Distribution System Health Study

Researchers in Norway have conducted an epidemiological study suggesting that repairs and maintenance works in water distribution systems are associated with increased risks of gastroenteritis among residents in the area affected by the work (1). The outcome of the study once again raises questions about the role of tap water as a contributor to endemic gastrointestinal disease in developed nations. This study differed from previous investigations of endemic disease because it specifically targeted areas of the distribution system affected by low pressure events. Previous research has highlighted how even transient low pressure events may permit ingress of groundwater, potentially containing enteric pathogens, into water distribution systems (2).

The study was conducted over a 12 month interval in urban areas of Norway with a total population of about 1.1 million. Tap water was provided by seven waterworks which individually served between 35,000 and 460,000 people. During the study the water companies were asked to notify the researchers of low-pressure episodes affecting their service area. Such episodes were defined as events were a section of the water distribution system was closed off, with a presumed loss of water pressure. Episodes could be planned (eg scheduled maintenance) or unplanned (eg spontaneous pipe breaks or damage during construction work).

Each waterworks was asked to identify up to two episodes per month where at least 10 households were affected by low pressure; the first planned episode and the first unplanned episode during the month. When notifiable episodes occurred, the
researchers were contacted and supplied with information on the time and place of the event, the climatic conditions, the reason for the event, any measures taken to prevent contamination, and the location of sewage pipes in relation to water distribution pipes. The waterworks personnel also provided their assessment on the risk of contamination associated with the episode (low, medium or high risk). The waterworks company randomly selected 10 “exposed” households (affected by the low pressure episode) and 10 “unexposed” households (in the same general area but unaffected by the low pressure episode) from its customer register and provided their contact details to researchers. A letter was sent to these households advising that they would be contacted by telephone and asked to participate in the study. The letter requested that one person aged over 16 years be prepared to answer questions on behalf of all household members.

Telephone contact was made with households between 8 and 14 days after the low pressure episode, and a standard questionnaire was administered. Data collected included demographic details of household members, average tap water intake at home, any overseas travel in the last month, whether children attended a daycare centre, employment of household members in kindergartens, the presence of pets or regular contact with other animals. People were asked about gastroenteritis episodes in household members during the week following the low pressure event, and whether they had noticed discoloration or a strange taste in tap water in the last 14 days, or if they thought any work had been done on the water pipes. In order to avoid bias in data collection, the same preliminary letter was sent to both exposed and unexposed households, and interviewers were unaware of the exposure status of the households.

Data from 88 low pressure episodes were included in the statistical analysis, with the number of episodes for individual waterworks ranging from 2 to 24 during the 12 month study. It was estimated that 5,935 households had been exposed to low pressure conditions from these 88 episodes. Some reported low pressure episodes were not able to be included in the study due to lack of interviewing capacity. A total of 612 exposed households and 547 unexposed households were interviewed from a target of 880 households (88 episodes x 10 households in each group). Reasons for missing interviews included inability to establish telephone contact (37%), relocation or no phone number obtainable (21%), refusal to participate (20%) or unknown reasons (15%). Six households (4 exposed and 2 unexposed) were excluded as they were unable to specify the time of gastrointestinal illness in relation to the low pressure episode.

The majority (63%) of low pressure episodes were due to mains breaks or leaks, 26% were due to changes of equipment (valves, pipes), while 11% were due to various other causes (cleaning of pipes, construction near pipes, defective valves etc). Waterworks companies reported flushing pipes to eliminate contamination after 87% of episodes, but only one of the seven companies chlorinated after repair work (performed in 12 of the 14 episodes reported by this company). Water samples were obtained for only 18 low pressure episodes and one was positive for *E. coli*. Householders were not advised to boil water following any of the episodes.

There were no significant differences between exposed and unexposed households in terms of demographics or most non-water related risk factors (e.g., children were in childcare, overseas travel, animal contact etc). More unexposed households had a member who worked in a kindergarten (7% compared to 4% in the exposed group) and this was statistically significant. In both groups, 83% of households reported average water consumption was more than one glass per person per day. The analysis of gastrointestinal illness was performed at the household level with a case household defined as having at least one person experiencing gastrointestinal illness during the observation period (the week following the low pressure episode). Gastrointestinal illness was defined as an episode of vomiting and/or diarrhoea with at least 3 loose stools during a 24 hour period.

There was a significant difference in the reported rate of gastrointestinal illness by exposed households (12.7%) compared to unexposed households (8%).
The crude relative risk (RR) was 1.58 (95% CI 1.1-2.3). Stratified analysis for foreign travel or employment at a kindergarten did not change the RR estimate. Exposed households were significantly more likely to say they believed there had been work/repair of water mains in the last two weeks compared to unexposed households (75% vs 25%, p less than 0.001). Exposed households were also more likely to report they had noticed water discoulouration (29% vs 7.3%), but reporting of bad tasting water was similar in both groups (3.8% vs 4.2%). To test the potential effect of bias due to participants being aware of some problem with the water supply, stratified analysis was carried out. Relative risks for “thought work/repair had been done”, “noticed discoulouration”, or “bad taste of water” were 1.38 (95% CI 0.9-2.1), 1.37 (95% CI 0.9-2.0) and 1.54 (95% CI 1.1-2.2) respectively. These relatively small changes in RR suggest that awareness of a water problem did not have a large influence on the results of the analysis.

Among exposed households there was a significant difference in reported illness rates between households with higher average daily water consumption (more than 1 glass per person) and those with lower water consumption (RR=4.9 95% CI 1.6-15.2). However in unexposed households, illness risks did not differ significantly with reported average water consumption.

When individuals (n=3020) were considered instead of households, the attack rate for gastrointestinal illness was 7.5% in the exposed group compared to 3.9% in the unexposed group (Odds Ratio 2.0, 95% CI 1.3-3.2). Illness rates were similar in males and females. The highest illness rates were seen in children aged 5 years and less (17.7% in exposed households, 10.0% in unexposed households), however the greatest difference between exposed and unexposed groups occurred in adults aged 20-39 years (OR=7.2, 95% CI 2.8-18.7). Symptoms of illness were similar in the exposed and unexposed groups, and most episodes of illness were of short duration (median 2 days, range 1-14 days). Details of individual water consumption were not collected, so it was not possible to assess individual risk in relation to water intake.

When the data for each waterworks were separately analysed, relative risks varied from 0.9 to 2.2. The waterworks with the lowest RR reported only two low pressure episodes during the study so the RR estimate was very imprecise. The next lowest RR of 1.1 was for the waterworks which hyperchlorinated after most low pressure episodes. The remaining five waterworks had RRs ranging from 1.3 to 2.2.

Relative risks were also assessed for different kinds of work or repairs on the distribution system. On univariate analysis a significantly increased RR was observed for swabbing (4 episodes, RR=2.2, 95% CI 1.1-4.2), and a significantly decreased RR for hyperchlorination (12 episodes from one waterworks, RR=0.4, 95% CI 0.2-1.0). Non-significant increases in RR were seen for rain during repair work, prolonged water shut off (more than 6 hours), and water and sewage pipes being in the same ditch. A non-significant decrease in RR was seen for flushing of pipes after repairs. Analysis using a multivariate logistic regression model showed a significantly increased risk for prolonged water shut off (RR=1.9 95% CI 1.0-3.4) and a significantly decreased risk for flushing (RR=0.4 95% CI 0.2-0.8). Of the 88 low pressure episodes examined, none were considered high risk by waterworks personnel, seven were considered medium risk, and the remaining 81 episodes were considered low risk. Medium risk episodes were significantly associated with a higher rate of illness in affected households (RR=1.8 95% CI 1.0-3.2) compared to low risk episodes.

Although all of the water supplies were disinfected with chlorine at their respective water treatment plants, chlorine residual levels in the distribution systems were low and would have had little protective effect against significant contamination ingress. Previous research has shown that even when measurable free chlorine residual is present, inactivation of viral or protozoan pathogens is slow, although bacterial pathogens and indicators may be rapidly inactivated (3). This may explain why E. coli was detected only once among water samples from 18 low pressure events in the Norwegian study despite the increased risk of gastrointestinal illness observed in exposed households.
Overall, the results of the study are consistent with the hypothesis that low pressure episodes permit ingress of enteric pathogens into the distribution system, and that this may result in a subsequent increase in the risk of gastrointestinal infections in consumers in the affected area. The dose-response relationship observed with water consumption among exposed households, and the reduction in relative risk seen with decontamination procedures (hyper-chlorination or flushing after repair work) are also consistent with this model.

The authors note a number of limitations with the study. Firstly, it was carried out in urban areas and may not be applicable to other settings. However rural systems may be even more vulnerable than urban systems due to longer distribution systems. Secondly, water exposures other than drinking were not assessed. For example, the authors suggest that use of tap water to fill small swimming/paddling pools may represent another exposure route contributing to illness rates. The observation period in the study was limited to one week after the low pressure events, so illnesses caused by pathogens with longer incubation periods (such as Cryptosporidium and Giardia) would have been missed, however these organisms are less common causes of gastroenteritis than bacterial or viral pathogens. Households and interviewing staff were not informed of the exposure status in order to minimise the potential for recall bias (over-reporting of illness by exposed households). However, the nature of low pressure events means that many households in the exposed group would have been aware of a recent interruption or problem with the water supply. Stratified analysis suggested this had a relatively minor impact on risk estimates.

One previous study has reported an association between low pressure events and gastrointestinal illness among residents of affected areas (4). Data from the control group in a UK case-control study of cryptosporidiosis was analysed and it was found that households affected by low pressure events in the two weeks before interview had a significantly increased risk of illness in the same period compared to households not affected by such events. However due to the limitations of the study design, the low pressure events relied on reporting by participants without confirmation by water companies, and the time relationship between events and the onset of illness could not be established. Therefore the association between low pressure events and illness could only be regarded as tentative. Other studies of endemic waterborne illness in developed nations have used point-of-use interventions (such as comparison of households with real and sham water treatment devices) to assess the contribution of waterborne pathogens to community gastroenteritis, however the design of such studies means that they measure rates of illness in a relatively large area over a prolonged time period rather than targeting short potential exposure periods in localised areas. This new study establishes a novel approach for assessing the role of transient distribution system contamination in endemic gastrointestinal illness.

The results of the Norwegian study suggest that individuals exposed to low pressure events have an increased risk of illness (7.5% in the week following exposure vs 3.9% for individuals in unexposed households), however it is not possible to extrapolate this to an overall estimate of disease burden as the prevalence of exposure to such events across the whole population is not known. The authors speculate that if 20% of households are affected once per year, then an estimated 33,000 cases of acute gastrointestinal illness may be occurring among the 4.5 million residents of Norway due low pressure events in water distribution systems. The illness burden from distribution system contamination may be higher if transient low pressure events rather than the more prolonged events examined in this study also contribute significantly to ingress of contamination. Conversely, risks may be lowered if water companies routinely use decontamination practices such as hyperchlorination and flushing after repair and maintenance work. If the illness rate in unexposed households represents the “background” gastroenteritis rate from all causes in the general population then it can be estimated that the average rate would be about 2 episodes per person per year or a total of 9 million episodes for the whole population. This is reasonably similar to previous estimates for other developed nations (around 1 case of gastroenteritis per person per year).

Health Stream thanks Dr Nygard for additional information on disinfection practices in the study area.


NHMRC Fluoridation Report

The Australian National Health and Medical Research Council recently published a systematic review of fluoridation (1). The review, released on 14 November, examined English-language publications from 1996 to December 2006. The outcomes of other systematic reviews prior to 2006 were also considered. The aim of the review was to assess the evidence on the caries reducing benefits and associated potential health risks of providing fluoride systemically (via addition to water, milk and salt) and by use of topical fluoride agents (such as toothpaste, gel, varnish and mouthrinse). The potential adverse effects assessed included dental fluorosis, fractures, and cancer. The report also provides background information on environmental sources of fluoride, naturally occurring fluoride levels in water, and fluoride levels in air, soil and food.

An initial broad literature search identified 5418 publications potentially relevant to fluoride and fluoridation. Review of abstracts for these publications reduced this to 408 articles, which were then obtained and reviewed in detail. A total of 77 articles were found to meet the relevance criteria for the systematic review. Articles were classified according to a quality of evidence matrix and then the body of evidence was assessed taking into account the type of epidemiological study designs which could be feasibly applied to each clinical question. For example, although the randomised controlled trial is recognised as providing the highest level of evidence for a single study, this design cannot be applied to water fluoridation as the intervention is made at the population rather than the individual level. The characteristics of the studies examined and the quality of evidence is summarised in an Appendix to the report.

