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Endemic Waterborne Disease Study

A recently published study from the US has found that point-of-use water treatment reduced the incidence of gastrointestinal illness in people aged 55 years and older by 12% although the tap water supply met current US water quality standards (1). The results of the study once again raise the issue of endemic waterborne disease due to pathogens in treated drinking water, and the adequacy of current methods of defining drinking water safety.

Endemic disease refers to the ongoing "background" occurrence of illness in a population over time in contrast to the short peaks of disease associated with point source outbreaks. A range of surveys and research studies have estimated that the background rate of gastroenteritis in developed nations is around 0.5 to 1.0 episodes of illness per person per year on average (2). Such illnesses are assumed to be predominantly of infectious origin and to arise from pathogens transmitted by the faecal-oral route. Possible modes of transmission include drinking water, food, recreational water, person-to-person contact, animal-to-person contact and faecal contamination of environmental surfaces. The number of cases of illness associated with endemic gastroenteritis far outweighs cases attributed to recognised outbreaks.

The degree to which treated drinking water meeting prevailing quality standards contributes to endemic gastrointestinal illness has been a matter of debate and research for more than two decades. This debate was stimulated by increasing recognition that viruses and protozoa from source waters could still be present and potentially infectious in treated water

which met conventional standards for absence of coliform bacteria. In addition to the hypothesis of infection due to faecal pathogens originating from source waters and not adequately removed by treatment, alternative or additional hypotheses have also been advanced relating to ingress of faecal pathogens in the distribution system, growth of opportunistic pathogens in the distribution system, and accumulation of pathogens in biofilms followed by sloughing events releasing them into the water.

A number of epidemiological studies of various designs have addressed this issue (3). The methodologically strongest studies have been randomised trials which used point-of-use devices to provide additional treatment to tap water for one group of consumers who were then compared to another group drinking conventional tap water. Prior to the most recent study described in this article, two randomised studies had been conducted in Canada, one in Australia and one in the US. The Canadian studies suggested a significant contribution to community gastroenteritis from waterborne pathogens, however these studies were unblinded, with participants being aware of whether or not they received a water quality intervention. This may have influenced the perception or reporting of illness differentially between the groups.

The Australian study and the US study used a blinded design where households were supplied with real or sham water treatment devices, and both participants and researchers were unaware of the water treatment status of each household until after the results had been analysed. Both studies found no evidence of waterborne gastrointestinal disease, with a non-significant 1% to 2% difference in disease rates between real and sham treatment groups. The Australian study was conducted in Melbourne in a system with a fully protected surface catchment, high quality source water and minimal treatment (disinfection only). The US study was conducted in Davenport, Iowa in a system with a poor quality surface water source and well operated conventional filtration and disinfection. All of these previous intervention trials focused on family groups containing children, as gastroenteritis is most common among young children and thus inclusion of this age group provides greater statistical power to detect differences in disease rates. In contrast, the most recent US study applied the randomised double-blinded design to examine the effect of point-of-use water treatment on gastrointestinal illness rates in adults aged 55 years and over.

The study participants comprised 988 individuals who were resident in 714 households in Sonoma County, California. Some of the participants were recruited from an existing cohort study of physical performance and age-related changes, while others were recruited by mail from a random sample of county residents meeting the study age requirements. Households were excluded if they included any employee of the Sonoma County Water Agency or any other water district, if any member was unwilling to sign a consent form for installation of the water treatment device, if they included any immuno-compromised individuals, or if they consumed less than 75% of their in-home drinking water from the household tap. The water treatment device was a counter-top model with a design similar to those used in the previous Australian and US randomised trials. The active devices comprised a 1 micron absolute filter (rated to remove protozoal cysts) and a UV unit (rated to inactivate bacteria and viruses). The sham devices were identical in outward appearance but did not affect the water quality.

The water supply for Sonoma County is derived from the Russian River which is subject to urban discharges and agricultural run-off. To obtain high quality water, a bank filtration system is used to draw water indirectly from the river. Water is pumped from a series of six collector wells drilled into the aquifer adjacent to the river. The water is naturally filtered as it is drawn from the river through layers of sand and gravel to the base of the wells which extend 50-60 feet below the level of the streambed. The water is then chlorinated before distribution to several towns through a system of underground aqueducts and storage tanks. The paper does not discuss water quality parameters, however media articles reporting the outcome of the study note that no positive results were found in the water supply during the 2008/09 year from 477 tests for *E. coli* and total coliforms. In the previous US study in

Davenport a major water quality monitoring study was undertaken in parallel with the epidemiological study, however it appears that no additional water quality monitoring was conducted in association with the Sonoma trial.

The study was conducted from 2001 to 2005, with individual households participating for two 26-week periods with a 2-week washout period in between. A crossover design was used with households receiving the opposite type of water treatment unit in the second 26-week period from the type assigned in the first period (i.e. real followed by sham, or sham followed by real). This design provides increased statistical power as it allows individuals to be compared with themselves as well as comparing the real treatment group with the sham treatment group. Participants recorded gastrointestinal symptoms in health diaries. The primary health outcome measured was highly credible gastrointestinal illness (HCGI), defined as any of the following four conditions, preceded by at least 6 HCGI-free days: (i) vomiting, (ii) watery diarrhoea, (iii) soft diarrhoea and abdominal cramps, and (iv) nausea and abdominal cramps. Daily longitudinal prevalence of HCGI, defined as total days of illness divided by total days in the study, was used as the secondary outcome in statistical analysis.

A quality assurance review in the middle of the study (conducted by an unblinded researcher not involved with participants or data analysis) revealed that a batch of 180 water treatment units had been wrongly labelled during manufacture. This error resulted in 157 households having the same type of treatment device throughout the study, rather than crossing over to the opposite type as intended for the second observation period. It was decided to exclude data from these households from analysis and the enrolment period was therefore extended to compensate for this data loss. The final sample consisted of 557 households (770 individuals) and 83% of these completed both observation periods. The dropout rate was not significantly different between the two device types. About 10% of participants were aged 85 years or older at enrolment while the remainder were fairly evenly distributed between 55-64, 65-74 and 75-84 age groups. The majority of people reported themselves to be in excellent (32%) or good health (54%) at enrolment.

A generalised estimating equation (GEE) was used to estimate the effect of real versus sham devices on health outcomes over the whole study population and generalised linear mixed models (GLMMs) were used to analyse the effects in individuals. The incidence rate ratios for HCGI for active versus sham treatment were 0.88 (95% CI 0.77-1.00) and 0.85 (95%CI 0.76-0.94) for GEE and GLMM models respectively. In other words, there was a 12 to 15% lower rate of reported HCGI (after adjustment for relevant covariates) when people were using real water treatment devices compared to sham devices. The results of analysis for the secondary outcome, daily longitudinal prevalence of HCGI, were similar.

The gastrointestinal illnesses experienced by study participants appeared generally to be mild with an average of less than 2 days of work missed per year due to such illness, and less than one medical consultation per 3 years on average for gastrointestinal illness. A total of 13 deaths occurred during the study (7 while using active water treatment devices and 6 while using sham devices) but none were attributed to gastrointestinal illness. One instance of hospitalisation due to infectious gastroenteritis was recorded (type of device not given) out of 69 hospitalisations in total (35 while using active device, 34 while using sham device).

There were no significant differences in the amounts of water reportedly consumed from real or sham devices, and participants were effectively blinded to the types of device assigned to them during the study. The number of reported episodes of HCGI declined in the second cycle compared to the first cycle. This has been reported in previous intervention studies and may represent a decline in enthusiasm by participants. However this effect was similar regardless of the order of device assignment (i.e. real-sham or sham-real). When sub-groups were analysed separately it was found that the effect of real water treatment devices was different between the genders, with a protective effect apparent only in men; relative risk of 0.76 (95%CI 0.60-0.95) for real versus sham treatment devices in men and relative risk of 0.99

(95%CI 0.85-1.17) for real versus sham treatment devices in women using adjusted GEE analysis. There were no clear trends in risk levels relative to age group, total daily water consumption, length of time in the study or employment status.

