was sampled from the aluminum gutter connecting the catchment to the downpipe. Stored rainwater was also sampled from the polyvinyl chloride storage tank. The major metal ions that were analysed were Al, Zn, Fe, Cu, Cr and Pb. Common anions were also investigated. Total coliform counts (TC), E. coli counts (EC) and heterotrophic plate count (HPC) were recorded.

It was found that 5 min after the initial precipitation, turbidity was the highest and ranged from 240 to 570 NTU in all events. Turbidity had a strong relationship with the number of dry days before the rainfall event. There was also a strong relationship between the turbidity and rainfall intensity, with intense rainfall rapidly washing deposited dust from the catchment. In the first flush of rainfall runoff at 5 min, there were significant levels of TC, EC and HPC recorded in all events from both the catchment gutter and the storage tank. This is because TC, EC and HPC represent the contamination of the catchment area by human-animal activities, dry deposition and residue from roof materials. The quality of the rainfall runoff was good after 10 min however. The levels of TC, EC and HPC were higher in first flush rainfall runoff than in rainwater and rainfall runoff in the storage tank. This is due to the first flush carrying microbial material from the roof catchment. The concentrations of the elements Al, Cu, Mn, Zn, Pb, Cr, As and Cd were found to be less than those of the Korea drinking water standard, although Al and Pb exceeded the drinking water standard in the first flush runoff at 5 min in all events.

The relationship between climatic, microbiological and chemical parameters was determined by principal component analysis and correlation analysis. The correlation analysis was conducted for two sample types: the first flush at 5 min (a) and collected rainwater in the storage tank (b). The number of antecedent dry days (ADD) was strongly related to turbidity ($r = -0.90$) and the concentration of metal ions ($r = -0.64$ for Al and $r = -1.0$ for Cu) in first flush runoff at 5 min. However the microbiological parameters were not related to ADD in the first flush runoff at 5 min ($r = -0.22$ for TC, $r = 0.14$ for EC and $r = -0.18$ for HPC). Also ADD was not related to the collected rainwater quality. The microbiological parameters were found to depend on the manual cleaning of the catchment and storage tank. Principal component analysis was conducted using SPSS software to select a subset of variables from the larger set of variables which had the highest correlations with the principal component factors. This produced 10 parameters (ADD, rainfall, turbidity, Al, Cu, Mn, Zn, Cr, As and Cd) which the quality of first flush runoff water at 5 min mainly depends on. Collected rainwater in the storage tank was found to mainly depend on 10 parameters (ADD, rainfall, TC, EC, Al, Cu, Mn, Zn, Pb and Cd).

The quality of stored rainwater depends on the conditions of the catchment and storage tank and the length of the antecedent dry period. Rainwater collected after first flush should only be used as green water unless it is specially treated. If the first flush water from the catchment is diverted and solids are separated then extended water utilisation could be achieved.

**Risk Assessment**

**Estimating the risk from sewage treatment plant effluent in the Sydney catchment area.**


When treated effluent from Sewage Treatment Plants (STPs) is discharged into receiving waters that are used for drinking, the pathogens released may pose a health risk to consumers. The Lake Burragorang
catchment (9,050 km$^2$) in Sydney, receives treated effluent from eight STPs along with run-off from urban, agricultural and forested areas. In 1998 after heavy rainfall, elevated levels of Cryptosporidium oocysts and Giardia cysts were found in the raw and filter water supply. This paper used Quantitative Microbial Risk Assessment (QRMA) to quantify health risks associated with Cryptosporidium and Giardia discharged from three STPs located within the Lake Burragorang catchment.

QRMA was used to estimate pathogen numbers, probabilities of infection and Disability Adjusted Life Years (DALYs) for drinking water consumers of Lake Burragorang water. Data were drawn from three STPs which included two extended aeration systems (XSTP1 and XSTP2) and one trickling filter system (TSTP). The QRMA examined both baseline and hazardous event conditions (e.g. STP failure and heavy rainfall). Lake Burragorang raw water is treated at Prospect Water Filtration Plant (WFP) using coagulation and deep bed mono-media filtration. The major exposure pathway was ingestion of treated water from Prospect WFP. Consumption was estimated at 0.75 L.person$^{-1}$.d$^{-1}$. The QRMA required the quantification of pathogen source loads, barrier effectiveness, intake and dose response in the form of probability density functions (PDFs) or equivalent. Sewage content and STP barrier performances were estimated. Other inputs were based on literature and consideration of exposure pathways attributes, particularly basic hydraulic loads and geography.