The main findings of the NHMRC review may be summarised as follows:

Dental caries
- there is strong evidence that water fluoridation is beneficial in reducing dental caries,
- fluoridation of milk is probably also beneficial in reducing dental caries, although the quality of evidence is weaker than for water fluoridation,
- the evidence on salt fluoridation is of poor quality and no conclusion can be made on caries prevention,
- topical fluoride products are beneficial in reducing dental caries. Combinations may be more effective than single products.

Dental fluorosis
- there is strong evidence that water fluoridation increases dental fluorosis, however the majority of cases are mild and not considered to be of aesthetic concern,
- there is some evidence that milk fluoridation and salt fluoridation increase dental fluorosis,
- there is some evidence that fluoridated toothpaste increases dental fluorosis. Advice to parents and use of low fluoride toothpaste in young children has reduced the incidence of dental fluorosis.

Fractures
- the evidence suggests either no effect or a slightly beneficial effect of water fluoridation at optimum levels (0.6 to 1 mg/L) on fractures,
- the evidence on milk or salt fluoridation, or topical fluoride products is insufficient to make any conclusions on fracture risks.

Cancer
- There is no clear association between water fluoridation and overall cancer incidence or mortality. Two recent studies showed significant effects on bone cancer, but one study suggested...
an increased risk while the other suggested a decreased risk.

Other adverse effects
- A number of studies of lower quality have examined a diverse range of possible adverse effects, however there is insufficient evidence to draw conclusions on any relationship between water fluoridation or other means of fluoride supplementation and adverse health effects.

In a public statement accompanying the review the NHMRC again endorsed its current position that “fluoridation of drinking water remains the most effective and socially equitable means of achieving community-wide exposure to the caries prevention effects of fluoride. It is recommended that water be fluoridated in the target range of 0.6 to 1.1 mg/L, depending on climate, to balance reduction of dental caries and occurrence of dental fluorosis”.

A few weeks after the release of the report, the Premier of Queensland announced that her government would act to fluoridate drinking water supplies in the state. Queensland has the lowest fluoridation coverage in Australia with less than 5% of the population having access to fluoridated water compared to at least 70% in other states and territories. The prevalence of tooth decay in Queensland children aged 5-12 year is double that of children living in the Australian Capital Territory, which has 100% access to fluoridated water. Within Queensland, tooth decay rates are noticeably lower in Townsville, the only major population centre with fluoridated water.

According to media reports, the state government will provide an estimated $35 million in capital costs for installation of fluoridation equipment while operating costs will be funded by an increase in water prices. The government has set a target of providing fluoridated water to 90% of Queensland residents by the year 2012. The fluoridation program will begin with water treatment plants serving the state capital Brisbane and larger water treatment plants in southeast Queensland.

Waterborne Outbreak In Finland

The town of Nokia in western Finland has been hit by a large waterborne disease outbreak. According to media reports, up to half of the town’s 30,000 residents may have been exposed to contaminated drinking water after a cross-connection resulted in sewage effluent entering the distribution system. The contamination apparently began on 28 November when a worker carrying out repairs opened a valve which separated drinking water from water used to clean the sewage treatment plant. A pressure differential between the systems caused sewage effluent to enter the drinking water supply.

The contamination was not discovered until two days later, around the same time that cases of severe gastroenteritis began to be reported by residents. During the interval an estimated 450,000 litres of filtered sewage effluent had entered the drinking water system. Local police investigating the incident are reported to have said they believe the contamination was accidental, however they are investigating if the pipe which permitted the cross-connection to occur was illegally installed.

Over a thousand cases of gastroenteritis are estimated to have been caused by the contamination, at least 250 people sought medical care and a number have been diagnosed with Campylobacter and Salmonella infections. A boil water alert was issued on 2 December, and the water company began a program of hyperchlorination and flushing to clear the contamination from the distribution system. An extended program of air scouring is also planned, although this will take several months to complete. The Finnish Defence Forces were called in to supply water tankers and assist with door-to-door deliveries of bottled water to residents, and schools were closed for a week. In an effort to limit secondary transmission of infections, health authorities have urged ill people not to return to work or school for at least two days after symptoms have resolved.

The Health ministry admitted that the outbreak had highlighted deficiencies in emergency response procedures, particularly in relation to communication with the public during the crisis. A spokesman for the

National Public Health Institute also said that hospitals and local governments had trouble coping with the outbreak and more resources were needed for outbreak and emergency response programs. The Accident Investigation Board of Finland has appointed a committee to examine the causes of the incident and the subsequent response by relevant authorities. Nokia was the home of the Nokia Corporation in the days when the main products of the company were paper, rubber and cables, however the current Nokia telecommunications company does not have any operations in the town.

News Items

Water Quality Research Australia Established
Australia’s new national water research centre, Water Quality Research Australia Limited (WQRA) was established as a legal entity on 12 October 2007 with the signing of an agreement between three founding members. Membership now stands at 40 organisations with a diverse mix of industry, research and government agencies. WQRA has been set up to succeed the CRC for Water Quality and Treatment (CRC) when the CRC terminates on 30 June 2008. WQRA is currently seeking a Chief Executive Officer and also invites Expressions of Interest for the position of Chair of the Board of Directors. Information on WQRA can be found at: www.waterquality.org.au

WHO Chemical Safety Guidance
The World Health Organisation has released a guidance document to assist policy-makers, regulators, managers and public health practitioners to evaluate and manage chemical risks in drinking water supplies. The document “Chemical safety of drinking-water: Assessing priorities for risk management” comprises three sections; Part A provides information on assessing priorities and developing and implementing risk management strategies, Part B gives guidance on identifying chemicals of concern for individual water supplies including both natural contaminants and those arising from human activities, and Part C provides more detailed information in a set of appendices. www.who.int/water_sanitation_health/dwq/en/index.html

Naegleria Found in Arizona Wells
A survey of wells operated by the Tucson Water company has found *Naegleria fowleri* present in 12 of 35 wells tested. The “brain-eating amoeba” (as dubbed in local newspaper headlines) has become an issue of concern in the area following the deaths of two young boys in 2002 (See Health Stream Issue 28 p4). Researcher suspect the organism may have colonised the wells as a result of using biodegradable oil in pumps, with the oil providing a food source for bacteria which are in turn consumed by the amoeba. Tucson Water is developing risk management procedures including 3-yearly sampling of wells with water temperatures above 77 degrees F, chlorinating any positive wells, and chlorinating wells before use if they have been offline for 6 months or more. Employees will also be warned to avoid inhalation of water before chlorination.

Bacillus Prompts Bottled Water Warning
The California Department of Public Health issued a warning to consumers on 5 December warning them not drink a particular brand of flavoured water produced in the state and sold nationwide. The warning follows detection of the bacterium *Bacillus cereus* in samples of the water, and one reported case of illness in Illinois possibly associated with the contaminated water. Four flavours of water are affected by the warning. Many toxigenic *B. cereus* strains are capable of producing two types of toxin, each causing distinct symptoms of either vomiting or diarrhoea.

PET Myth Returns
The urban myth that re-filling plastic drink bottles poses a risk of exposure to cancer-causing chemicals has been revived by an email circulating in Australia. According to media reports the email cites a US singer who said on a celebrity chat show that she attributes her breast cancer to drinking water from plastic bottles left sitting in the sun. The email has caused the Plastics and Chemicals Industries Association (PACIA) to once again issue a statement about the safety of PET bottles, and refer to a previous statement by Food Standards Australia New Zealand. (See Health Stream Issue 32 p5 for a report on the PET urban myth).
**From the Literature**

*Web-bonus articles*

Summaries of these additional articles are available in the web page version of Health Stream and are included in the searchable archive at: [www.waterquality.crc.org.au/pubs](http://www.waterquality.crc.org.au/pubs)

**Drinking water arsenic exposure and blood pressure in healthy women of reproductive age in Inner Mongolia, China.**


**Workshop overview: arsenic research and risk assessment.**


**Implications of biofilm-associated waterborne Cryptosporidium oocysts for the water industry.**

Angles ML, Chandy JP, Cox PT et al. (2007) Trends in Parasitology, **23**(8); 352-6.

**Gastroenteritis associated with accidental contamination of drinking water with partially treated water.**


**Intake and risk assessment of nitrate and nitrite from New Zealand foods and drinking water.**


**Domestic rainwater harvesting to improve water supply in rural South Africa.**

Mwenge Kahinda J-m, Taigbenu AE and Boroto JR. (2007) Physics and Chemisty of the Earth, **32**(15-18); 1050-7.

**Impact of bathers on levels of Cryptosporidium parvum oocysts and Giardia lamblia cysts in recreational beach waters.**


**Grand rounds: nephrotoxicity in a young child exposed to uranium from contaminated well water**

Magdo HS, Forman J, Graber N et al. (2007) Environmental Health Perspectives, **115**(8); 1237-41.

**Problems with provision: barriers to drinking water quality and public health in rural Tasmania, Australia.**


**Comparing serologic response against enteric pathogens with reported diarrhea to assess the impact of improved household drinking water quality.**

Crump JA, Mendoza CE, Priest JW et al. (2007) American Journal of Tropical Medicine & Hygiene, **77**(1); 136-41.

**Arsenic**

Comparison of health effects between individuals with and without skin lesions in the population exposed to arsenic through drinking water in West Bengal, India.


In West Bengal, India there are more than 7 million people exposed to arsenic through drinking water at levels much higher than the World Health Organisation (WHO) acceptable limit of 10 micro g/l. Associations have been found between arsenic ingestion and hyper-pigmentation, keratosis of skin, anaemia, burning sensation of the eyes, solid edema of the legs, liver fibrosis, chronic lung disease, gangrene of the toes and neuropathy as well as cancers of skin, lung, liver, bladder, kidney and prostate. Skin lesions generally develop more than 10 years after first exposure and are recognised as the most sensitive end points of chronic arsenicism. However, only 15% to 20% of those exposed to arsenic contaminated water develop skin lesions. This study assessed the prevalence of neuropathy, respiratory illness and eye problems in those with and without skin lesions as a result of arsenic exposure, and compared them with a group of unexposed individuals from an area not affected by arsenic.

This cross-sectional study was conducted between January 2003 and May 2005 and included individuals from five villages exposed to arsenic in West Bengal. There were 373 individuals with skin lesions and 352 without skin lesions from the arsenic exposed area recruited. These individuals ranged from 15 to 70 years of age and had at least 10 years of exposure. Also 389 unexposed subjects aged between 15 and 70 were recruited from a different area. Participants were interviewed using a structured questionnaire which recorded information on lifetime residential history, occupation, diet, and smoking habits. A team of expert physicians with at least 15 years of experience interviewed and examined each participant. Water, urine, nail, hair and blood samples were collected from participants and arsenic concentrations measured.
There were no significant differences between the three groups in terms of age distribution, smoking habits and occupation types. For those in the exposed population (with and without skin lesions) the arsenic content in drinking water and other biological samples was significantly higher ($P<0.001$) when compared with the unexposed group. The difference in arsenic concentration in the drinking water of the exposed group with skin lesions and the exposed group without skin lesions was not significant. However, a significantly higher amount of urinary arsenic was detected in the group without skin lesions, and a significant retention of arsenic in nail and hair was found in the skin lesion group. The arsenic concentration in the drinking water of the exposed study area ranged from 50 to 1188 micro g/L, while that of the unexposed area ranged from 0 to 10 micro g/L. Among the exposed group, those with skin lesions had a higher risk for conjunctivitis (odds ratio) OR: 7.33, 95% CI: 5.05-10.59), peripheral neuropathy (OR: 3.95, 95% CI: 2.61-5.93) and respiratory illness (OR: 4.86, 95% CI: 3.16-7.48) compared to those without any skin lesion. Those without skin lesions in the exposed group showed a higher risk for conjunctivitis (OR: 4.66, 95% CI: 2.45-8.85), neuropathy (OR: 3.99, 95% CI 1.95-8.09) and respiratory illness (OR: 3.21, 95% CI: 1.65-6.26) when compared to arsenic unexposed individuals. The trend test for OR of the three diseases in the three groups was found to be statistically significant.