Overall this was a well-conducted study with effective randomisation, a low dropout rate and successful blinding. The apparent protective effect of real water treatment devices on the study population as a whole was modest (about 12%) and in some analysis models reached statistical significance at the p=0.05 level. However, the fact that the protective effect was confined to men is certainly puzzling. This observation implies that a proportion of HCGI experienced by men in the study was attributable to pathogens in tap water, but HCGI occurrence in women was not significantly influenced by the same tap water. There is some evidence of gender differences in occurrence of gastrointestinal diseases however the available data seem to suggest that women are more susceptible than men rather than less susceptible. Surveys in several countries have indicated that women report diarrhoeal illness more frequently than men. US studies have also indicated women are more likely than men to be hospitalised or to die from such illnesses. A review of waterborne outbreaks in developed nations also noted that women predominate among identified cases and fatalities, although data were limited and the imbalance may be due to chance (4). There seems to be no obvious reason to expect that older women would be less susceptible than older men to infection by the range of enteric pathogens potentially transmitted by a chlorinated drinking water supply such as that in Sonoma County.

(1) Colford JM Jr, Hilton JF, Wright CC et al. (2009) The Sonoma Water Evaluation Trial: A Randomized Drinking Water Intervention Trial to Reduce Gastrointestinal Illness in Older Adults. American J Public Health **99**(11):1988-1995.
(2) The calculated rate of gastroenteritis depends on the symptom definition. Usually a single episode of diarrhoea or vomiting is not considered to constitute gastroenteritis.
(3) See Health Stream Issue 43 article *US Waterborne Disease Estimate* for a brief summary of a Journal of Water and Health 2006 Supplement which reviewed studies on endemic waterborne disease.
(4) Safe Drinking Water: Lessons from Recent Outbreaks in Affluent Nations By SE Hrudey and EJ Hrudey. ISBN: 1 84339 042 6 IWA Publishing.

Report on Colorado Outbreak

The Colorado Department of Public Health and Environment (CDPHE) has released a report detailing its investigation of the waterborne *Salmonella* outbreak in the town of Alamosa in March 2008 (1). The investigation concluded that the most likely cause of the outbreak was ingress of faecal contamination from small animals or birds through holes and cracks in a ground level water reservoir. Water from the affected reservoir was supplying about 75% of the town's water needs at the time of the outbreak, resulting in the rapid spread of contaminated water through most of the distribution system. The outbreak is believed to have caused as many as 1,300 cases of illness and one death among the population of 9,800 residents. It also resulted in significant economic disruption to the town and surrounding region over a five week period until a safe water supply could be restored.

The water supply for Alamosa is drawn from a deep confined artesian aquifer several hundred feet below the surface. The town has seven wells drawing from the aquifer, although not all are used simultaneously. At the time of the outbreak, three wells were operating. There are also two elevated storage reservoirs (capacity 500,000 and 150,000 gallons respectively), one ground level storage reservoir (capacity 320,000 gallons) and about 50 miles of distribution pipes. Prior to the outbreak, the water was distributed without chlorination as the town had been granted a waiver from disinfection by the State of Colorado in 1974. Bacteriological monitoring records showed few problems with microbial water quality in previous years and only one non-acute violation of the US EPA Total Coliform Rule in November 2002. However the water supply was non-compliant in terms of chemical quality as it contained levels of arsenic in excess of the current US maximum contaminant level of 10 micrograms /litre. A central water treatment plant was being built to reduce arsenic concentrations and this plant was scheduled for completion in late 2008.

The first signs of the outbreak were recognised on 12 March when three cases of salmonellosis were reported by local medical providers to the regional

epidemiologist in the Alamosa County Nursing Service. These cases were reported to the CDPHE on 14 March, and by 17 March evidence from the preliminary epidemiological investigation had suggested the possibility of waterborne spread of the infection (2). Staff of the Safe Drinking Water (SDW) Program within CDPHE were then contacted. They verified that the last routine sampling of the water supply had been carried out on 5 March and no coliform positive samples were found. Widespread sampling of water from the distribution network was ordered on 17 March. By 19 March the results from 10 water samples were available: one was positive for coliform bacteria and two had elevated turbidity levels. Meanwhile the number of laboratory confirmed cases of salmonellosis had risen to 18, with a further 25 suspected cases reported. The epidemiological evidence for a waterborne source had strengthened, and at this point the Chief Medical Officer for Colorado and the SDW team decided to issue an order warning the public not to consume Alamosa tap water, but to use bottled water instead.

The decision to issue a "bottled water" advisory on 19 March rather than "boil water" advisory (as would be more usual in cases of microbial contamination) was based on several factors. Firstly it was anticipated that the entire distribution system would have to be disinfected and flushed, potentially dislodging accumulated biofilms, pipe deposits and sediment which might contain high levels of arsenic and other metals. Secondly, the source of the contamination was unknown, and there existed some possibility that non-microbial contaminants might also be present. Thirdly, boiling would tend to concentrate arsenic and perhaps other chemical contaminants in the water.

On the same day that the bottled water notice was issued, the CDPHE issued notices to the Colorado's Water/Wastewater Agency Response Network (CoWARN) initially alerting the network to the existence of the situation in Alamosa, and then requesting equipment and personnel needed for the emergency response. WARN networks have been formed in most US states as a result of Homeland Security Presidential Directives relating to emergency preparedness and response. The networks provide a means for public and private utilities to rapidly request and receive assistance in the form of equipment, materials, services and skilled personnel during emergency response and recovery. These activities are facilitated by a pre-existing template mutual aid agreement and protocols that cover legal, liability and reimbursement issues which would otherwise require time-consuming negotiations when emergency situations arose. The CDHPE report on the Alamosa incident repeatedly emphasises the key role of CoWARN in enabling an effective response to the waterborne outbreak by making additional human and material resources rapidly available to assist the local water utility.

On 20 March a plan to decontaminate the Alamosa water supply was developed which involved draining, cleaning and disinfecting the three storage tanks, then disinfecting and flushing the entire distribution system. The aim was to provide an initial chlorine level of 25 mg/L with a hold time of 24 hours and a residual chlorine level of at least 10mg/L after this time had elapsed. These targets are in excess of US standards for decontamination of water distribution systems, however the report notes that a conservative approach was deliberately taken as the system was previously unchlorinated, and there was uncertainty over the chlorine demand and how this would affect the stability of chlorine residuals. Five additional water samples were collected from the distribution system for *Salmonella* testing before the disinfection program began. All of these samples proved to be positive for *Salmonella* by PCR, confirming the widespread contamination.

The decontamination program began with the draining of the in-ground reservoir on 21 March. Chlorination equipment was then connected to the well which fed into the reservoir. An internal inspection of the reservoir structure revealed a number of holes in the upper corners and cracks in the roof and sides. The defects in the above-ground section were also visible from the outside of the reservoir. There was no evidence of birds having entered the structure (no nests or droppings observed inside the reservoir). About 12 to 18 inches of sediment was removed from the bottom of the reservoir, and the holes were patched. The reservoir

walls were sprayed with a strong chlorine solution (50mg/L) to counteract the initial chlorine demand, and then it was filled with highly chlorinated water (25 mg/L). This water was left standing in the reservoir for about 39 hours, after which chlorine levels were checked and were found to still be around 25mg/L. The two elevated storage reservoirs were then filled with highly chlorinated water and left standing for 24 hours. Physical inspection of the elevated reservoirs was not performed until several days later, as these procedures could only be undertaken by a specialised company.

After disinfection of the three storage reservoirs, flushing of the distribution system with highly chlorinated water (25mg/L) was commenced. During the flushing program members of the public were notified to avoid contact with tap water when high chlorine levels were present in their area due to the possibility of eye and skin irritation. After each sector had been flushed, tests were carried out for total coliforms and *Salmonella*. Inadequate disinfection was encountered only in one area where lower flushing velocities had been used due to concerns over the physical condition of old pipes and valves. The disinfection and flushing procedure was carried out again in this area, and subsequent test results were negative.