The annual infection baseline risk probability 95$^{th}$ percentiles for the two pathogens and three STPs under dry weather conditions were in the range of $10^{-7}$ to $10^{-9}$ person$^{-1}$.y$^{-1}$ and were well below the risk benchmark of $10^{-4}$ person$^{-1}$.y$^{-1}$ proposed for Giardia. The highest disease burden estimate was ca 0.01 μDALY at the 95$^{th}$ percentile. It was found that XSTP1 posed a slightly higher risk than XSTP2 and this was attributed to the treated flows from XSTP2 being intercepted en route by a secondary storage reservoir, large enough to act as a barrier. The estimated viable pathogen numbers in the treated potable water were >9 orders of magnitude less than the current detection limits applicable to most environmental samples (ca 1 cyst or oocyst per 10 L). The catchment and constructed barriers were found to reduce exposure concentrations to viable protozoans by 10 to 14 orders of magnitude.

Three hazardous event scenarios were explored using XSTP1: 1) complete failure of the Prospect WFP during dry weather flows; 2) failure of Lake Burragorang as a barrier, caused by the short circuiting of flood waters comparable to the 1998 incident; and 3) concurrent STP bypass and high short circuiting flows. The first event scenario showed only a small daily risk as such a malfunction would not be expected to affect all WFP treatment units and would be rapidly identified and real world impacts would probably be small to tolerable, despite their significance. In the second event scenario, the inactivation and travel time benefits associated with Lake Burragorang were removed as a result of high short circuiting flood water, however a higher dilution effect was assumed. The net effect of this scenario was that the risks were five orders of magnitude below $3 \times 10^{-4}$.person$^{-1}$.d$^{-1}$ (equivalent to the $10^{-4}$.person$^{-1}$.y$^{-1}$ benchmark). The third event scenario produced daily risks that were elevated, however the $10^{-4}$ benchmark should not have been exceeded provided that the event only occurred for a few days.

The results of this paper should be seen as provisional and reflective of some simple assumptions (e.g. homogenous dilution in high flows). Therefore it provisionally appears that the STPs that are currently discharging into the waterways of the catchment do not pose an unacceptable or unmanageable risk to Sydney’s drinking water consumers. The results presented here have the benefit of being clear in their origin and being open to both auditing and revision as necessary.

**Water Consumption**

Drinking sufficient water can improve weight status, reduce dental caries and improve cognition among children and adolescents. As children spend most of their day at school or in child care, it is an important public health measure that safe, potable drinking water is available in these places. This study examined access to drinking water and challenges and strategies for improvement of drinking water availability and consumption. Also recommendations to enhance drinking water access and intake in schools and child care settings were considered.

The main source of tap water in most U.S. schools and larger child care facilities are drinking fountains. Also tap water may be provided in pitchers or other dispensers. Some schools also provide bottled water at no cost or for purchase in vending machines or school stores. Drinking water access in U.S. schools is ultimately influenced by federal, state and local regulations and policies. The Healthy, Hunger-Free Kids Act of 2010 authorises funding and sets policy for the Food and Nutrition Service of the US Department of Agriculture’s (USDA) child nutrition programs, including the National School Lunch Program (NSLP) and the School Breakfast Program and Child and Adult Care Food Program (CACFP). This act requires that schools participating in the federally funded meal programs make water available during meal times at no cost to students. Also it mandates that child care facilities provide free drinking water during the day. State agencies administer the federal meal programs, and their nutrition standards may exceed federal requirements. State child care licensing agencies may also mandate that clean, sanitary drinking water is available for children to serve themselves. In addition, states may have rules such as building codes that manage drinking water infrastructure in schools. In additional to federal and state regulations, school board policies and child care operational guidelines can affect drinking water access policies at the local level.

There are a number of barriers that may limit schools and child care facilities from improving drinking water access and consumption. These include deteriorating drinking water infrastructure. As 73% of U.S. schools were built before 1969, it is not surprising that many schools require significant infrastructure repairs to old plumbing and fixture. There are concerns with contaminants such as lead entering into school drinking water from solder, plumbing or fixtures. In 2006, only 56% of U.S. school districts required drinking water inspections for lead and only 22% of districts had model drinking water quality policies. In cases where drinking water quality is poor, schools may not have the resources to replace old plumbing or fixtures. For schools and child care faculties that provide bottled water, drinking water quality may also be of concern as bottled water is not regulated by the EPA like tap water but instead monitored by the U.S. Food and Drug Administration (FDA). FDA regulations apply only to packaged water that is transported across state boundaries and also exempts carbonated or seltzer water. Bottled water is tested less frequently than tap water and often by a laboratory that is not state certified.

Another barrier is limited drinking water availability. In some schools drinking water outlets may be inadequate in number, inconveniently located and poorly maintained which discourages students from using school drinking fountains. In some areas such as school cafeterias or portable classrooms, drinking water access may not be a major consideration. Some schools may have policies discouraging water consumptions such as a ban on reusable water bottle use because of concerns that students will bring alcoholic beverages to school, or policies that forbid water consumption in the class room to prevent disruptions.