There was no significant difference in the level of arsenic in drinking water in the groups with and without skin lesions, and this suggests the possibility that genetic variation may be a strong factor in susceptibility to arsenic toxicity. This study provides considerable evidence that ingestion of inorganic arsenic through drinking water is a risk factor for peripheral neuropathy, conjunctivitis and respiratory illness even in exposed individuals who remain lesion free. Those with skin lesions were found to retain much higher levels of arsenic in their nail and hair and excrete much lower amounts of arsenic through urine compared to those without skin lesions. A higher retention of arsenic would be expected to cause more damage to the cells resulting in skin lesions. The authors suggest that those with lower capacity to methylate the inorganic arsenic (which is necessary before it can be excreted in urine) might retain it in the body and as a result develop skin lesions. Comparison of genotyping information between the groups would be required to confirm this hypothesis.

**Arsenic, internal cancers, and issues in inference from studies of low-level exposures in human populations.**

Cantor KP and Lubin JH. (2007) Toxicology & Applied Pharmacology, **222**(3); 252-7.

Most of the evidence showing an association between inorganic arsenic in drinking water and elevated cancer risk for internal organs comes from studies of populations with high exposure levels above 150-200 micro g/L. Findings from epidemiological studies in populations with lower levels of exposure to arsenic in drinking water (below 100 micro g/L) are varied and in general do not show levels of cancer risk that would be expected from linear extrapolation of finding from high exposure studies. This paper discusses statistical aspects of these studies, particularly the effects of exposure misclassification and small study size.

Relatively small errors in assessment of historical exposure to arsenic during relevant exposure periods may have a great effect on the risk that is observed in epidemiological studies. Misclassification can be expressed in terms of specificity (probability that an exposed individual is classified as exposed) and sensitivity (probability that a non-exposed person is classified as non-exposed). Some error in estimating past exposures is unavoidable and when a true risk exists and the misclassification of exposure is non-differential (i.e. similar among cases and non-cases), the risk estimate is typically biased toward the null (no effect). The greater the exposure misclassification, the greater the decrease in the observed risk. This limitation is of particular concern in low-exposure situations where expected excess risk is relatively small and the error in exposure estimates can be of such degree that detection of this small excess is difficult. Many of the low-exposure studies also are small in size which limits their statistical power to detect lower levels of risk.
The authors illustrate the effects of exposure misclassification and sample size using graphs which show the Odds Ratios (ORs) estimated for 2000 computer simulated case-control studies with sample sizes of either 100 cases + 100 controls, or 1000 cases +1000 controls, and sensitivity and specificity levels of 1.0 (no misclassification), 0.9 or 0.7. Simulations were run assuming a true OR of 1.0 (no increase in risk associated with exposure) or 2.0 (a doubling of risk associated with exposure). Each individual case-control study produces an estimate of the true OR (either 1.0 or 2.0), but for small studies there is a considerable overlap in the two OR distributions even when no misclassification occurs. Larger studies produce narrower distributions with little overlap when misclassification is absent, however overlap increases (and ability to distinguish low risk from no risk decreases) as misclassification increases. These factors suggest that estimation of risks for low level arsenic exposure requires studies with large samples size and improved accuracy of exposure assessment. The authors note that such a study is currently underway in the US.

Bacteriophage

Simple and rapid F+ coliphage culture, latex agglutination, and typing assay to detect and source track fecal contamination.

Coliphages are bacterial viruses that infect enteric bacterial species, and have been suggested as a possible alternative to faecal bacterial indicators of water quality, particularly as their properties may more closely resemble those of human viruses. F+ coliphages can be divided into two families, those containing RNA genomes (F+ RNA coliphages) and those containing DNA genomes (F+ DNA coliphages). The F+ RNA coliphages can be serotyped into distinct groups present in human faecal waste (groups II and III) or animal faecal waste (groups I and IV). Current coliphage recovery and detection assays are time consuming, and the aim of this study was to develop, optimize and validate a same-day microbial water quality monitoring assay using F+ coliphages.

The latex agglutination method used involves particles coated with antibodies (or antigens) and visual detection of the binding and clumping of target antigens (or antibodies) with adjacent detector particles. Latex agglutination assays are generally rapid, specific, uncomplicated and inexpensive making them suited for field or laboratory diagnostic kits such as those used to detect adenovirus and rotavirus in stools. Environmental samples generally have low levels of coliphage antigens which means a culture step needs to be used before coliphage detection by particle agglutination. A 180 minute F+ coliphage culture enrichment was developed as a modified version of the 16- to 24-h culture step of EPA method 1601, to rapidly enrich both F+ RNA and DNA coliphages to levels amenable to particle agglutination. Preliminary trials showed that rapid F+ coliphage cultures gave equivalent results to those from EPA method 1601 with overnight enrichment. The enriched F+ coliphage culture is able to be assayed directly by typing, with no plaque purification or centrifugation. Typing was performed on a cardboard card by mixing a drop of coliphage enrichment culture with a drop of antibody-coated polymeric beads as detection reagent. Visual agglutination or clumping of positive samples was found to occur in less than 60 seconds. The CLAT (culture, latex agglutination and typing) assay was found to have sensitivities of 96.4% (185/192 samples) and 98.2% (161/164 samples) and specificities of 100% (34/34 samples) and 97.7% (129/132 samples) for F+ RNA and DNA coliphages, respectively. CLAT accurately detected and subtyped prototype F+ RNA coliphage strains into serogroups I, II, III and IV and did not react with F+ DNA coliphage prototype strains or controls. Using the same panel of F+ coliphage field strains, the CLAT assay had a similar performance and typing alibility as an RT-PCR-probe hybridization assay.

This F+ coliphage CLAT method was found to be simple, rapid and inexpensive and is a novel tool for monitoring the microbiological quality of water and other environmental media. It could be used in developed and developing countries and for identifying and tracking human and animal faecal waste sources.
Biofilms

Prevalence of bacterial pathogens in biofilms of drinking water distribution systems.

Water is normally disinfected prior to being distributed to the consumers and the microbial levels of the water are required to be within set limits when leaving the treatment plant. However, by the time the water reaches the consumers tap the quality may be very different from the quality at the time of treatment. This can often be due to recontamination after treatment as a result of regrowth of sub-lethally damaged bacteria or contamination from bacteria living in biofilms. This study was undertaken to determine the prevalence of Aeromonas, E. coli, Pseudomonas, Salmonella, Shigella and Vibrio in biofilms in drinking water distribution systems in large and small towns and home storage systems in South Africa.

Biofilm samples were collected from September 2001 to August 2002. There were 95 samples collected from two well-serviced urban areas (31 from Pretoria and 30 from Pietermaritzburg), a semi-urban developing community (Botshabelo five tap and 17 bucket samples) as well as other towns with small distribution networks (22 samples). The water from the two urban areas had been treated with chlorination and chloramination whereas the rest of the water was only chlorinated. Biofilm samples (c. 1cm$^3$) were taken using a sterile swab from the inner surface of the service pipe and in the case of the buckets an equivalent sized area was swabbed. Water from the systems was tested for the presence of faecal coliforms. The heterotrophic culturable count was determined for both the water and biofilm phases of the samples. Biofilm samples were analysed to determine the number of potential pathogens (Aeromonas, E. coli, Pseudomonas, Salmonella, Shigella and Vibrio). These pathogens were quantified by the three-tube most probable number (MPN) method using enrichment broths and plating on selective agars.

The heterotrophic culturable counts in the water samples ranged from $1.0 \times 10^4$ to $1.9 \times 10^9$ colony forming units (cfu) per ml and for the biofilms analysis of the same samples between $1.0 \times 10^4$ and more than $1.9 \times 10^9$ cfu cm$^2$. Bacterial biofilms were present on the walls of all of the surfaces tested. Faecal coliforms were found in 7.7% of the tap samples and 23.5% of the buckets. These waters were not in compliance with the South African National Standard. Some sampling points had a variety of potential pathogens isolated at densities up to $10^9$ cfu cm$^2$. Pathogens isolated included Aeromonas, E. coli, Pseudomonas, Salmonella, Shigella and Vibrio. Samples from the larger distribution networks of Pretoria and Pietermaritzberg in general had much lower incidence of pathogens than those from the small towns and Botshabelo. The containers in Botshabelo in general harboured a higher number of pathogens than the tap except for Salmonella.

The partial sequences of the 16S rDNA genes of 74 randomly selected isolates were determined and revealed 5 Acinetobacter, 15 Aeromonas, 4 Enterobacter, 6 Klebsiella, 6 Pantoea and 34 Pseudomonas along with one or two representatives of various other genera. There were no putative Salmonella or Shigella confirmed however, indicating that none of these virulent pathogens could be detected in the drinking water-associated biofilms tested. The Pseudomonas isolates were all very similar to each other, and none of those isolated belonged to the nosocomial pathogens P. aeruginosa or P. mendocina. The selective culture media was found to be not as selective as reported when used for analysis of non-medical samples with a high incidence of false positives. Therefore, bacterial analyses of water based on selective isolation and culturing techniques should be interpreted cautiously. Water needs to be protected from the source to the tap using a comprehensive safety plan. Such a plan should address multi-barrier treatment and integrity of the water distribution systems to avoid pathogens entering the system.

Comment Exposure to the opportunistic pathogens detected in this study also occurs through other routes including food, and may be of public health significance.
Copper

Case study of complaints on drinking water quality: relationship to copper content?

In November 2001, an investigation was undertaken of the origin of health complaints relating to drinking water quality reported by consumers in specific districts of Talca (a city of 175,000 inhabitants located 450km south of Santiago), Chile. Complaints included gastrointestinal (GI) symptoms including vomiting, diarrhoea, abdominal pain and other non-specific subjective symptoms. Drinking water consumed in Talca comes from suppliers who obtain water from local wells. This report tested the hypothesis of a potential association between symptoms and copper (Cu) exposure from drinking water by examining the prevalence of GI symptoms by level of exposure to Cu in drinking water.

Households were grouped into three categories: category 1, two districts with Cu plumbing for tap water where residents reported health complaints; category 2, two districts with Cu plumbing for tap water where residents reported no health complaints and category 3, a district with plastic (PVC) plumbing for tap water where residents reported no health complaints. The final study population consisted of 1778 families: 682 category 1, 700 category 2 and 396 category 3. Participants answered a questionnaire about characteristics of the home (year of construction, years living in the home, type of tap water piping, change of piping system within recent years, etc), demographic data (sex, age and time spent at home), presence of chronic diseases and information on self-perception of symptoms experienced during the last 3 months. A subsample of 80 homes with Cu pipes was randomly selected for water sampling which included 40 homes from areas where GI symptoms were frequently reported and 40 homes of families reporting no GI symptoms. Water samples were taken from the cold water kitchen tap in the early morning at least 8 h after the last use (stagnant water) and after running water for 2 minutes and analysed for Cu concentrations, pH, alkalinity and temperature.

Men in category 1 had significantly higher percentages of GI symptoms than those in category 3. Women in category 1 had significantly higher percentages of GI symptoms than women in other categories. When category 3 was compared to categories 1 and 2, GI symptom reports in category 3 were twofold less than in the other categories (6.6% vs 12.3%, x² = 41.7, p less than 0.0001). There was a significantly greater prevalence of GI complaints reported by the mothers of children less than 12 years in category 1 than in categories 2 (p less than 0.006) and 3 (p less than 0.001). Subjects who lived in homes with Cu pipes reported a significantly higher percentage of abdominal pain and diarrhoea than subjects living in households with PVC piping. Subjects living in homes with Cu piping also had a higher frequency of episodes of allergies, bronchitis and emotional stress. A univariate analysis found that age (x² test, p less than 0.001), sex (x² test, p less than 0.03), category (x² test, p less than 0.001), presence of Cu pipes for the cold water kitchen tap (Fisher test, p less than 0.001), consumption of bottled water (Fisher test, p less than 0.001), and year of construction of home (Fisher test, p less than 0.0001) were all related to GI symptoms. Backward stepwise multiple logistic regression model analysis of the significant variables found in the univariate assessment identified less than 12 years living in the house, female sex, home built during or after 1996 and consumption of less than 200 mL of bottled water were risk factors for GI.