The flushing operation was completed on 2 April, some 13 days after decontamination of the water supply began. The CDPHE notes this was much less time than the three to four weeks initially estimated. On 2 and 3 April the elevated tanks were taken out of service for inspection and cleaning. Both were found to contain sediment and one had holes in the top due to missing bolts that might have allowed faecal material from birds to enter the tank. Minor repair work was needed on both tanks. During the flushing process, monitoring of arsenic, lead, copper and disinfection byproducts in the distribution system showed a slight increase in arsenic levels (from 26 microgram/L to 32 microgram/L) but other parameters remained below regulatory limits. After flushing was completed, chlorination was maintained throughout the system at levels of 1-2mg/L. During the disinfection and flushing program precautions were taken to protect the town's sewage treatment plant from the effects of high chlorine levels that could have disrupted biological sewage treatment steps. Sewage inflows were monitored for chlorine levels and, when necessary, sewage was diverted to sludge ponds or treated by addition of sodium bisulphite to neutralise chlorine.

Based on the results of post-disinfection water quality tests, the CDPHE replaced the "bottled water" advisory with a "boil water" advisory on 3 April. They advised the City of Alamosa that further information would be needed before the boil water advisory was lifted, including a report on data collected, a summary of disinfection and flushing operations, certification that repairs to water storage tanks had been carried out, and confirmation that several high-hazard cross-connection risks discovered during the investigation had been addressed. Just when these final requirements for returning to normality had been fulfilled, an unexpected setback occurred when on 8 April the SDW team learned that some evidence of *Cryptosporidium* and *Giardia* contamination had been found in water samples taken on 20 March. These tests had been performed by the Centres for Disease Control and Prevention (CDC) who had communicated the results to the relevant agencies specified under the National Incident Management System, however the findings had not been passed on to the CDPHE.

The possible presence of protozoal contamination in the water supply system meant that the boil water alert could not be lifted as the decontamination procedures performed may not have been adequate to deal with these more chlorine resistant organisms, particularly *Cryptosporidium*. In order to rapidly assess whether such organisms were indeed present, the SDW team decided to test water samples by Microscopic Particulate Analysis. This required the collection of multiple 7-gallon water samples which were then transported overnight by road to the testing laboratory some 300 miles away. Tests of these samples on 10 and 11 April failed to detect *Cryptosporidium* or *Giardia*. A review of epidemiological data also failed to provide any evidence of increased rates of illness due to these pathogens during the *Salmonella* outbreak. As the

CDC tests had been only weakly positive for protozoal genetic material, it was concluded that there was no definitive evidence of viable protozoa in the water supply, and a decision to lift the boil water notice on 11 April was confirmed. Among the conditions for lifting the notice were undertakings by the City of Alamosa to carry out additional repair work on the elevated water storage reservoirs, and permanent disconnection of the underground storage reservoir from the drinking water system.

The investigation uncovered a number of possible sources for the *Salmonella* contamination, however after considering all the evidence it was concluded that the most likely cause was ingress of faecal contamination into the ground level reservoir through holes and cracks in the structure. It was evident that the reservoir had been in a state of poor repair for some years and the inside had apparently had not been cleaned for at least 11 years. US federal regulations did not require inclusion of water storage tanks or distribution systems in sanitary surveys for groundwater supplies until December 2009, however Colorado state regulations did cover such facilities prior to the outbreak. Despite this requirement, the reservoir had not been included in the facility inventory for the most recent sanitary survey conducted by the SDW Program in 2007. The report states that due to personnel limitations the SDW sanitary inspections tended to focus on treatment issues for surface water supplies, implying that storage and distribution issues and groundwater systems generally may have been overlooked. The investigators also note that the attention of the local water utility was concentrated on the new water treatment plant which was due to come into service a few months after the outbreak. In addition to reducing arsenic levels in the water supply, the new plant would also provide disinfection. When this facility was commissioned, it was planned to remove the ground level reservoir from the water supply and use it for storage of irrigation water. This may have contributed to the failure to address the poor physical condition of the reservoir.

Serotyping and pulsed field gel electrophoretic analysis of *Salmonella* Typhimurium strains from water samples and human outbreak cases showed a single strain was involved. This suggests the contamination probably originated from one animal or a small number of animals. Calculation of the number of *Salmonella* bacteria required to contaminate the entire 1.6 million gallons of water in the storage tanks and distribution system suggested that only a few grams of animal faeces might be needed. A number of animal faecal specimens were collected from the vicinity of water storage facilities and analysed during the investigation but none were positive for *Salmonella*. Water utility staff reported that small animals such as rabbits were sometimes observed near the reservoir, and animal footprints were often seen in the snow around the tank during the winter months. The investigators speculated that the relative warmth of the tank (due to an incoming water temperature of about 75 degrees F from the deep aquifer) and venting of warm air through the holes might have attracted animals during the cold season. A significant snowfall event had occurred about a month prior to the outbreak, and this was followed by two relatively warm periods each lasting a few days where temperature rose above freezing. This may have allowed contaminated snowmelt to enter the reservoir.

Contamination was apparently present at least intermittently from late February or early March (estimated from symptom onset on 6 March in the first laboratory confirmed cases) until 20 March when the last pre-disinfection samples were taken. The daily outflow of water from the reservoir exceeded the storage capacity, so the duration of contamination may indicate either multiple episodes of faecal ingress, or persistence or perhaps growth of *Salmonella* bacteria due to the warm water temperature and stagnant areas within the reservoir where water did not mix thoroughly.

The detailed assessment of the water supply system, operational practices and monitoring records also revealed a number of shortcomings which did not play a role in the outbreak, but nevertheless constituted a risk to water quality and safety. For example, it was found that although the correct number of water samples was being regularly tested under the Total Coliform Rule (TCR), the sampling locations and dates of sampling were in violation of

the TCR requirements. Samples were usually collected from points where each well entered the distribution system and at the outlet of the ground level reservoir, rather than from locations representing the whole distribution system. In addition samples were generally collected on the same day rather than being spread over the month. Three extreme hazard cross-connection risks were identified where there was potential for contaminated water from business premises (two mortuaries and a combined meat packing facility/restaurant) to flow back into the distribution system in the event of low-pressure events in the distribution system. More than 100 lower risk potential cross-connection sites were also detected.

Significant corrosion was found in the well casing for one of two wells where video inspection records were available from prior to the outbreak. Although all the town wells draw water from a deep confined aquifer (believed to be secure from microbial contamination), the well shafts pass through a shallow unconfined aquifer. Contamination from this shallow aquifer could potentially enter the water supply if the integrity of the well casing was breached within the shallow aquifer zone.

In summing up the lessons from the outbreak, the investigators note the outbreak was detected rapidly by the public health surveillance system and the probable link to the drinking water system was identified within one week of the first laboratory confirmed case being reported. The CoWARN system allowed a very rapid and effective response to be mounted, with equipment and personnel from other utilities being available within 24 hours of the initial call for assistance. The National Incident Management System Incident Command System was effective in coordinating communication with the media, distribution of bulk water supplies to businesses, managing volunteers and public communication activities. Local, state and federal laboratories cooperated effectively in providing rapid testing and assisting with logistical issues surrounding sample transport, however there was a failure in the communication chain regarding reporting of CDC test results to the CDPHE.

The outbreak response was very demanding on the personnel resources of the SDW Program as emergency response staff were not trained in drinking water system operations, and thus the SDW team had to provide review and input to communication and coordination activities and operational decisions. In addition to dealing with restoration of the public water supply, the SDW team also had to respond to numerous requests from businesses for technical advice and approval to establish individual water supplies to enable them to keep operating during the crisis. The report notes that under-resourcing of the Colorado SDW Program has been a long standing issue and that although staff numbers have increased significantly in recent times, they are still below the levels deemed adequate by the US EPA.