The increasing availability of sodas and other sugar-sweetened beverages is a barrier to improving drinking water consumption. In 2008, up to 77% of U.S. public secondary schools had soda or sports drinks available for purchase. Bottled water has also become increasingly available in U.S. schools however the cost of bottled water may discourage children from drinking adequate amounts. Many U.S. schools rely on revenue from beverage sales and advertising to help fund school activities. Such schools may fear revenue loss if they remove sugar-sweetened beverages from vending machines and ban junk food marketing.
There are a number of ways to improve drinking water provision and consumption in schools and child care facilities. The EPA has developed guidelines for schools and child care facilities on how to test their drinking water, correct water quality problems and communicate drinking water assessments to staff, students and parents. To improve the quality and appeal of tap water, schools and child care facilities can restore deteriorating drinking water infrastructure or at a minimum set and maintain hygiene standards for drinking water outlets. Some schools lack the resources to install new drinking water infrastructure however they may be able to secure funding to cover such repairs from government, the private sector or other nongovernment entities. As an alternative, free bottled water may be provided or filters placed on older drinking water fountains. Bottled water should be a temporary solution until schools can provide an alternative free tap water source. Policies can be implemented that promote free drinking water access and intake at the federal and state levels. Key policy interventions may take place at the local level as well though school district wellness policies and child care facilities’ operational guidelines.

In addition to implementing policies that support drinking water access, schools and child care facilities can educate staff, students and parents about the importance of drinking more water. Along with improving drinking water availability, schools can decrease competitive beverage access by restricting the sale and advertising of sugar-sweetened beverages. Although some schools may perceive that they are dependent on sales and advertising revenue for these products, studies suggest that revenue loss is insignificant when schools restrict competitive food and beverage sales and advertising. Some schools have found that their profits are maintained or increased when they sell healthier foods and beverages and involve students in the process. Future research is required to examine ways in which to encourage drinking water access, in particularly in non-school settings such as homes, child care facilities and parks and recreational areas.

Water Footprint

The real water consumption behind drinking water: The case of Italy.

This study aimed to evaluate and compare two alternative types of drinking water: tap water and water sold in polyethylene terephthalate (PET) bottles, using the Water Footprint method. The Water Footprint (WF) measures the total demand for water, both direct and indirect, consumed or polluted, in the supply chain of an activity or product. In 2009, Italians were the second highest consumers of bottled water in the world, with 192L consumption per capita. An analysis of the Italian bottled-water market may provide an insight into future growth trends of the global bottled-water market and its environmental and social implications.

Samples of natural mineral water, marketed in PET bottles by six Italian companies, were analysed. The companies were selected to provide a representative sample of the Italian market and they differed in regard to location, volume of water bottled per year, market distribution in Italy and bottling strategies and practices. The Siena municipality (Italy) tap water (hereafter TWS) was also analysed. This system is representative of contemporary tap water supply chains in Italy. In 2007, the population of Siena (60,000 persons) used about 7 GL of water.

The Water Footprint calculation of drinking water (WFdrinking water) used a Life Cycle approach with both direct and indirect water uses monitored throughout the supply chain, from the spring to the consumer’s table, including the upstream production of all materials, energy carriers and transport involved for both bottled and tap water.

Despite the very different life cycles, PET-bottled (BW) and TWS had quite similar WFs (i.e. 3.43 L and 3.63 L, respectively), which means that when a volume of 1.50 L is delivered to the final user in Italy a total average use of about 3.50 L of water occurs. In both cases, the extra cost, in terms of WFdrinking water for non-drinking water uses, was mainly due to water
consumed during processing. The influence of water processing for bottled water was lower than for tap water (36% and 59%, respectively). The higher value for tap water was because of high rates of leakage from pipelines, which causes annual water losses of more than 50%. This leakage, plus assumed wastage by consumers, counterbalanced the lesser use of water to produce materials, energy and transport for tap water in comparison to bottled water.

The WF of bottled water was greatly influenced by the production of plastic materials. Water consumption in the PET-bottle life cycle is already quite optimised and could only be further reduced through improvement in business and packaging strategies. However, a water use reduction policy could involve a choice of materials having less water-intensive production. Two materials that are currently used for water bottles in Italy are PET (70%) and glass (30%). Glass is generally less water-intensive than PET. PET generally requires about 2.50 L per average bottle (weighing 37 g) and glass about 0.76 L per average bottle (weighing 390 g). Another possible bottle material is Polylactic acid (PLA). This is derived from renewable biomass sources and requires about 1.40 L of water per average bottle (weighing 27 g) and would allow a water saving of about 45% if used instead of PET.

In calculating the WF of BW and TWS, a further component, the grey water contribution of cooling water was added. When the contribution of cooling water is included in the calculation, the WF of BW doubled (6.92 L). The extra volume of water (3.49 L) was mainly due to plastics (73%) and corrugated cardboard (27%), for which the production is particularly water-cooling intensive. The WF for TWS did not change significantly (3.63 L).

Further aspects need to be investigated to provide a more comprehensive overview of the water systems. Recycling strategies of the different material (PET, PLA, glass) could be considered to improve the findings. Also, including wastewater recovery operations might decrease total WF as the recovered water could be re-used (and thus not lost) in other life cycle systems or directly in the life cycle of drinking water production (e.g. as cooling water).