The stagnant Cu concentrations in the drinking water of the households studied were below the US EPA Maximum Contaminant Level Goal (less than 1.3 mg Cu/L). The mean stagnant water Cu concentration was 0.50 ± 0.32 mg/L and running water Cu was 0.06 ± 0.05 mg/L. The mean pH in stagnant water in category 1 was significantly lower than in those from category 2 (6.64 ± 0.11 vs 6.92 ± 0.26 respectively, p less than 0.01). The Cu concentration in stagnant tap water samples was significantly lower in category 2 than in category 1 (0.16 ± 0.13 vs 0.68 ± 0.36, respectively, p less than 0.01). There were 33% and 100% of homes from category 1 and 2 that had less than 0.5 mg Cu/L, respectively.
The data obtained from interviews in Talca suggests that Cu exposure was related to the GI complaints, however measurements of Cu concentration from stagnant tap water samples were below the No Observed Effects Level (NOEL) for acute GI responses to Cu of 2 mg Cu/L determined from human studies. The limitations of this investigation are that participants were aware of the potential Cu problems with local newspapers and television reporting on these matters and public discussion leading to a consensus that symptoms were due to the high Cu exposure from drinking water. Also the health survey was performed about 8 months after the complaints had occurred and the water sampling 6 months after the survey. A second water survey conducted a further 6 months later to check for seasonal differences found similar copper levels. Laboratory studies mimicking the most aggressive water composition found in Talca suggested that stagnant copper levels in new homes might reach 2-3 mg/L, but this would rapidly fall within a few weeks due to natural ageing processes. All homes assessed in the health study were built greater than two years earlier which would make Cu leaching from pipes less likely to contribute to the Cu in drinking water. In addition individuals with Cu piping in their home reported significantly more symptoms not likely to be Cu intake (eg allergies, bronchitis), as well as reporting symptoms plausibly related to copper exposure (eg nausea, vomiting, diarrhoea).

Comment Overall these results suggest the association between copper exposure and illness may have been due to reporting bias as participants were aware of their exposure status and had been influenced by the widespread publicity of the problem. The paper makes no mention of any changes of water source or treatment that may have affected water quality during the relevant period. There is no information on microbial water quality or whether this was investigated and ruled out as a possible reason for the apparent outbreak.

Fluoridation

Socio-economic differences in public opinion regarding water fluoridation in Queensland.


Fluoride added to drinking water is effective in the prevention and reversal of dental caries and is a cost-effective public health intervention. There have been concerns raised about the safety of fluoridation however there is no clear evidence of the negative health effects apart from concerns regarding dental fluorosis. More than 70% of Australians have fluoridated drinking water however in Queensland less than 5% of the population has access to fluoridated drinking water. There is evidence that poor oral health is associated with relatively low socio-economic status (SES) and also that water fluoridation reduces oral health disparities between SES groups. The aim of this study was to measure public opinion about fluoridation of drinking-water supply and to examine associations between support for fluoridation and socio-economic status.

Data was collected in Queensland in July and August 2006 as part of the annual Queensland Social Survey. A representative sample of the Queensland population was surveyed using a computer-assisted telephone interview (CATI) survey. Those interviewed were 18 years or older who at the time of the survey were living in a dwelling unit in Queensland and could be directly contacted on a land-based telephone service. There were three questions in the survey relating to the public’s opinion of water fluoridation which required a “Yes”, “No”, and “Don’t know” response. These questions were: 1. Do you support the idea of adding fluoride to your local drinking water? 2. Do you believe that fluoridation of the water supply is safe? 3. Do you believe that fluoridation of drinking water is effective in the prevention of tooth decay? A range of demographic data was also collected including age, gender, presence of children in the household and the postcode of residence. Residential postcode was used to determine the Socio-Economic Indices For Areas (SEIFA) to investigate the socio-demographic relationships (expressed as quartiles) with public opinion about water fluoridation.
There were 1,220 completed telephone interviews, and 70% of respondents supported water fluoridation of their local supply. There was lower agreement in the 55 year and older age group (63.6%) and higher agreement in the 35-44 year-old age group (77.0%). More than 71% of the total sample agreed that water fluoridation was safe. The lowest agreement was in the 18-34 age group (64.4%) and the highest in the 35-44 year age group (80.4%). The highest percentage of agreement about the effectiveness of fluoridation of drinking water in preventing tooth decay was in the 35-44 year age group with more than 80% agreeing. Logistical regression analysis for each question found that there was a significant association between the SEIFA quartile and response opinion. The top two quartiles were significantly more likely to agree with the statement relating to the support of adding fluoride to local drinking water than the lowest SEIFA quartile. The top two SEIFA quartiles were also significantly more likely to agree with the statement on safety than the lowest quartile. There were age and socioeconomic differences found on the question relating to the effectiveness of fluoride in the prevention of dental decay with 35-44 year olds (OR 1.78; 95% CI 1.15-2.76) and 45-54 year olds (OR: 1.50; 95% CI 1.01-2.22) being more likely to agree with the statement than 18-34 year olds. The two top SEIFA quartiles were more likely to agree with this statement than those in the lowest SEIFA.

There was general support found in this sample of the Queensland population for fluoridation, including its safety and its benefits in the prevention of dental decay. There were significant differences between SES categories for all of the questions asked, with the two highest SEIFA quartiles being more likely to agree with the statements relating to implementation, safety and effectiveness of water fluoridation than the lowest quartile. Those demographic groups that may benefit the most from water fluoridation are the least likely to favour it. Accurate, easy to understand scientific information about water fluoridation needs to be provided to those groups that may benefit the most from its implementation. This paper suggests that the addition of fluoride to public drinking water would be supported by most of the population 18 years and over in Queensland.

Gastroenteritis

Large outbreak of viral gastroenteritis caused by contaminated drinking water in Apulia, Italy, May-October 2006.

An unusually high number of patients with acute diarrhoea were reported by the accident and emergency departments in Taranto, Apulia, Italy at the end of July 2006. A field investigation was conducted and included case ascertainment and descriptive epidemiology, microbiological investigation of stool samples and environmental samples and a case-control study. The outbreak investigation was conducted between July and October 2006 and included hospitals in the entire province of Taranto. A case was defined as a patient with diarrhoea (at least three loose or liquid stools in a day) and one or more of the following symptoms: fever greater than or equal to 38 degrees C, headache, vomiting, abdominal pain and nausea. Of the six hospitals in Taranto, five provided information on patients with acute gastroenteritis. Data was collected retrospectively between May and July and prospectively for August and September 2006. Cases were also reported by the special medical facilities set up for tourists in the summer season.

There were 2,860 patients with gastroenteritis symptoms from 1 May to 30 September 2006 which were either admitted to hospital or seen by the hospitals’ outpatient accident and emergency units. For the same period in 2005 there were only 586 patents with gastroenteritis treated by the same hospitals. The first peak in incidence was seen at the end of June and the second peak at the end of July. By mid-September the number of cases per week was similar to that seen during the same period in 2005. The mean age of cases was 25 years. The highest incidence by town was in the city of Taranto with 9.5 cases per 1,000 inhabitants. There were 361 cases reported by the tourist medical facilities which was significantly more than a year before.

Stool samples were collected from patients and tested for gastrointestinal bacteria and parasites.
Environmental samples were collected and included: tap water from the water distribution system across the whole area affected by the outbreak, sea water and shellfish. The water samples were collected at the local waterworks from major water pipelines and wells, and from tap water in pubs.

A case-control study was conducted to see if there was an association between the occurrence of gastroenteritis and the exposure to one or more risk factors. The case group included 166 gastroenteritis patients treated at the accident and emergency departments of the hospitals in Taranto province between 1 August and 15 September 2006. The control group included 146 non-hospitalised healthy individuals who were resident in the same area as case patients during the study period. Cases were matched by age to controls. Study subjects were interviewed using a standard questionnaire.

Of the 70 stool samples, 34 (48%) were positive for rotavirus and 28 (40%) were positive for norovirus. Of the environmental samples of tap water collected in Taranto city, no faecal indicator bacteria or endotoxins were detected. Of the 44 samples tested, 4 (9%) were positive for norovirus and 11 (25%) for rotavirus. The molecular profiles identified in some tap water samples of rotavirus and norovirus were the same as the ones found in some patients’ stool samples. Sequence analysis showed the new norovirus strain GGII.4 2006a and rotavirus genotype G9. Of the 12 sea water samples, four (33%) were positive for norovirus and one (8.3%) for rotavirus. None of the shell fish samples were positive for bacteria or viruses. The risk factors found to be significantly associated with the onset of acute diarrhoea/gastroenteritis were the use of tap water (OR = 2; 95% CI: 1.23-3.36) and the use of water of uncertain origin in the 72 hours before the onset of symptoms (OR = 3.9; 95% CI: 1.41-10.54).

The epidemiological investigation and the laboratory tests found that the possible source of infection was the drinkable tap water which was contaminated with at least rotaviruses and noroviruses. An extra chlorination treatment of household water supplies was performed starting from the 34th week of 2006 to stop possible contamination of the water. The systematic technical and microbiological investigations of the pipelines and wells of the water distribution systems did not show the source of contamination however technical problems at the local chlorination treatment facilities could not be excluded. This outbreak of viral gastroenteritis is probably the largest one to date associated with drinking tap water in Italy.

Household Interventions


In El Paso County, Texas there are an estimated 3,500 people living in colonias (unincorporated neighbourhoods) who do not have piped water who have poor living conditions and substandard housing. Colonia residents either collect water themselves using available containers or rely on water delivery trucks to fill large open containers outside the home such as discarded 55-gallon drums. A project was conducted to improve the water supply available to households in colonias by providing a 2,500-gallon water storage tank to homes lacking piped water. The tanks were filled by a water delivery truck and pipes were connected to homes so that each household could have running water. The aims of this study were to: evaluate water quality from different drinking water sources used by colonia residents; to evaluate how the intervention (the installation of the large storage tanks) affected drinking water quality; and study how delivery of water affects the quality at various points during the transport of water.

Four contiguous communities of El Paso County, Texas were studied between September 1998 and December 1999 where funding was received to install 102 x 2,500-gallon water storage tanks. Interviews were conducted and data was gathered on water collection, use and storage practices. Data was collected before installation of the intervention, one month after the intervention and nine months after the intervention. Drinking water samples were analysed for residual chlorine, turbidity, total coliforms and Escherichia coli. A series of water
samples were collected between collection and delivery of water by the delivery trucks to examine changes in water quality. Samples were taken from the distribution standpipe where the tanker trucks fill up, the tanker truck once it arrived at the home, and the household’s large storage tank before it was filled with water and after being filled.

Results of questionnaires and drinking water analysis were completed for 35 households before the intervention, 59 households one month after intervention and 34 households nine months after intervention. After the tanks were installed many of the households did not change the source of their drinking water to the large storage tanks. Therefore, the drinking water quality results were combined from the three collection times and compared on the basis of where the household’s drinking water came from. There were 37 samples analysed from households that purchased their drinking water and stored it in a small container (29 from a vending machine and 8 from a store). All of the samples from stores were positive for total coliforms (38% greater than 10 CFU/100ml) and 59% of the samples from vending machines were positive for total coliforms (38% greater than 10 CFU/100ml). There were 43 samples from households that collected drinking water from a municipal supply and stored it in small containers (less than 10gal.). There were 26 (60%) of these samples from small containers that tested positive for total coliforms (35% greater than 10 CFU/100ml). There were 48 samples from households that received their drinking water from delivery trucks with 71% of these samples with total coliform levels greater than 10 CFU/100ml.

Data were compared from 35 households prior to installation of the water storage tanks and 34 households nine months after tank installation to compare pre-intervention and post-intervention drinking water quality. The percentage of samples with total coliforms was found to be higher for the samples collected at the 9-month follow-up visit and the geometric mean of total coliforms was also higher. The percentage of households with adequate free chlorine was equal for samples from baseline and the 9-month follow-up. There were 3 samples positive for E. coli prior to the intervention and one positive sample after the intervention. It was generally found that having adequate residual chlorine resulted in very low total coliform levels. The water quality during transport and delivery by tanker trucks was assessed and water quality generally worsened as the water was taken from the standpipe and delivered to the storage tank. There were 30% of samples taken immediately after water delivery to the home that had high total coliforms (more than 10 CFU/100ml). Mean free chlorine levels were found to drop from 0.43 mg/l, where the trucks filled their tanks, to 0.20 mg/l inside the household’s tank immediately after delivery.

Education of families on safe water treatment and storage in the home, especially for homes not connected to a public water distribution system is recommended. The use of small-mouthed container should be promoted as they allow for easy fill-up and dispensing and prevent people from contaminating the drinking water during storage. It is recommended that households do not drink water directly from large water storage tanks unless chlorine levels are adequately maintained. Where water must be delivered in trucks, the amount of chlorine added to the water should be adjusted to a level that will protect the water quality during storage.