In the wake of the Alamosa outbreak the Colorado Safe Drinking Water Program has announced a number of actions to reduce the possibility of further waterborne outbreaks. These include:

- updating and modification of state regulations concerning groundwater disinfection and the granting of disinfection waivers.
- a review of all systems with current disinfection waivers to assess whether the waiver should be withdrawn and disinfection required.
- higher prioritisation of responses to regulatory violations and deficiencies in non-disinfected systems.
- inclusion of water storages and distribution systems in sanitary inspections, as well as improved oversight of total coliform monitoring practices.
- requiring timely correction of deficiencies identified during inspections.
- ensuring compliance with maintenance of chlorine residuals in disinfected systems.
- revision of regulations governing cross-connection risks.
- training initiatives to help public drinking water system operators improve operating and maintenance practices for storage tanks and distribution systems.
- development of strategies to enhance response capabilities for drinking water emergencies.

(1) This outbreak was initially reported in Health Stream Issue 49, March 2008. The CDPHE investigation report can be obtained from:
www.cdphe.state.co.us/wq/drinkingwater/AlamosaOutbreak.html
(2) Details of the epidemiological investigation which linked the *Salmonella* cases to the water supply have not yet been released, however the clues which may suggest a waterborne origin for outbreaks include a higher risk of illness in those reporting cold tap water consumption compared to those reporting no or little cold tap water consumption, the geographic pattern of cases relative to water distribution zones, and lack of association with food items, food venues, social events or other non-water exposure sources among cases.

Industrial Exposures To Legionella

Health agencies in the UK recently identified two cases of *Legionella* pneumonia linked to workplace exposures to water aerosols. These cases once again highlight the potential health risks of *Legionella* growth in warm water sources coupled with the use of spray-generating devices. The investigation was triggered when two middle aged men were admitted to the same West Midlands hospital with legionellosis on the same day in May 2008. Both men worked at a factory which manufactured construction and agricultural equipment, but they had no other apparent common exposures to aerosolised water sources. Potential sources of aerosol exposure assessed at the workplace included the hot and cold water supplies to restrooms and changing rooms, a paint mist trap using ambient temperature water, and a degreasing/rinsing tunnel using water-based solutions (at 55-60 degrees C or 25-38 degrees C) to clean metal parts before painting. Water tests revealed *Legionella pneumophila* serogroup 1 in samples from the degreasing/rinsing tunnel at levels above 30,000 colony-forming units per litre. There was no aerosol extraction system on the tunnel and brushes covering the conveying railings (which would have reduced spray emissions from the tunnel) were missing. One of the infected workers worked in the section of the factory containing the degreasing/rinsing tunnel while the other walked past this equipment several times a day. After initial cleaning and shock disinfection of the water tanks supplying the degreasing/rinsing tunnels, a biocide dosing regime was established to combat *Legionella* growth. Procedures were also introduced to drain and clean the tanks every weekend when the plant closed.

Eleven other workers at the plant who had been absent from work due to respiratory illness at some time during the previous four weeks were tested for urinary *Legionella* antigen, but none were positive. The investigators note that aqueous cleaning systems are replacing solvent-based cleaning systems for metal degreasing because of health concerns over solvent exposures for workers. However these aqueous systems may generate unforseen health risks due to the combination of warm water temperatures, nutrients from washing metal parts, recirculation of water, and convoluted surfaces which favour biofilm growth. If aerosols are allowed to escape from the equipment, workers may be at risk of infection. Five similar aqueous cleaning systems were subsequently tested by the UK Health and Safety Executive and *Legionella* bacteria were detected in four systems, suggesting that contamination is common. This has led to the recommendation that these systems need to be included in *Legionella* risk assessment and management plans for workplaces.

Legionnaires' disease cluster linked to a metal product aqueous pre-treatment process, Staffordshire, England, May 2008. Coetzee N et al. Euro Surveill. 2009;**14**(40).

News Items

Australian Drinking Water Guidelines Revision

The National Health and Medical Research Council (NHMRC) in collaboration with the Natural Resource Management Ministerial Council (NRMMC), has issued several documents for public comment:

- draft revisions to Chapters 6, 9 and 10 of the Australian Drinking Water Guidelines (ADWG).
- a large number of new Fact Sheets and revised versions of existing Fact Sheets from the ADWG.
- a discussion paper on *Health Based Targets For Microbial Safety Of Drinking Water*. This paper canvasses the inclusion of quantitative definitions of microbial safety in the ADWG in an analogous fashion to the approach already adopted in the Australian Guidelines for Water Recycling (2006).

These documents can be obtained from the NHMRC web site: http://www.nhmrc.gov.au/guidelines/consult/consultations/draft_adwg_guidelines.htm
Public submissions close on 15 January 2010.

From the Literature

Web-bonus articles available at:

www.wqra.com.au/WQRA_publications.htm

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Arsenic

Arsenic exposure predicts bladder cancer survival in a US population.

Kwong RC, Karagas MR, Kelsey KT et al. (2009) World Journal of Urology.
doi: 10.1007/s00345-009-0477-y

Chronic arsenic exposure has been associated with a number of types of cancer, including bladder cancer. However, arsenic compounds have been used historically as medicines and studies conducted in the 1990s suggested that inorganic trivalent arsenic may be a useful therapeutic agent for treatment of blood-related cancers including leukaemia, multiple myeloma and lymphoma. Clinical trials are currently underway to assess the efficacy of arsenic for solid tumours including bladder cancer. This study explored the relationship between inorganic arsenic exposure from contaminated drinking water and bladder cancer survival in a large population-based study in New Hampshire. In this region of the US around 40% of residents drink water from private wells, many of which contain arsenic.

All bladder cancer cases diagnosed among New Hampshire residents and registered with the state cancer registry from 1 July 1994 to 31 December 2001 were eligible. There were 832 bladder cancer cases interviewed, representing 85% of eligible cases identified. Sociodemographic, water consumption and lifestyle information was collected by interview. Tumour tissue samples were reviewed to assess tumour histology, stage and grade. Cause of death information was only available on cases that died prior to June 2006 due to the lag time for inclusion in the national death registry. Of the 298 total deaths, 87 were classified as attributable to bladder cancer. Death from other causes or unknown causes were excluded from the analysis of bladder cancer cause-specific mortality.

At the time of interview of cases, samples of toenail clippings were collected and analysed for arsenic and other trace elements and water samples were collected from the current household's drinking water supply and analysed for arsenic. Groups were created for high versus low arsenic exposure analysis using

the 75th percentile as a cutoff, which was equivalent to a toenail arsenic level of 0.12 g/g or 0.74 micro g/L in household drinking water. Low arsenic exposure was used as the reference group (less than or equal to 25th or 0.057 micro g/g toenail, 0.11 micro g/L drinking water). Arsenic consumption was calculated by multiplying the drinking water arsenic concentration at home by the number of glasses the subject reported consuming from the questionnaire.

There were 534 surviving cases and 71% of these were male. Of the 250 deceased cases, 84% were male. The majority (75%) of participants had stage Ta or T1 tumours when diagnosed and 12% had stage T2 or higher. The median survival time for these groups was 8 and 6 years, respectively. A total of 33% were current smokers and 49% former smokers at the time of diagnosis. Cox-proportional hazard regression analysis was performed comparing high arsenic exposure (greater than 75th percentile) to the low exposure (less than or equal to 25th), grouped by toenail arsenic level. A significant hazard ratio (HR) of 0.5 (95% CI 0.4-0.8) was found, indicating that those with higher arsenic exposure had more prolonged survival after adjustment for age, sex, smoking status, stage, grade and therapy. A dose-response relationship was seen for better survival with high toenail arsenic levels (*p*-trend = 0.004) (Log-rank *p* value less than 0.001). Cox-regression analysis using high versus low arsenic consumption (calculated as arsenic concentration in well water times number of glasses consumed) showed a similar trend with HR 0.7 (95% CI 0.5-1.1). There was a suggestion also of a slightly improved survival with household drinking water arsenic level above the current US MCL (greater than 10 micro g/L), compared to lower levels, but the confidence intervals were wide [HR 0.7 (95% CI 0.3-1.5)]. High toenail arsenic levels were associated with longer survival HR 0.5 (95% CI 0.3-1.1) compared to low arsenic levels. The effect of high versus low toenail arsenic level on overall survival did not differ strongly between non-invasive and invasive tumours. Logistic regression analysis with adjustment for age, gender and smoking showed that high toenail arsenic levels decreased the odds of being diagnosed with a tumour of stage I or higher [OR 0.7 (95% CI 0.5-0.90)] compared to having low arsenic exposure.