**NDMA**

**Estimation of the total daily oral intake of NDMA attributable to drinking water.**

Changes in US EPS regulations on disinfection by-products are causing some United States drinking water suppliers to switch from free-chlorine to alternative disinfectants such as chloramine. Chloramination may reduce total DBP levels however it may result in the formation of nitrosamines such as N-Nitrosodimethylamine (NDMA). Some early studies have indicated that chloramination may lead to higher levels of NDMA than chlorination. NDMA been classified as a probable human carcinogen. This paper estimates NDMA concentrations in drinking water and food and calculates the average daily dose (ADD) for
ingestion route exposures for the U.S. population. It also estimates the proportional oral intake (POI) of NDMA attributable to the ingestion of drinking water relative to that of NDMA present in food and formed endogenously in the human body. Three age groups were examined: bottle-fed infants (less than 6 months), children (6 months to 17 years) and adults (greater than or equal to 18 years). An exposure model was developed that used NDMA concentration point estimates for each source and parametric distributions of averaging times, exposure duration, intake rates and body weight under the assumption of independence of the parameters.

Food ingestion rates were developed for cereal, dairy, fish, meat, vegetables, beer, powered infant formula and foods high in nitrate and nitrate levels including beets, lettuce, spinach and pork. Drinking water ingestion rates were developed for adults and children and for infants (not accounting for water used to reconstitute powered formula) using mean and standard deviation values. NDMA concentrations in drinking water were estimated from a 2001-02 survey of 21 U.S. and Canadian drinking water treatment plants that reported a range of NDMA levels from below the minimum reporting level (MRL) of $6 \times 10^{-4}$ micro g/L to $2.3 \times 10^{-2}$ micro g/L. A point estimate for NDMA in reconstituted infant formula was calculated to be $8.3 \times 10^{-2}$ micro g/L. The distribution of NDMA concentrations in meat, fish, diary, cereal and vegetables were based on results of European studies conducted between 1987 and 1992. Distributions of NDMA concentrations in beer were developed from values reported in two surveys of North American beers. NDMA concentrations from endogenous formation from the nitrosation of ingested secondary and tertiary amines were estimated from an in vitro study resulting in an estimation of 0.37 micro g NDMA formed endogenously per gram of nitrate/nitrite-rich food.

Bottle-fed infants were found to receive their largest NDMA exposure doses from powdered infant formula reconstituted with drinking water contributing 0.07 micro g/day or 98% of total intake. The largest source of NDMA intake for children (9.96 micro g/day) and adults (23.1 micro g/day) is predicted to be from endogenous formation, contributing 99% of total intake for both age groups. The next largest source of daily NDMA intake for children and adults on average was from meat (0.04 micro g/day), contributing 0.30% of total intake. A sensitivity analysis was performed to measure the potential importance of the model inputs to the variance of the ADD estimates. Results indicated that endogenous nitrosation contributed over 99% to the variance and dominated the overall uncertainty and obscured the contributions of other model parameters. Therefore endogenously formed NDMA was excluded from the final sensitivity analysis.

The estimated Lifetime average daily dose (LADD) of NDMA in drinking water over a 75 year lifespan was estimated at $7.3 \times 10^{-7}$ micro/kg-day. This represented 0.02% to 0.003% of total LADD from all sources depending on whether in vitro or in vivo estimates of endogenous NDMA formation were used in models. Exogenous sources were found to contribute about 2.8% of total exposure, with the remainder due to endogenous production of NMDA. The results from this study suggest that the occurrence of NDMA in finished drinking water for the US population leads to low exposures relative to other ingestion route NDMA sources. The mean concentration of NDMA in drinking water would have to increase about 47-fold for the POI to reach 1% relative to all sources of NDMA included in the model studied here. The NDMA contribution from food is small however it is relatively high compared to NDMA in drinking water. The contribution of NDMA formed endogenously greatly increases the total NDMA encountered and reduces the contribution of contaminated drinking water ingestion to total NDMA exposure.

Comment This study considered only ingested NDMA and thus excluded cigarette smoke which is a significant exposure route in smokers and others exposed to cigarette smoke. The authors note that their estimates are based on limited data but are largely consistent with an independent estimate of NDMA intake performed recently by WHO. NDMA is only one of many nitrosamine compounds that may be present in drinking water or food or produced by endogenous formation.
Nitrate

Nitrate in drinking water and risk of death from colon cancer in Taiwan

Nitrate in drinking water comes from a variety of natural and man-made sources. Several studies have shown a direct relationship between nitrate intake and endogenous formation of N-nitroso compounds (NOCs). Most of these NOC compounds are potent animal carcinogens. This study was undertaken to assess whether \( \text{NO}_3^- \)-N levels in drinking water correlates with colon cancer.

There were 322 municipalities in Taiwan examined in the study. Data on all deaths of Taiwan residents was obtained from 1999 through 2003. The case group included all eligible colon cancer deaths occurring in those between 50 and 69 years. The control group included all other deaths excluding those deaths associated with gastrointestinal disease. Control subjects were pair matched to cases by sex, year of birth and year of death. Information was obtained on \( \text{NO}_3^- \)-N levels in each municipality’s treated drinking water supply. Four finished water samples were collected, one for each season. The municipality of residence for cases and controls, identified from death certificates was assumed to be their source of exposure to nitrate via drinking water.

The final data included 252 municipalities and 2234 colon cancer cases with complete records for 1999-2003. The mean \( \text{NO}_3^- \)-N level in drinking water of colon cancer cases was 0.43 mg/L (SD=0.44) and controls has a mean \( \text{NO}_3^- \)-N level 0.44 mg/L (SD=0.44). Adjusted odds ratios (ORs) and 95% confidence intervals (CIs) for colon cancer death were 0.98 (0.84-1.14) for the group with water \( \text{NO}_3^- \)-N levels between 0.23 and 0.45 mg/L and 0.98 (0.83-1.16) for the group with \( \text{NO}_3^- \)-N levels of 0.48 mg/L or more. The results of this study show no statistically significant association between \( \text{NO}_3^- \)-N levels in drinking water and risk of death from colon cancer. Future studies need more precise individual intake estimates of nitrate through food and water and need to control for personal risk factors such as physical activity and meat and fat consumption.

Comment This ecological study was unable to assess whether people drank tap water or differed in other habits that may have affected cancer risks.

Pesticides

Pesticides in surface drinking-water supplies of the northern Great Plains

In the northern Great Plains of the United States and Canada, pesticides have been found in atmospheric samples, in surface and groundwater and in a variety of food products. Some studies have shown an association between environmental exposure to agricultural chemicals and a number of adverse health outcomes. In this study the potential for occurrence of pesticides in drinking water of residents of 15 rural communities in the northern Great Plans in Canada was assessed.

The drinking water reservoirs and water treatment plants associated with the 15 communities studied were in Manitoba, Saskatchewan and Alberta. Communities were selected where the source of drinking water in reservoirs was mainly from snowmelt and rainfall runoff from agricultural crop lands. Reservoir water samples were collected in 2003 every 2 weeks from early May through mid-August to coincide with the spring application of herbicides and organophosphorus insecticides. Water samples were also collected once before ice formation (October 2003), through the ice in mid-winter (January 2004) and after spring snowmelt runoff (April 2004 and 2005). Simultaneous reservoir and treated drinking water samples were collected in early July 2004 and 2005. Drinking water samples were collected after water treatment at the beginning of each distribution system where water was first accessed for drinking by the community.

Assays were carried out for 45 pesticides and degradation products during the study. Two
insecticides, 27 herbicides and two degradation products were detected in reservoirs used as sources for drinking water. Insecticides were detected infrequently and at concentrations less than 20 ng/L. There were 7 herbicides consistently present in water samples from the 15 drinking water reservoirs. There appeared to be no distinct geographic pattern of herbicide concentration, and detection rates were similar for all three provinces. For six herbicides, concentrations were significantly greater in July sampling than in early spring. Up to 15 herbicides were detected in single reservoir water samples.

On average, water treatment reduced herbicide concentrations in drinking water by 14-86% of those in reservoir water. After treatment there were still 3-15 herbicides remaining in potable water supplies at a combined concentration of less than 2,500 ng/L. Herbicide reduction was highly variable from one site to another and often from one year to another. There appeared to be no apparent differences in herbicide reduction for different water treatment procedures. The single facility with membrane filtration however had the highest average percent reduction for three of the five herbicides found in drinking water at that facility. Drinking water guidelines have been established for only seven of the herbicides commonly found in drinking water. The individual herbicide concentrations found here were mostly one to three orders of magnitude lower than established guidelines. Drinking water guidelines however have not been established for exposure to mixtures of pesticides. The toxicity of mixtures of pesticides in water may be different from the sum of the toxicities of the single compounds if synergistic effects occur.

Management practices could be implemented in small reservoirs to reduce concentrations of pesticides. This would require cooperation of the land owners who farm the catchments surrounding reservoirs. To reduce deposition of application drift to reservoirs, decreased aerial application of pesticides near drinking water reservoirs is required along with spraying when wind speeds are optimal and use of precision applicators. Concentrations in runoff to reservoirs could be reduced through use of pesticides with lower water solubility.

Public Perception

A qualitative exploration of the public perception of municipal drinking water.

In Canada and the USA use of alternative water sources including bottled water and water treatment devices is commonplace and sales continue to rise. In Canada there have been a number of epidemics of waterborne gastrointestinal illness and boil water advisories in recent years. Several studies have suggested that alternative water is being used as it has perceived improvements in sensory quality and safety over regular tap water. A more detailed understanding of alternative water use and the perceptions of municipal drinking water is needed. The purpose of this study was to explore the drinking water perceptions and self-described behaviour and needs of participants served by municipal water systems in the City of Hamilton, Ontario, Canada.

Three focus groups were conducted in September 2003 with English-speaking adult residents of the City of Hamilton who were supplied by a municipal system. Two focus groups were conducted with men and women between 36 and 65 years of age (n=7 for each group) and one with men and women between 20 and 35 years of age (n=6). The focus groups were moderated by a trained facilitator and gathered data regarding participant perceptions of water quality, alternative water sources and their self-identified need for information regarding drinking water.

Convenience was the most common reason cited for bottled water use, but some participants used bottled water as they considered it to be superior in taste and safety compared to regular tap water. Some of the participants were concerned that off-colours and odours of tap water were suggestive of problems with water safety. The use of water treatment devices was common and many participants perceived these devices to be safer than regular tap water. There was much discussion of the perceived benefits of treatment devices however only one participant mentioned the possible problems that can result with
water quality if these devices were not properly maintained. Participants reported that marketing influenced societal perception of tap water and consequently the use of alternative water sources. Negative effects on the perception of tap water by children were considered important. Some participants showed trust and support for water utility employees in the City of Hamilton however many in the wake of the Walkerton *E. coli* outbreak were suspicious and sceptical regarding the abilities and integrity of these employees and the safeguards in the system. Concerns about the municipal water system were wide ranging and included: source water protection, water treatment and testing and the distribution system.

Participants stated they were largely uninformed regarding municipal water testing and treatment and indicated a keen desire for more information regarding all aspects of water testing as well as the treatment process, its efficacy and what health hazards might remain after water treatment. The participants in the study were unaware that much of this information is currently available on the City of Hamilton’s website. Participants required information in clear language without scientific jargon. Participants obtained information about drinking water using a variety of media including newspapers, flyers, television, radio and the internet.

This study provided a more in-depth understanding of participants’ perceptions of drinking water in the City of Hamilton. There were some positive perceptions however there were wide-ranging concerns about the municipal water system and many reasons for alternative water use. The collection of valid and reliable information regarding the perceptions of drinking water is essential to the development of effective public education programs, water utility strategic planning and drinking water policy. These focus groups demonstrated that some residents had serious concerns about tap water, and further research is needed to evaluate how representative these views are of the whole community.

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Health Stream Issue 48 - Web bonus articles

Arsenic

Drinking water arsenic exposure and blood pressure in healthy women of reproductive age in Inner Mongolia, China.


High levels of drinking water arsenic exposure have been associated with various adverse health outcomes including cancers. The potential health effects at lower levels of drinking water arsenic are of interest also. Two previous studies have examined the relationship between drinking water arsenic and elevated blood pressure (hypertension) using exposure categories well above the current US maximum contaminant limit of 10 micro g of As/L. This cross-sectional study focused on 6-week post-partum blood pressure levels of women in an area in Inner Mongolia, China known to have a gradient of exposure to arsenic in drinking water. Elevated blood pressure is strongly associated with several forms of cardiovascular disease, and associations between drinking water arsenic and population levels of blood pressure may provide evidence of a cardiovascular effect at lower levels of arsenic exposure than has been previously published.

The health data used in this study was collected from a database of routine prenatal and post-partum healthcare visits in Lin He, Hanggin Houqi and Wu Yuan counties in Ba Men, Inner Mongolia. All of the women had a pregnancy outcome between December 1, 1996 and December 31, 1999. Demographic information including maternal age and body weight was collected during the first prenatal visit. Post-partum information was collected 6-weeks after delivery. Drinking water arsenic exposure was determined for each individual on the basis of 14,866 well-water measurements in 2270 subvillages throughout the study area between 1991 and 1997. Exposure was assessed by matching subjects to the arsenic well-water database. Individuals were assigned exposure categories based on the average well-water arsenic measurements of their subvillage. Exposure categories were as follows (all units in micro g of As/L): below the limit of detection (BLD) to 20; 21 to 50; 51 to 100; and greater than 100. Blood pressure measurements were obtained from the routine prenatal and postnatal health visits. The main health measurement used in this study was the women’s 6-week post-partum blood pressure measurements.

There were 8,790 women with health and exposure information included in the study. Both mean systolic and mean diastolic blood pressures were higher at progressively higher levels of drinking water arsenic ($p$ less than 0.0001). Overall models for both systolic and diastolic blood pressure found a slight but statistically significant increase in blood pressure with each of the different arsenic categories compared to the referent. Crude and adjusted models restricted to women with body weight information available show a similar direction. Increasing arsenic exposure categories from 21 to 50, 51 to 100 and greater than 100 micro g of As/L lead to an increase in systolic blood pressure of 1.88 (95% CI=1.03, 2.73), 3.90 (95% CI=2.52, 5.29) and 6.84 mm Hg (95% CI=5.40, 8.28), respectively compared to women in the referent category (BLD to 20 micro g of As/L). Controlling for age and body weight did not appreciably change these estimates for systolic blood pressure. Diastolic blood pressures showed a similar pattern as arsenic exposure categories increased from 21 to 50, 51 to 100 and greater than 100 micro g of As/L a change of 2.10 (95% CI=1.37, 2.84), 2.72 (95% CI=1.53, 3.92), 3.17 mm Hg (95% CI=1.92, 4.41) respectively was found, compared to women in the referent exposure category. Controlling for age and body weight did not appreciably change the diastolic estimates. For both the systolic and diastolic blood pressure measurements there were statistically significant trends across the arsenic categories ($p$ less than 0.0001).

The study results show a possible dose-response association between drinking water arsenic exposure and elevated levels of systolic and diastolic blood pressure in this population of healthy women of
reproductive age. The results provide evidence of a relationship between drinking water arsenic exposure above 21 micro g of As/L and blood pressure which is a significantly lower exposure threshold than has previously been reported in the literature. The authors note limitations to this study including lack of body weight information for 37% of women, and absence of information on actual water consumption habits. However since even slight changes in the population mean blood pressure can lead to large shifts in risk for cardiovascular events, further investigation of the effects of relatively low levels of arsenic exposure is warranted.

**Workshop overview: arsenic research and risk assessment.**


In May, 2006 the United States Environmental Protection Agency (USEPA) held a workshop entitled “Research and Risk Assessment for Arsenic”. Experts were invited from government agencies, academia, independent research organisations and consultants to present their current research. There have been many advances in the understanding of inorganic arsenic (iAs) toxicity in recent years however, the specific modes of action (MOAs) by which iAs induces its adverse health effects including cancer have not yet been determined. This paper presents a brief overview of the workshop goals, regulatory context for arsenical research, MOA analysis in human health risk assessment and the application of MOA analysis for iAs and dimethylarsinic acid (DMA\(^\text{\text{\textsuperscript{+}}}\)).

The main goals of the meeting were to characterise the current state of the science, suggest how existing data could be used most effectively to assess human health risk and consider future research priorities. There are many regulatory and economic impacts of human health risk assessments for arsenicals. In January 2001 the USEPA promulgated a maximum contaminant level (MCL) of 10 micro g/L based on lung and bladder cancer risk and an MCLG (maximum contaminant level goal) of zero for arsenic as it is classified as a human carcinogen. This Arsenic Rule became effective in January, 2006.

MOA analysis is based on all data available for a compound and knowledge of a specific adverse health effect. The analysis firstly presents a biologically plausible description of the key events which would result in the compound inducing the adverse health effect with the test species. Biological plausibility then needs to be established that these key events can occur in humans, and lastly a quantitative dose-response relationship needs to be defined.

The shape of the dose-response curve for low-dose exposure to iAs has yet to be determined and it is difficult to establish from the available epidemiological studies alone. There are many biological processes that have been identified as being involved in iAs-induced toxicity and carcinogenicity, but as yet there is no consensus on defining a series of key events that meets the requirements of a MOA analysis for humans. In 2001 the National Research Council concluded that even with “extensive research investigating the modes of action of iAs, the experimental evidence does not allow confidence in distinguishing between various shapes (sublinear, linear, supralinear) of the dose-response curve for tumorigenesis at low doses.” Research on MOAs for iAs has been difficult because there are few animal models for iAs-mediated carcinogenesis. Also, a number of different metabolites of iAs may play a key role in toxicity and carcinogenicity but there is an incomplete understanding of which metabolite(s) or mixtures of metabolites mediate the adverse effects.

The main sources of human exposure to inorganic arsenic are drinking water, diet, air and anthropogenic sources such as wood preservatives and industrial wastes. Human are also exposed to organic arsenicals when used as wood preservatives and herbicides (e.g, monomethylarsonic acid, DMA\(^\text{\text{\textsuperscript{+}}}\)). Sufficient evidence now exists for proposal of an MOA for DMA\(^\text{\text{\textsuperscript{+}}}\) leading to bladder tumours in rats through a non-linear pathway, and this is currently under reviewed by the USEPA Science Advisory Board. The proposed MOA for DMA\(^\text{\text{\textsuperscript{+}}}\) identified in
the rat bladder cancer model may also be a plausible MOA in humans.

**Biofilms**

**Implications of biofilm-associated waterborne Cryptosporidium oocysts for the water industry.**


*Cryptosporidium* has been responsible for a number of drinking water disease outbreaks in developed countries. Current management practices to prevent *Cryptosporidium* from entering drinking water supplies are focused on source-water management and water treatment as *Cryptosporidium* is resistant to chlorination. To properly assess the risk of waterborne *Cryptosporidium*, a more detailed understanding of the fate of *Cryptosporidium* oocysts in water distribution systems is required with particular emphasis on the interactions of *Cryptosporidium* in biofilms.

The main aetiological agents of cryptosporidiosis in humans are the species *Cryptosporidium parvum* (predominantly zoonotic) and *Cryptosporidium hominis* (predominantly anthroponotic). The primary hosts for *C. parvum* and *C. hominis* are therefore restricted mostly to cattle, sheep or human faecal sources. Determining the point sources and loads, genotypes and transport of *Cryptosporidium* in source-water catchments is therefore an important step in establishing and managing the risk to the quality of drinking water and to public health. Water treatment is the main physiochemical barrier to preventing *Cryptosporidium* from entering the drinking water distribution system. Treatments such as coagulation, flocculation and sand filtration all reduce *Cryptosporidium* concentrations. Disinfection methods such as membrane filtration and ultraviolet irradiation can further reduce concentrations. *Cryptosporidium* however can still enter drinking water supplies and result in outbreaks of cryptosporidiosis.

Biofilms are an integral part of the water distribution system and form whenever a surface is in contact with water. Both bacterial and viral pathogens can become incorporated in biofilms and it possible that *Cryptosporidium* oocysts may also become incorporated. There is little information in the literature that considers the interaction of oocysts with biofilms. One recent study showed that *C. parvum* oocysts had greater surface deposition on biofilms formed from a monoculture of bacterium *Pseudomonas aeruginosa*, than on clean surfaces with oocysts retained in the biofilms for over 24 h. A study using a mixed population of microorganisms isolated from reservoir water showed that the majority of oocysts introduced to a laboratory-scale reactor attached in clusters in the denser regions of biofilm with a large amount of the surface-associated oocysts remaining viable for at least 15 days. This highlights the possibility that detachment of biofilm-associated viable oocysts may occur at concentrations that represent an infectious dose.

Another study found that the majority of oocysts introduced to a pipe-rig constructed from exhumed 70 year-old drinking water pipes became incorporated into the existing biofilm and were sporadically released from the biofilm. Furthermore oocysts were detected in the water phase up to two weeks post-inoculation. Free chlorine was applied at concentrations typically experienced in a drinking water distribution system downstream of a chlorinated reservoir with little impact on oocyst detachment. Outcomes from this study were confirmed by another set of studies undertaken in laboratory-scale biofilm reactors. An increase in oocyst detachment was found with increased linear flow velocity as might occur during mains flushing or hydrant sampling and oocysts were detected up to 58 days following inoculation; this has implication for distribution system management. The results from the experimental studies and observations during distribution system contamination events do not support hydrant sampling as the sampling procedure itself may cause resuspension of oocysts and lead to a confusing view of system recontamination. Neither the pipe-rig study nor the biofilm-reactor studies assessed the infectivity of oocysts.

It has been proposed that the presence of oocysts in biofilms is of no concern because source-water
loading and treatment removal efficiency determine the number of oocysts in a distribution system with biofilms not contributing to the total oocyst loading in a system. Under such circumstances, effective risk management involves understanding the genotypes of Cryptosporidium that are present in source water, their loads and transport and the effectiveness of treatment processes in removing them. However during unusual conditions that contribute to distribution system contamination, oocysts may accumulate in distribution system biofilms, persist past the initial contamination events in an infectious state and subsequently detach from the biofilms. Under such conditions the ability of oocysts to incorporate into biofilms and sporadically detach raises new risk issues that need to be considered so that more vigorous risk assessments can be undertaken and system managers can make more informed operational decisions. Of great importance is the determination of the factors that contribute to the loss of oocysts infectivity, how long oocysts remain infectious in biofilms and how long the risk remains following a contamination event. Infectivity may be lost rapidly as biofilms may actually reduce the risk from oocyst contamination by incorporation of oocysts into the biofilm. It is also important to quantify the degree of oocyst resuspension and understand the system parameters that contribute the most to oocyst detachment. Further research needs to consider these issues so that effective management of drinking water distribution systems occurs particularly during contamination incidents.

Gastroenteritis

Gastroenteritis associated with accidental contamination of drinking water with partially treated water.

In the Netherlands there are several newly built residential areas that have a dual water distribution system where partially treated surface water (known as grey water) is supplied for household purposes such as toilet flushing, washing machines and garden taps. This paper describes an outbreak of gastrointestinal illness that occurred in a new housing estate in the central part of The Netherlands, where 30,000 households were served by a dual water system. On the 3rd of December 2001, two people living in this estate complained about an unusual odour and taste of the tap water. Tap water samples taken of the 4th of December revealed an abnormal count of total coliform bacteria. Previously on the 29 of November 2001, the drinking water system had been connected to the grey water system in order to flush and clean it after maintenance work. This cross-connection was not removed when the grey water system was operational again and accidental higher pressure in the grey water system caused grey water to circulate into the drinking water pipes. One general practitioner in the affected area on the 6th of December informed the local public health service of an excessive number of patients with nausea, vomiting and diarrhoea attending his practice over the previous days.