Baffled by Odds Ratios?
Confused by Confounding?
Don't know a Case-control from a Cohort study?
Readers who are not familiar with such terms can find explanations in the *Epidemiology Spots* in Issues 1- 6 of Health Stream.
Look for the **Past Issues** link on the Health Stream web page at:
http://www.wqra.com.au/hs/hscurrent.htm

The reduced hazard ratio for survival associated with high toenail arsenic exposure was found among the cases who had a history of smoking [overall survival HR 0.5 (95% CI 0.3-0.7); bladder cancer survival HR 0.4 (95% CI 0.2-0.9)], in contrast to the non-smokers [overall survival HR 1.2 (95% CI 0.4-3.9); bladder cancer survival 1.4 (95% CI 0.3-6.7)]. The interaction between high toenail arsenic and smoking was not statistically significant. Drinking water arsenic levels were associated with similar differences on the basis of smoking status. This study found a decreased risk of overall death for patients exposed to higher amounts of arsenic through drinking water, with a non-significant similar trend for cause-specific mortality. The authors suggest several possible explanations including differences in the biology of arsenic-related tumours, direct effects of arsenic on tumour growth, interaction between arsenic and cancer treatments.

<u>Comment</u> *Arsenic levels in drinking water this study were much lower than encountered in regions of the world (eg Taiwan, Bangladesh) where there is strong evidence of arsenic-induced cancers. Most of the bladder cancer cases in this study are likely to be attributable to other causes (eg smoking) rather than arsenic exposure.*

<u>Disinfection Byproducts</u>

Impact of chlorinated swimming pool attendance on the respiratory health of adolescents.
Bernard A, Nickmilder M, Voisin C and Sardella A. (2009) Pediatrics, **124**(4); 1110-1118.

Swimming pools are most commonly disinfected with chlorine-based disinfectants which inactivate a wide spectrum of waterborne pathogens, however

there are also some disadvantages including irritation of the skin, eyes and upper respiratory tract of swimmers in contact with pool water or air. It has been known for several years that elite swimmers have a higher prevalence of respiratory symptoms, asthma and airway inflammation than other athletes. It has been assumed that this was due to selection bias attributable to the lower asthma producing potential of indoor swimming compared with other sports (i.e. that people diagnosed with asthma are encouraged to swim as a preferred form of exercise). It is now being increasingly acknowledged that these respiratory problems may be attributed, at least in part, to chlorine disinfection of pool water. Recent studies have found that indoor chlorinated pools may be detrimental to the airways of children causing epithelial damage and increasing asthma risk as well as contributing to the development of allergic diseases. The aim of this study was to assess for the first time the overall impact of chlorinated pool exposure on the respiratory health of adolescents by considering the total time spent in indoor and outdoor chlorinated pools.

Adolescents were recruited from 3 secondary schools in the southern part of Belgium, in the cities of Louvain-la-Neuve, Bastogne and Lessines. Students in Louvain-la-Neuve had access to an indoor pool disinfected with the copper-silver method, whereas students at the other two schools could visit only indoor pools disinfected with chlorine. Parents completed a questionnaire asking about the health of their child and risk factors for asthma and allergic diseases. The questionnaire also included questions intended to estimate the total time the child had spent in indoor or outdoor chlorinated pools. Students were examined in schools and measured for height and body weight and questioned about respiratory symptoms. A blood sample was collected and screening undertaken for exercise induced bronchoconstriction (EIB). Asthma was defined either as “ever asthma” corresponding to asthma diagnosed at any time by a physician, or as “current asthma” corresponding to physician-diagnosed asthma that was currently being treated with medication and/or was associated with positive EIB test results. Allergies were screened for by measuring total and aeroallergen-specific immunoglobulin E (IgE) concentration in serum and participants were classified as nonatopic or atopic on the basis of this. Associations between outcomes and cumulative chlorinated pool attendance (CPA) were assessed in four categories, less than 100 hours, 100 to 500 hours, 500 to 1000 hours or greater than 1000 hours.

Over 70% of eligible students at the three schools participated, giving 847 subjects aged 13 to 18 years. The three groups had significant variation in several baseline characteristics associated with asthma risks (eg breastfeeding, childcare attendance, maternal smoking during pregnancy), however these were adjusted for in statistical analysis. As expected, students in Louvain-la-Neuve had much lower CPA levels than students in the two other cities. A subgroup of 114 students with a lifetime CPA value of less than 100 hours was chosen as the reference group. The associations between chlorinated pools and outcomes studied were examined with increasing cumulative CPA. The rate of sensitization to major aeroallergens did not vary with CPA, whereas the total serum IgE concentrations showed a tendency to decrease. There was little variation found in FEV1 values, showing only a modest increase between lowest and highest CPA categories. Prevalences of wheezing and EIB, although increasing in all groups with CPA values of greater than 100, did not show any significant exposure-related trend. However, the prevalences and odds of ever asthma, current asthma, cough and shortness of breath increased almost linearly with the time spent in chlorinated pools. Even when adolescents with a diagnosis of asthma were excluded, cough and shortness of breath persisted (*P* for trend of .004 and .05 respectively). The risk of hay fever was increased in all groups with CPA values of greater than 100 hours whereas the risk of allergic rhinitis was only increased in the group with the highest CPA value.

The risks of respiratory symptoms and asthma associated with CPA were strongly affected by atopic status. Of those adolescents with atopy with serum IgE levels of greater than 30 KIU/L or aeroallergen-specific IgE, the odds ratios (ORs) for asthma symptoms (wheezing, cough, shortness of breath) and for ever or current asthma increased with the lifetime number of hours spent in chlorinated pools, with an

OR of 7.1 to 14.9 when chlorinated pool attendance was greater than 1000 hours. Adolescents with atopy with CPA greater than 100 hours had greater risk of hay fever (OR 3.3-6.6) and those with attendance of greater than 1000 hours had a greater risk of allergic rhinitis (OR 2.2-3.5). These associations were not found among those without atopy or among those who attended a copper-silver pool. The population attributable risks (PARs) for atopic diseases associated with CPA were calculated by considering as exposed the students with atopy who had spent more than 100 hours in chlorinated swimming pools. When atopy was defined on the basis of total serum IgE levels then PARs for ever asthma were 63.4%, for current asthma, 79.2%, for hay fever, 62.1% and for allergic rhinitis, 35.0%. Similar PAR estimates were obtained when atopy was defined as sensitization to any aeroallergen. This study shows that CPA during childhood interacts with atopic status to increase the risk of asthma, hay fever and allergic rhinitis. The authors postulate that chlorination products may disrupt epithelial barriers, enhancing penetration of allergens. Differences in exposure-response relationships between hay fever and asthma may reflect primarily differences in the doses of chlorination products deposited in the upper and lower respiratory tract respectively.

Comment This cross sectional study cannot establish a temporal relationship between exposure to chlorinated swimming pools and development of respiratory symptoms, only that the observed associations exist in this population. A prospective study would be required to determine when development of symptoms or atopy occurs relative to pool exposure.

Giardia

Outbreak of giardiasis associated with a community drinking-water source.
Daly ER, Roy SJ, Blaney DD et al. (2009) Epidemiology and Infection.
doi: 10.1017/S0950268809990744

Large outbreaks of giardiaisis associated with community water sources have been uncommon in the USA since the Safe Drinking Water Act of 1974 and subsequent amendments. This article reports on a large outbreak of giardiasis associated with a community drinking water system in 2007 in New Hampshire, USA. After routine water sampling detected the presence of total and faecal coliform bacteria within the distribution system, a boil water order was issued by the New Hampshire Department of Environmental Services (NHDES) on 9 September 2007 for a 205 home community served by a common water system. The community groundwater system consisted of a west system (system A) and an east system (system B), with a number of wells supplying each system. Water was usually distributed without filtration or disinfection. On 17 September NHDES received reports from two residents of system A alleging infection with *Giardia*. The New Hampshire Department of Health and Human Services (NHDHHS) was notified and an outbreak investigation began.