A retrospective cohort study was commenced on the 20th of December 2001 where the affected area (area A) was compared to a reference area (area B) in terms of the incidence of households reporting gastrointestinal complaints. The study population included 938 possibly exposed households from area A and 1613 non-exposed households from the adjacent non-exposed area B. Area B also had a dual water system and was similar to the exposed population in regard to socioeconomic status, age distribution and time of residence in the area. In both areas questionnaires collected information on: number of household members; clinical symptoms reported in the household including: diarrhoea, vomiting, nausea, abdominal pain, abdominal cramps, blood in stool, fever, headache, muscle pain, cold chills, itching and coughing and/or sneezing; for each symptom, date of onset in the first ill individual of the household; having one or more of the above symptoms after 9 December; consultation with GP and absence from work or school. Questionnaires also collected information on regular daily water consumption for each individual in the household. In the exposed area another questionnaire assessed compliance with the water boiling advice which was given by the water company on 5 and 6 December.
There were two hundred random households from area A and B who were asked to send in a stool sample, preferably from one person in the household that had symptoms of GE recently. All samples were tested for norovirus (NoV), *Giardia lamblia* and *Cryptosporidium parvum*. Environmental investigations were performed to compare pathogens in stools and water. Samples of drinking water leaving the treatment plant were tested as part of routine analyses and included testing for *E. coli* and coliform bacteria, faecal streptococci and spores of *Clostridium perfringens*. On the 20th of December a 1000 L sample of grey water was tested for NoV.

The incidence of general practice consultations of GE in area A was compared with the incidence of consultations in two control areas (B and C) of the same housing estate during 29 November to 9 December. Two local health centres were selected: one situated in area B that receives mainly patients from areas A and B and the other situated in area C (a more distant area in the same new housing estate, also with dual water system but no exposed to contamination), that mainly receives patients from area C. The incidence of consultations for GE by day and by area of residence was calculated and compared between the three areas.

Of the initial households there were 921 exposed and 1529 non-exposed included in the study. In area A, 223 (54.1%) case-households occurred compared with 117 (24.1%) in area B (RR 2.3, 95% CI 1.9-2.7). The daily incidence of case-households increased during 29 November to 9 December in both areas A and B. All of the symptoms of GE were reported at least twice as often in area A than in area B. In area A, the proportion of case-households increased with the average daily amount of water consumed per individual in the household with a clear dose-response relationship found. A similar trend was also found in area B. There were 31 households from area A that returned stool samples and completed questionnaires and 33 from area B. In area A one sample was positive for NoV genogroup 1, genotype Birmingham and one was positive for *G. lamblia* both samples were from case households. In area B, one sample was positive for NoV genogroup 11 which was collected from a household that reported GE symptoms after 9 December 2001. The drinking water samples taken in area A yielded isolates of coliform bacteria and faecal streptococci. The *E. coli* strains isolated were non-pathogenic. The grey water samples were positive for NoV RNA genogroup 1 at a concentration of 1600 RNA-containing particles per litre.

The general practice study included 1866 inhabitants of area A, 2875 inhabitants of area B and 5788 inhabitants of area C. During the study period, 37 individuals were diagnosed with GE in area A (19.8 cases/1000 inhabitants) compared with 20 (7.0 cases/100 inhabitants) in area B (RR<sub>AB</sub> 2.8, 95% CI 1.7-4.9) and 19 (3.3 cases/1000 inhabitants) in area C (RR<sub>AC</sub> 6.0, 95% CI 3.5-10.5).

The cohort and the general practice study both suggest an outbreak of GE complaints and GP consultations for GE in the area exposed to contaminated drinking water with a clear dose-response relationship with drinking tap water. The results suggest that consumption of drinking water contaminated with grey water increased the risk of acquiring GE. The microbiological evidence was inconclusive however circumstantial evidence suggests NoV may have been responsible for the outbreak with other pathogens involved to a less degree. An outbreak of GE as well as a clear dose-relation with water also was found to occur in the adjacent reference area B although drinking water samples taken in this area showed no evidence of contamination. The authors suggest that this may be explained by some Area B residents visiting or working in Area A, although reporting bias in response to media publicity may also have played a role.

In 2003 the Dutch environmental authorities banned the use of grey water (with the exception of rainwater use for flushing toilets) based on extensive environmental studies and risk assessments. Further studies are being conducted to assess the possible health risk associated with using rainwater.

Comment This outbreak was previously reported in Health Stream Issue 30 p5. The use of the term “grey
water” to describe partially treated but undisinfected surface water in this paper differs from its normal usage in Australia where grey water means wastewater from indoor uses except for toilet waste.

Nitrate and Nitrite

Intake and risk assessment of nitrate and nitrite from New Zealand foods and drinking water.

This paper reports analytical results for nitrate and nitrite concentrations in 100 processed foods and 100 vegetable samples purchased from retail outlets in New Zealand and prepared for consumption. These concentration values were combined with 24 hour diet recall information to estimate individual nitrate and nitrite intake. The contribution from nitrate in drinking water is included at a population level.

There were 100 processed foods selected as food likely to contain nitrite including bacon, ham, saveloys, luncheon sausage, salami, beef sausages, pizza, corned beef, hamburger, ground beef, cottage cheese, cream cheese dip and cheddar cheese. Similarly 100 vegetables were selected as the most likely contributors to dietary nitrate intake including: cabbage, lettuce, silverbeet, spinach, celery, broccoli, watercress, beetroot (canned), potatoes, carrot and pumpkin. The 200 foods were purchased in Christchurch and Auckland over a 3-week period from a range of retail outlets. Samples were prepared as they normally would be prior to consumption. Nitrate data were obtained for 1021 samples collected from 521 drinking water supplies throughout New Zealand. There were 4398 individual estimates of dietary exposure (expressed in mg day\(^{-1}\)), one for each respondent to the 24-h 1997 National Nutrition Survey (NNS). Water consumption was assumed to be 1.5 litres of drinking water day\(^{-1}\) including water based drinks such as tea, coffee, cordial and powdered drinks, and 0.2 litres for water taken up in cooking (e.g. rice and pasta). Population exposures were determined for exogenous nitrate from food and water, nitrite from food, and for total nitrite including a proportion from the endogenous conversion of nitrate. Two conversion factors were applied of 5 and 20% representing average and high levels of conversion from nitrate to nitrite.

Nitrate was found in at least one sample of each food except cheddar cheese and cream cheese based dips where none was detected. Nitrite was detected in half of the processed foods and meats but not in any of the vegetables samples above the limit of detection, apart from broccoli at 27 mg kg\(^{-1}\) nitrite. Levels of nitrate were highly variable within a food type. Dietary exposure to nitrate and nitrite was assessed by combining mean nitrate and nitrite levels from the current survey with 24-h dietary recall information from the NNS and nitrate exposure from water. Water contributed an additional 0.03 mg kg\(^{-1}\) body weight day\(^{-1}\) to nitrate exposure day\(^{-1}\) for 50% of the population. The maximum exposure to nitrate from water was 3.6 mg kg\(^{-1}\) body weight day\(^{-1}\) and shows water may contribute up to 72% of the Acceptable Daily Intake (ADI) for nitrate (0-5 mg kg\(^{-1}\) body weight day\(^{-1}\)) however 99% of the population receive less than 1.0 mg kg\(^{-1}\) body weight day\(^{-1}\). The mean dietary exposure to nitrate from food and water combined was estimated to be 16% of the ADI. The mean dietary exposure to exogenous nitrite (excluding any contribution from the endogenous conversion of nitrate) was approximately 13% of the ADI (0-0.07 mg kg\(^{-1}\) body weight day\(^{-1}\)). When a contribution from the conversion of dietary nitrate to nitrite is included, the ADI for nitrite is exceeded 10% of the time for an average conversion rate (5%) and 50% of the time for those with a high conversion rate (20%).

The mean adult daily intake of exogenous nitrate and nitrite from food and water combined should not pose a health risk for the average consumer. A maximally exposed New Zealand adult is estimated to have an intake of up to seven times the ADI for nitrate and three times the ADI for nitrite. The authors suggest that the current ADI for nitrite needs re-evaluation as those who have a high rate of conversion of nitrate to nitrite may be at risk from the adverse effects of nitrite exposure.
**Rainwater**

**Domestic rainwater harvesting to improve water supply in rural South Africa.**

In South Africa there are 3.7 million people who have no access to any form of water supply infrastructure and an additional 5.4 million people who have some access but still lack a basic level of service. Domestic rainwater harvesting (DRWH) is an alternative for South Africa and involves the collection of water from rooftops, courtyards and similar compacted or treated surfaces, stored in underground tanks (UGTs) or aboveground tanks (AGTs) to be used for domestic purposes, garden watering and small scale productive activities. One of the targets of the 7th Millennium Development Goals (MDGs) is halving the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015. As part of an effort to achieve the MDGs, the South African government has committed to providing financial assistance to poor households for the capital cost of rainwater storage tanks and related works in rural areas. As more people adopt DRWH some critical issues emerge for consideration including the health implications, the sizing of the storage tank and the management strategy.

During the Demonstration Phase of the rainwater harvesting (RWH) pilot program, 64 UGTs were constructed in 26 villages in 4 provinces in South Africa. These tanks collected water from land surfaces, and the water quality is not suitable for potable use. Results of this Department of Water Affairs and Forestry (DWAF) Demonstration Phase showed that the total DWAF investment per household for a 30 m³ tank comes to 22,800 Rand or 3,167 USD.

The main advantage of DRWH is that water is provided on-site to the household and people do not have to walk long distances to fetch water. The quality of the water delivered and used by households is important and influences hygiene and public health. The quality of the water is particularly important due to the large number of people in South Africa who are infected with HIV (estimated at 5.5 million) and who are susceptible to a wider range of common illnesses and diseases than individuals who are not immunocompromised. The impact of waterborne disease in South Africa is significant with an estimated 43,000 deaths every year from diarrhoeal disease, and the annual public and private direct health care costs incurred due to diarrhoea alone of at least 3.0 billion Rand. DRWH has the potential to supply better quality of water at the household level and therefore reduce the water related disease, however data are lacking on water quality and safety. There are two areas of concern about health and DRWH: water quality and possible direct health effects due to contaminants, and insect vector breeding in stored water and potential for vector-borne diseases.

The quality of the harvested and stored rainwater depends on the characteristics of the area including: topography, the weather conditions, proximity to pollution sources, the type of catchment area, the type of water tank, and the handling and management of the water. Sources of contamination of rooftop RWH tanks include: dust from the soil, leaves from trees, repellent insects, chemical deposits and bird droppings. Maintenance of DRWH systems includes periodical cleaning of the catchment area and the interior of the water storage tank as well as the diversion of the first millimetres of rain. Another maintenance procedure involves the periodic addition of a disinfectant such as chlorine to the cistern to kill existing bacteria.

Mosquitoes are the main insect vector than need to be considered in the context of DRWH. Mosquitoes are responsible for various diseases including malaria which is the most common in South Africa. There are three provinces in South Africa affected by malaria that require special measures to prevent the breeding of mosquitoes in the DRWH tanks. Preventive measures are divided into three groups: prevention of mosquito breeding in the surroundings of the tank (chemical and biological measures may be used to kill immature mosquitoes during larval stages), prevention of mosquitoes breeding in the tank, and
Lastly if eggs or larvae are present in the DRWH, various ovicidal and larvicidal measures have to be considered.

The size and design of the water storage tank needs to be considered as the tank cannot be standard due to a number of factors. The water availability needs to be taken into account including rainfall distribution and intensity, the characteristics of the catchment area such as size and land cover and alternative water supplies available. The water requirement also needs to be assessed as South Africa has 5 seasonal rainfall regions and the water requirement varies from one rainfall region to another. The technical constraints need to be considered such as the limitation of space, and suitability of each site for an above ground or below ground tank. There are also socio-economic constraints as most rural households in South Africa are below the poverty line and cannot afford the cost of a rainwater tank.

The current water legislation does not give a clear legal framework for the adoption of DRWH, making DRWH illegal by strict application of the law. Therefore there is a need for clear policy that will provide a framework that will enable more widespread adoption and sustainable use of DRWH. Guidelines on the operation and maintenance of DRWH systems need to be written and provided to rural communities.

DRWH appears to be a promising alternative for supplying freshwater to South African households however the sustainability of DRWH requires close cooperation between the government, the private sector and the rural households as well as an integrated system approach where the quantity and quality of the water supplied as well as the associated costs of implementation are considered.

Recreational waters

Impact of bathers on levels of Cryptosporidium parvum oocysts and Giardia lamblia cysts in recreational beach waters.

US Environmental Protection Agency data from 2006 shows that about 30% of the US population visit coastal areas each year and many go swimming. Use of recreational beach waters provides health benefits but also entails potential health risks from exposure to a variety of viral, bacterial and protozoan pathogens that may be present in the water. Cryptosporidium oocysts and Giardia cysts may enter surface waters from urban runoff, agricultural runoff, wastewater discharges, leaking septic systems, direct faecal waste from wildlife, and human faecal accidents or diapered children shedding protozoa while bathing. Recreational water quality criteria are based on measurement of E. coli or Enterococci with no current requirement for testing of Cryptosporidium and Giardia. This study was undertaken to determine if the number of bathers in a recreational beach area has an effect on the concentration of waterborne C. parvum oocysts and G. lamblia cysts in that area. In order to control for the possible influence of bathers stirring up sediment (which may contain faecal bacteria and possibly pathogens), samples were taken at weekends when bather numbers were high and weekdays when bather numbers were low.