To identify risk factor for giardiasis, a cohort study was conducted. Questionnaires were distributed to water system customers asking about water consumption habits, use of water filtration devices and details of gastrointestinal illness experienced since 15 August. An environmental investigation was conducted to assess potential entry point(s) of contamination in the water supply and distribution system. Human stool specimens were examined by direct fluorescent antibody (FA) testing and polymerase chain reaction (PCR) testing and subtyping. There were 31 confirmed (n=17) and probable (n=14) giardiasis cases from 27 of the 43 responding system A households; four suspected cases were also identified. There were no confirmed cases identified in system B. A total of 200 surveys were distributed to system A and system B households, and 62 (31%) completed surveys were returned. As cases of illness were confined to system A, only the surveys returned by residents of this system were included in the analysis (43 households containing 100 individuals). Consuming tap water was significantly associated with illness. Of the 63 individuals who consumed tap water, 27 (43%) reported illness compared with three (9%) of the 33 who did not consume tap water [risk ratio (RR) 4.7, 95% CI 1.5-14.4]. The risk of infection was increased by drinking four or more cups of tap water a day (RR

5.0, 95% CI 2.5-10.0) and a significant trend was found between drinking increasing amounts of tap water and increased risk of infection (x^2 test for trend = 28.9, *P* less than 0.001).

One of the two wells serving system A was found to be at moderate risk of surface water influence from a nearby brook. This well had been brought online by the previous owner of the water system without a permit from NHDES. A beaver dam was present on the brook but no significant human interaction with the brook was identified. Faecal coliforms were identified in this well on 10 September and the well was then hyperchlorinated. Repeat coliform testing of distribution samples were negative following hyperchlorination however chlorine residuals were high in the samples and this made the bacteria assay invalid. When chlorine residuals dropped, distribution samples were positive again for total and faecal coliforms signifying ongoing system contamination. There were no positive detections of Giardia cysts in samples of well water. On 21 September the well was disconnected from the system and thereafter no faecal coliform positive distribution samples were found. Human stool samples from 14 patients were found to be FA positive for *G. intestinalis*. Additional stool samples from three patients were found to be FA- and PCR-positive for *G. intestinalis.* The *G. intestinalis* was identified as assemblage B and three specimens from unrelated cases which were characterised by DNA sequencing of part of the triosephosphate isomerise (TPI) gene were found to exhibit a single subtype. The subtype found in human stool specimens in this outbreak has been previously found in beavers in Massachusetts and a Barbary macaque (monkey) in Italy. Giardia cysts were detected at concentrations of 40-50 cysts/litre in a water sample taken in early October from the brook near the contaminated well, although DNA sequencing of the TPI gene showed some differences from the human outbreak cases. The subtype found in the brook is commonly found in humans in the USA, Australia and Egypt and ringed seals in Canada.

This outbreak of human giardiasis is the largest such outbreak associated with a community drinking water system in the USA in 10 years. The epidemiological investigation showed that illness was significantly associated with consuming tap water, and evidence from laboratory and environmental investigations suggested that water from one of the two wells in system A had been contaminated by a nearby surface water body. The outbreak occurred in late summer when the water system experienced high summer usage. Despite the negative PCR result of samples from two beavers trapped during the investigation, the unique subtype previously found in beavers and the presence of these animals in the brook suggest that beavers could have been the source of contamination. The finding of different genetic subtypes in the human outbreak cases and in surface water one month after the outbreak does not exclude this explanation as the prevalence of *Giardia* cysts in surface water in the USA and Canada is high. This outbreak may have been prevented by adherence to state and federal drinking water regulations related to placement of wells and associated treatment.

Naegleria fowleri

Occurrence of *Naegleria fowleri* in Arizona drinking water supply wells.
Bright KR, Marciano-Cabral F and Gerba CP. (2009) Journal / American Water Works Association, **101**(11); 43-50.

Naegleria fowleri is a protozoa which can cause a rare but fatal disease known as primary amoebic meningoencephalitis. *N. fowleri* mainly affects healthy children and young adults with a history of swimming and/or diving in freshwater lakes and ponds. Infections have generally been associated with forcible entry of water into the upper nasal passages, from which the organism may infect the olfactory nerves and then spread to the brain. In 2002, two fatalities occurred in children in Phoenix, Arizona who had no known exposure to lakes or ponds. Investigations showed the presence of *N. fowleri* in the undisinfected tap water supply which was drawn from deep groundwater, and it was concluded the children had most probably been infected from tap water. The presence of *N. fowleri* in drinking or bathing water is not currently regulated in the United States. This study investigated the presence of *N. fowleri* in high-volume public drinking water supply

production wells operated by municipal utilities or private water companies in the greater Phoenix and Tucson Arizona metropolitan areas.

The study was carried out in two phases. Phase 1 was an initial survey (*n*=58) to identify wells testing positive for the presence of *N. fowleri* (or *N. fowleri* DNA). A total of 58 wells were sampled for Naegleria during September (1 litre grab samples from at or near the wellhead, prior to disinfection, and collected after flushing to reduce turbidity). Phase 2 involved sampling every other month (April, May, June, August and October the following year) in a subset of wells previously identified as either positive (*n*=5) or negative (*n*=2) for *N. fowleri*. A number of samples were also collected from other wells (*n*=55) not previously tested. In Phase 2, samples were initially collected as water was turned on ("initial") and then after an approximate three borehole volumes had flushed through the system ("purged"). Well water samples were also tested for a number of water quality parameters. Each well water sample (phase 1 and phase 2) was tested for the presence of *N. fowleri* DNA via polymerase chain reaction (PCR). Positive and negative PCR products were coded to prevent bias and confirmed by gene cloning and sequencing. During phase 2 of the study, each well water sample was also tested for the presence of viable amoebae.

In phase 1 of the project, of *N. fowleri* was detected in five of 58 wells tested. In phase 2 there were 14 of the 113 wells that were tested multiple times. Five of the 14 wells always tested positive for *N. fowleri*. During the whole of the phase 1 and phase 2 sampling periods, *N. fowleri* was detected in 12 of 113 wells (10.6%), with 29 of 185 samples (15.7%) testing positive. Analysis for the detection of live amoebae during phase 2 found live flagellates of undetermined species in 20 of 62 (32.3%) wells and in 26 of 125 samples. Viable *N. fowleri* was only confirmed by PCR in one well which tested positive for the presence of *N. fowleri* DNA on five separate occasions. This may be because of the low occurrence of the infectious form of the organism in water, because the organisms detected by PCR were no longer viable or because of the differences in the assay volume for detection of live trophozoites (0.75 mL) versus PCR (30 mL equivalent volume of non-concentrated sample). Coliform bacteria were present in 8.9% of the wells tested, *E. coli* were not detected in any wells and heterotrophic bacteria exceeded 500/mL (for at least one sample) in 51.3% (58 of 113) of the wells. There were no correlations found between heterotrophic bacteria, coliforms, *E. coli*, temperature, specific conductance or turbidity in relation to the presence of *N. fowleri* in wells. *N. fowleri* was most frequently detected after the well was purged (86.2% of all positive samples) suggesting that the organism was present in the aquifer or was released from the well casing or pump column during pumping.

Chlorination or other forms of disinfection may be effective for controlling *N. fowleri* transmission via drinking water but there is no guidance on the required dosages and contact time for drinking water storage tanks or distribution systems. Laboratory studies suggest that both cysts and trophozoites are fairly resistant to free chlorine. It is not known why some wells are positive for the presence of *N. fowleri* while others are only transiently positive. Further research needs to consider the maintenance of wells and other characteristics that may influence the occurrence of *N. fowleri* and also the effectiveness of well borehole chlorination or other practices in eliminating the organism from wells.

Comment The investigation into the Naegleria deaths in Phoenix, Arizona was reported in Health Stream Issue 28. Australian experience has shown chloramination to be effective in eliminating this organism from pipelines and distribution systems.

Perfluorinated compounds

A cross-sectional analysis of type II diabetes in a community with exposure to perfluorooctanoic acid (PFOA).

MacNeil J, Steenland NK, Shankar A and Ducatman A. (2009) Environmental Research, **109**(8); 997-1003.

Perfluorooctanoic acid (PFOA, C8) is used in the manufacture of several types of fluoropolymers as a polymerisation aid. PFOA is considered a probable

human carcinogen by the US Environmental Protection Agency however its human health effects are not well established. An increase in diabetes mellitus mortality has previously been reported in workers exposed to PFOA. Since 1951, PFOA has been used in manufacturing fluoropolymers at the DuPont's Washington Works plant in Washington, West Virginia. In 2001, a class-action lawsuit by local residents alleging contamination of drinking water supplies resulted in the implementation of a large cross-section health survey called the C8 Health Project. This paper describes a sub-study of the relationship between serum PFOA and type II diabetes in the community.

The C8 project began testing in August 2005 and completed testing in August 2006. Data were collected on 69,030 subjects with at least 1 year of exposure. Self-reported information on diabetes status was validated through examination of medical records, (referred to as 'validated type II diabetes'). PFOA was measured in the serum of participants and also fasting serum glucose level. The analysis was restricted to adults greater than or equal to 20 years of age (N = 54, 468). A prevalence case-control analysis was conducted to examine the relationship between exposure and type II diabetes. Cases were either those with self-reported type II diabetes or validated type II diabetes. Controls were those who did not report type II diabetes and were not found to have a diagnosis of type II diabetes after medical review. The primary analysis was restricted to long-term residents (N=13,922) of contaminated water districts (greater than or equal to 20 years, i.e. residence since 1985 or earlier). Type II diabetes cases for this analysis (N=1055) were restricted to those with medical record validation who had lived in a contaminated water district for at least 10 years prior to diagnosis. Risk factors in the final model included: age, gender, race, family history of type II diabetes and use of cholesterol- or blood-pressure lowering medication. An analysis was also conducted without the use of blood pressure or cholesterol medications. A linear regression analysis was also conducted for fasting serum glucose levels excluding those who reported eating in the 6 h prior to their blood draw and all subjects who self-reported or had validated type II diabetes (N=21,643). The final linear regression model included the risk factors of age, BMI, gender, diabetes family history and race.

There were 4278 cases of self-reported type II diabetes and 3539 cases of validated type II diabetes. Self-reported age-adjusted prevalence of diabetes in this population was 7.8% which is similar to that of Ohio (7.1%) and West Virginia (10.1%), based on 2005 data. Median serum PFOA was 28.1 ng/ml for all study subjects, 30.3 ng/ml for self-reported type II diabetes subjects, 32.6 ng/ml for validated type II diabetes and 48.5 for validated type II diabetes in long-term residents, diagnosed in the last 10 years. Odds ratios (ORs) for the primary analysis restricted to those who had lived in their contaminated water district for at least 20 years (mean duration = 31.7 years) with cases restricted to those medically validated with a least 10 years exposure before their diagnosis were calculated and after adjusting for covariates, there were no clear trends found for odds of diabetes with increasing decile of serum PFOA. Instead people with serum PFOA levels in the upper deciles showed lower risks of self-reported or validated Type II diabetes than the lowest (referent) decile, but without any consistent negative trend. The upper decile was also split into two for analysis but no increased risk of disease was found in the top 5%. ORs for PFOA decile without cholesterol- or blood-pressure-lowering medication showed little change. The ORs for final models with self-reported type II diabetes and validated type II diabetes with no restriction on length of residence showed no clear trend in the risk of diabetes with level of serum PFOA. The regression model for the log of fasting glucose level showed no consistent pattern between fasting serum glucose by decile and serum PFOA.

In this analysis there were no clear trends found between risk of type II diabetes or fasting serum glucose and serum PFOA level. The data here are limited by the cross-section nature of the study and the possibility of a causal relationship can not be ruled out on the basis of. Future analyses are planned using more detailed temporal exposure estimates. These analyses will be able to more accurately estimate exposure prior to disease development.

Public Perception

Perceptions of drinking water quality and risk and its effect on behaviour: A cross-national study.
Doria MdF, Pidgeon N and Hunter PR. (2009) Science of the Total Environment, **407**:5455-5464.

A mixed-methods approach was used with quantitative (survey) and qualitative (focus groups) methods to compare perceptions and water uses in UK and Portugal. A survey was mailed to 500 people randomly selected from phone directories in each country. The survey was backed up by a telephone call between 3 weeks and 4 months after the mail survey. The response rate was approximately 41% in both countries (n= 203 in the UK and n= 204 in Portugal). The survey consisted of a questionnaire about water related perceptions and behaviours. Respondent's agreement with several statements was measured using a Likert-type scale from "completely disagree" (1) to "completely agree" (7). The variables that explained cross-national differences were identified using a univariate generalised linear model (GLM) approach. Structural equation models (SEM) were also used and tested with empirical data and extended to included additional variables.

Three focus group sessions were conducted in each country and participants were recruited in Norwich (UK) and Lisbon (PT) using street adverts and leaflets. There were eight people invited to attend each session. The moderator introduced the discussion items which were derived from the survey items. Focus group results were analysed for patterns that support, contradict, or extend the theoretical patterns described by the quantitative models. The majority of UK participants (80%) used tap water as their main type of drinking water at home, but less than half of Portuguese participants did so. Water flavour was found to have a strong influence on perceived water quality. Perceptions of risk and context also influenced perceived quality but the strength of these relationships varied depending on the country. Perceived water quality was also influenced by trust in water companies. The perception of risks associated with tap water was moderately explained by flavour, memorability, context and negative information from friends. The influence of flavour on risk perception and other organoleptic variables was evident in the quantitative research however this relationship was disputed during the focus groups. It is possible that the association between organoleptics and risk is intuitively used and may be questioned when people have time to think about it in a focus group situation. There were also other inconsistencies between the quantitative and qualitative results; the direct association of chlorine with risks which was apparent in the quantitative research was challenged in the focus groups, with some participants stating that chlorine taste and/or odour revealed water safety. Also in the survey results lead had a significant effect on risk perception however this was not evident in the focus groups. Trust in water suppliers appeared to be largely influenced by the same factors that influence risk perception, namely by water flavour, colour, memorability and interpersonal information from friends and family. This was consistent with focus group results which suggested that trust in water companies is characterised by the absence of aesthetic, health and supply problems. Quantitative research showed a considerably high level of trust in water companies.

Flavour was found to be the most relevant variable and explained consumption more than perceived water quality. Tap water consumption was moderately influenced by satisfaction with flavour and weakly influenced by risk perception. The main factors identified in this study as affecting bottled water consumption correspond mostly to those found in other countries such as Canada, France and the US. There were several similarities and differences found in the way tap water quality and risks are perceived in Portugal and the UK. There were no significant differences found at the p less than 0.001 level in relation to the magnitude of perceived water quality, risk, flavour, odour, trust in water companies, hardness, lead, chlorine and memorability. On average, UK and Portuguese participants did not consider concentrations of tap water chlorine and lead to be excessive and did not regard their water as too hard. Focus group results indicated that UK participants seemed to be more critical about chemicals in drinking water than Portuguese

participants. These differences may result from cultural attitudes towards drinking water and may have implications for the public acceptability of European-wide standards for drinking water. Differences were also found regarding the influence of different variables on perception of quality and risk including colour, pressure, interpersonal information and tap/bottled water consumption.

Water Quality Management

Adaptive management for mitigating *Cryptosporidium* risk in source water: A case study in an agricultural catchment in South Australia.
Bryan BA, Kandulu J, Deere DA et al. (2009) Journal of Environmental Management, **90**(10); 3122-3134.

This paper presents a case study of the management of the pathogen *Cryptosporidium* in source water entering a drinking water supply in the Myponga catchment in South Australia using an adaptive management framework. The adaptive management framework includes a phase of explicit learning and adaptation which is used to inform planning of the next round of management. This study evaluated a recently completed water quality management program in the Myponga catchment. This information was then used to inform analysis and planning for a second round of management actions providing a practical example of an adaptive loop for the management of water quality.

The Myponga River catchment covers around 123 sq km and is situated 50 km south of Adelaide. The dominant land use in the Myponga catchment (61%) is broad scale grazing (mainly beef cattle and sheep, with some horses and deer). Other significant land uses include native vegetation (13%) and dairying (13%). The effectiveness of past water quality management programs in relation to the adoption of practices by landholders was evaluated using a socio-economic survey of land use and management in the catchment. During January to April 2007, a face-to-face interview and survey of 36 landholders in the Myponga catchment was undertaken. The survey included over 50 questions on land use and management relevant to water quality. Dairy farmers were also asked about effluent and nutrient management practices. The impact of past management on the mitigation of *Cryptosporidium* risk in source water was also evaluated on the basis of the analysis of water quality monitoring data. Water quality testing for enteric protozoa has been conducted in the Myponga catchment by SA Water since 1998. Samples were taken near the gauging station which captures run-off from 62% of the reservoir catchment area. Sampling is triggered by rainfall events rather than peak run-off events and therefore may underestimate *Cryptosporidium* loads.

Quantitative risk assessment was used in analysing and planning the next round of water quality management in the Myponga catchment. This study used an established, numerical process-based pathogen budget model to estimate the source apportionment of *Cryptosporidium* risk and the effectiveness of catchment mitigation benefits of a number of alternative management strategies. A baseline model was developed for the Myponga catchment including all potential sources of human-infectious *Cryptosporidium* under current land use and management. The survey of land use and management was the main data source to specify parameter values in the pathogen budget model with the addition of a previous livestock survey, spatial information on land use and property boundaries and other data. Scenario analysis was used to assess the impact of a range of management actions in the catchment in mitigating *Cryptosporidium* export to the reservoir. There were a total of 30 management scenarios specified. In the scenario analysis the baseline pathogen budget model parameter values were varied to estimate the effect of management actions on reducing *Cryptosporidium* export. The mitigation impact of catchment management scenarios was described relative to the baseline model by log removal and a measure of effectiveness (% change from baseline).

The survey results of the past catchment management programs revealed that the implementation of source water quality management programs led to the widespread adoption of best practice water quality management by dairy farmers. Low rates of adoption however, were found amongst other landholders.

This difference may be explained largely by the fact that past programs were targeted towards dairy farmers. The analysis of water quality sampling data shows that from 2000 to 2007, SA Water's *Cryptosporidium* target of 0 cells/10 L in source water has been exceeded 100% of the time as detected at the inlet of the Myponga reservoir. Between 1 July 2001 and 30 June 2004 there were 51 water quality related incidents reported, 40 of which were linked to the detection of *Cryptosporidium* at the inlet to the reservoir. The median *Cryptosporidium* concentrations in source water samples increased from 3 oocysts/10 L in 2000 and peaked in 2003/2004 at 8 oocysts/10 L and have declined since then to 5/oocysts/10 L in 2007.

Most dairy farmers were found to practice stock and effluent management to minimise the contribution of pathogens to waterways. Dairy farmers were found to limit the access of young stock to water courses whereas non-dairy landholders did not. The decline in annual median oocysts concentration since 2004 was found to coincide with and is consistent with catchment management activities since 2000. A direct causal relationship was not established, however the monitoring data may reflect an initial beneficial impact of past catchment management programs on *Cryptosporidium* export. There may also be a number of other factors that influence *Cryptosporidium* concentrations such as land use change, sampling uncertainty and variation in catchment hydrology. The sampling results are nevertheless a positive sign. Despite the recent reductions, oocyst level still exceed SA Water targets and put ongoing pressure on the treatment system as a reliable barrier to mitigation.

The pathogen budget model showed under baseline land use and management conditions that almost all of the total human-infectious *Cryptosporidium* stock in Myponga catchment is generated by non-dairy calves (78%), dairy calves (17%) and lambs (5%). The model estimates that only about 1.4% of the total *Cryptosporidium* stock is exported to Myponga reservoir with around 65% of the export occurring in wet weather events. Non-dairy calves accounted for 87% of human-infectious *Cryptosporidium* export in dry weather and 95% in wet weather. Assessment of management scenarios suggests that most of the possible reduction in *Cryptosporidium* oocysts exported to the Myponga reservoir (91.8% in wet weather and 89.7% in dry weather) could be achieved by restricting watercourse access of non-dairy calves to 5%. Only slightly greater mitigation benefit (91.9% in dry weather and 89.8% in wet weather) could be achieved through restricting watercourse access of all non-dairy cattle to 5%. This case study of the Myponga catchment provides a practical and successful example of a passive adaptive management framework. The information gained was used to refocus, refine and re-prioritise the next round of management of *Cryptosporidium* risk in source water.

Water Treatment

Development of a mobile water maker, a sustainable way to produce safe drinking water in developing countries.
Groendijk L and de Vries HE. (2009) Desalination, **248**(1-3); 106-113.

This paper reports on the development and laboratory testing of a solar powered mobile water treatment unit with a production capacity of approximately 500 L/day for use in developing countries. The unit consists of a feed water tank, a membrane module with tubular ceramic membranes and an anodic oxidation disinfection unit. A feed water storage tank is situated 3 metres above the membrane filtration unit to provide a constant Trans Membrane Pressure (TMP) of 0.3 bar. Feed water is transferred to the tank using a hand pump. A control box controls the charging of the solar power panel and also controls the disinfection level of the filtered water. Prior to raw feed water being pumped into the water supply tank it passed through a raw filter nylon screen of 0.13 mm to remove large particles which could clog the membrane inlet tubes. Ceramic tubular ultra filtration (UF) membranes with a total area of 0.8 sq m and pore size of 40 nm are used. The permeate flows to a disinfection unit powered by a 6 V battery which produces a low voltage electrical field to generate hypochlorous acid from the chloride naturally present in water. This inactivates

microorganisms and also provides a post-disinfection residual of free chlorine.

In the laboratory tests, the filtration unit was operated for 10 hours a day and the filtration tests were conducted for about 52 weeks. Sewage effluent was used as the feed water. Each morning the module was first backwashed with permeate using compressed air from a container which is initially filled using a bicycle pump. A forward flush of feedwater in combination with a few pulses of compressed air on the permeate side of the membrane is then done. Water production then commenced with continuous filtration all day or sometimes start-stop filtration, simulating use by a person several times a day. When production ceased the tap water valve was closed for a relaxation period until the next morning. These tests showed that the water production rate declined slowly during 10 hours of operation as the membrane became fouled. Failure to perform the daily backwash/ forward flush cycle caused a decrease in water production. Using surface water as the feed water, satisfactory production rates could be maintained for at least two months using this cleaning regime, indicating that membrane fouling was reversible and easily removed. Water quality tests using surface water showed a reduction in turbidity from 100 NTU to less than 0.2 NTU. Colony forming units (22 degrees C) were reduced from more than 1000/mL to 23/mL. Other organisms were reduced to less than 1/mL from initial counts of more than 275/mL (coliforms at 37C), more than 600/mL (E. coli), more than 300/mL (Clostridia), and more than 600/mL (Aeromonas). No bacteriophages were detected in raw water or processed water. The free chlorine concentration in the permeate was 0.2 mg/L. The long-term tests in the laboratory showed no decrease of flow rate (60 L/hour) during 1 year of operation, even with some breaks of 3-4 weeks without production. The solar panel was big enough to provide sufficient back up energy for 3 days of water production. In over 2 years no parts have been replaced or repaired, making the system very reliable.

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