Water samples were collected at the Hammerman Area of Gunpowder Falls State Park (a recreational beach area on the Gunpowder River in Chase, MD, USA) over the months of July, August and September 2006. There were 60 samples collected, three per day within a 1 hour period in mid-afternoon, at three sites within a section of the bathing area. Of these samples, 33 were collected on weekdays and 27 on weekends. As well as water collection, measurements were taken for dissolved oxygen, conductivity, salinity and water temperature. Rainfall data were also obtained for the area. Bathers numbers were counted prior to sample collection and grouped into six categories ranging from 0-1 bathers to 50-68 bathers. Water samples were assessed for turbidity and tested for potentially viable C. parvum oocysts and G. lamblia cysts using the multiplexed fluorescence in situ hybridisation (FISH) method.

The concentrations of both *C. parvum* oocysts and *G. lamblia* cysts were significantly higher during the weekends than during weekdays (two-sample t-test; *P* less than 0.01). The highest weekday value for *C. parvum* was 7 oocysts/L, and all the other 32 weekday samples had 4 oocysts/L or less, with the mean concentration of 1.5 oocysts. The highest weekday concentration for *G. lamblia* was 4 cysts/L, with a mean concentration of 0.6 cysts/L. The weekend concentration for *C. parvum* ranged from 2 to 42 oocysts/L, with a mean concentration of 13.7 oocysts/L. The weekend concentration of *G. lamblia* ranged from 0 to 33 cysts/L with a mean concentration of 9.1 cysts/L. For both of these protozoa, it has been shown that as few as 10 oocysts or cysts from some isolates can cause infection in humans.

The mean water turbidity was 54 formazin attenuation units (FAU) for weekends and 40 FAU for weekdays. Water turbidity values were statistically significantly higher on weekends than on weekdays (two-sample t-test; *P* less than 0.04). Bather category score was also statistically significantly higher on weekends than on weekdays and water turbidity was positively correlated with bather category score (*P* less than 0.01). Both bather category score and water turbidity levels were statistically significantly related to the concentrations of waterborne *C. parvum* oocysts (Pearson correlation; *P* less than 0.04). Bather category scores were found to be statistically significantly related to concentrations of *G. lamblia* cysts (Pearson correlation; *P* less than 0.02). There was one sampling day when levels of *G. lamblia* cysts were quite high and bather numbers were low, however 5 days before this there had been significant rainfall of 10.5 cm. The beach had been closed for several days due to high faecal bacteria levels following this rain event.

This study showed a significant relationship between the number of bathers in recreational water and the concentrations of *C. parvum* oocysts and *G. lamblia* cysts at a recreational beach area. Significantly higher values of concentrations of waterborne *C. parvum* oocysts and *G. lamblia* cysts and turbidity values were found on weekends when numbers of bathers were highest compared to weekdays when numbers of bathers were significantly lower. This study provides evidence that recreational beach areas should be tested when numbers of bathers are greatest. All samples for this study were collected on days determined as acceptable by bacterial standards when the beach was open to the public. Therefore alternative indicators need to be examined to better represent waterborne human-virulent protozoa and predictive models need to include the impact of bathers on the levels of waterborne pathogens. Limiting the number of bathers in recreational beach areas is one way to decrease the impact of bathers on the levels of pathogens in recreational waters.

Comment: Outbreaks attributable to Cryptosporidium and Giardia in natural water bodies are rare compared to swimming pools, and have generally occurred in situations where there is high bather density and a low degree of water mixing and dilution. The degree to which specific pathogens contribute to water-related illness in non-outbreak situations is not certain. Human enteric viruses are suspected to be the major agents of disease, but there are few data to support this assumption. This paper highlights the importance of faecal pollution from bathers in contributing to health risk, an issue which is not addressed in current management practices for recreational waters.

Uranium

**Grand rounds: nephrotoxicity in a young child exposed to uranium from contaminated well water.**


In the United States, groundwater is the main source of drinking water for approximately 42 million people or 14% of households. Groundwater may be contaminated by a wide variety of industrial pollutants and naturally occurring toxic chemicals. Private wells that tap groundwater have been associated with episodes of human exposure to toxic
A clinical assessment was conducted to assess the uranium exposure of family members. A 24-hr measurement of urine uranium was obtained from all family members in October 2000, 4 weeks after ceasing well water consumption. Six weeks after ceasing consumption, an additional 24-hr collection was obtained from the parents in November 2000. At least one urine uranium level was found to be elevated in six of the seven family members with levels ranging from less than 1 micro g/L to 6.2 micro g/L, which is significantly above the mean concentration in the U.S. population of 0.009 micro g/L. When adjustment for urinary volume was considered, uranium excretion ranged from 1.1-2.5 micro g uranium/24 hr. To assess the possible occurrence of renal tubular injury, measurements were made of urine beta-2-microglobulin levels in family members. Elevated beta-2-microglobulin levels were found in five of the seven family members suggesting possible proximal tubular injury.

A urinary beta-2-microglobulin excretion rate (micrograms beta-2-microglobulin per gram creatinine) was calculated. The beta-2-microglobulin excretion rate was normal (less than 40 micro g/mmol creatinine) in all family members except for the 3-year old who had a urinary beta-2-microglobulin excretion rate of 90 micro g/mmol creatinine. Three months after the family had ceased consuming the well-water, the child’s urinary beta-2-microglobulin excretion rate had fallen to 52 micro g/mmol creatinine.

This case study shows the potential for significant residential exposure to naturally occurring uranium in groundwater. The hazards of consuming groundwater from untested private wells are demonstrated here. These observations support the results of previous epidemiological studies showing that chronic low-level exposure to uranium in drinking water may result in mild injury to the proximal renal tubule. This study shows that young children are particularly sensitive to environmental exposure which is a result of the large amount of time they spend in their homes, the developmental immaturity of their kidneys and other organ systems and the large volume of water they consume relative to their body mass. The sensitivity of young children to these environmental exposures needs to be
considered when setting standards for uranium and other chemical contaminants in drinking water.

Water quality

Problems with provision: barriers to drinking water quality and public health in rural Tasmania, Australia.

Having access to safe drinking water is essential to human health however many populations in rural and regional areas within Australia have water supplies of poor quality. In Tasmania, over one-third of the drinking water supplies are unsafe for consumption according to the national guidelines. Most of these supplies are in rural areas. This article discusses key constraints in the protection of public health and the delivery of safe drinking water to rural Tasmanian communities.

Semi-structured interviews were conducted with 12 local government representatives, from each of the rural local government municipalities in Tasmania. The 12 participants had public health responsibilities for the management of drinking water within their municipality. Interviews lasted for on average one hour and participants were asked about their public health roles, processes of risk assessment, regulatory responsibilities and the key barriers affecting the provision of safe drinking water in their municipality.

One of the most important determinants of drinking water safety and quality in Tasmania was found to be locality. Participants identified their rural location as considerably impeding their ability to meet regulatory requirements and provide safe drinking water to communities. All of the participants identified that adequate water supply infrastructure was the key to providing safe drinking water to communities. Most of the participants acknowledged that their council did not have adequate infrastructure and resources required to meet regulatory requirements of the Public Health Act (1997). More than half of the participants identified inadequate infrastructure as a reason for supplying untreated drinking water to their communities. Potential public health solutions to these problems may include in-line filter systems in households, or sustained involvement and contribution of the Tasmanian state government to maintaining and upgrading drinking water supply and treatment systems throughout Tasmania.

All of the participants identified that one of the most important steps in providing safe drinking water is protecting water sources such as catchments from contamination. Ten of the participants stated that competing land and water uses in rural Tasmania was making the protection of drinking water supplies in some Tasmanian municipalities very difficult. More than half of the participants raised concerns over the effect of industries such as forestry and their use of chemicals such as herbicides and pesticides and fertiliser on municipal water sources. Participants believed that testing of drinking water for chemical contaminants, which is not mandatory in Tasmania, was an increasingly relevant issue that needed to be considered by local and state government, particularly in the light of the concerns of competing land uses on water sources. It was highlighted that knowledge of contaminants is itself problematic when there is not an easy solution to the contamination. Possible ways of addressing these issues include introducing integrated catchment management schemes in Tasmania. This would involve various parties and interests in drinking water being brought together to achieve whole-catchment improvements.

Other problems relating to the provision of safe drinking water included the physical and economic feasibility of testing for all drinking water contaminants. Councils have limited income for all services and the rate-paying base of many of the municipalities in low, so financing water provision to meet regulations is a problem. Limited staff numbers is a further problem. Nearly all participants argued that the state government should provide support for basic services such as water as a priority issue.

This study highlights that rural Tasmanians are not being provided with safe drinking water supplies. There is a need for water quality to be given greater
attention and funding by state and federal governments. This study also shows the importance of a holistic and integrated approach to managing drinking water resources in rural Tasmania.

Household Interventions

Comparing serologic response against enteric pathogens with reported diarrhea to assess the impact of improved household drinking water quality.


Evaluations of the health effect of water and sanitation interventions commonly use rates of self-reported diarrheal illness as their main outcome measure. Such measures may be subject to recall bias by study participants that could influence the results obtained. Serologic assays have the potential to provide a more objective and pathogen-specific measure of exposure to enteric infection rather than reported diarrhoea. This paper reports on a randomised controlled trial of household-based drinking water treatment interventions for diarrhoea prevention in rural Guatemala where serology was examined as an alternative outcome measure to diarrhoea prevalence.

The study was conducted between September 2001 and August 2002 in 12 indigenous Kachiquel Mayan villages in a region in the highlands 30 km north of Guatemala City. Those households with an infant less than 12 months of age or a mother in her last trimester of pregnancy were identified in the 12-village area. There were 492 households randomly assigned to 5 different water treatment groups or control. The water treatment groups included: flocculant-disinfection, flocculant-disinfection plus a customised vessel, sodium hypochlorite, and sodium hypochlorite plus a vessel. Diarrhoea prevalence was ascertained during weekly visits by a field worker over a 52 week period. A blood sample was drawn from all study infants greater than or equal to 6 months but less than 12 months of age at study entry and at study end. Serological assays for Cryptosporidium parvum, Giardia intestinalis, enterotoxigenic E. coli (ETEC), and Norovirus were conducted. Height and weight of subjects was measured at entry to the study.

Paired sera were collected from 343 subjects who met the age criteria. The proportion of infant subjects experiencing a serologic response was 24% for C. parvum, 16% for G. intestinalis, 10% for ETEC and 56% for Norovirus. Associations between antibody response and diarrhoea prevalence were examined by comparing illness rates in children with and without a serological response to each of the four pathogens. Only G. intestinalis antibody response was associated with significantly higher diarrhoea prevalence ($P =0.0134$). There were no statistically significant differences in serologic responses to individual enteric infections when infants were grouped by household intervention type (flocculant-disinfectant vs hypochlorite-disinfectant vs control group).

In unannounced evaluations of home drinking water in 10% of households, the detection of free chlorine was higher in intervention groups (27% to 44% of households) compared to the control group (2%). The median free chlorine concentration in all household drinking water was 0.05 (0.01-2.73) mg/L. Serological responses of subjects living in households with drinking water free chlorine concentrations above the median were compared with those with free chlorine concentrations below the median as higher free chlorine concentrations provide evidence of intervention use. There was a trend toward a reduction in ETEC seroconversion being associated with evidence of intervention use (ie free chlorine above median level), however this was not statistically significant. There was no evidence of a reduction in seroconversion rates found for C. parvum, G. intestinalis, or Norovirus with intervention use.

The antibody response to G. intestinalis was significantly associated with diarrhoea prevalence suggesting that this may be a useful parameter in assessing health-effect measures for household-based water intervention studies. The authors comment that
uptake of the assigned interventions appears to have been low as judged by the results of unannounced checks for free chlorine in stored water. This may help to explain why the interventions did not appear to reduce seroconversion rates. Ability to detect seroconversion following infection also depends on the time between blood samples and the persistence of the relevant antibodies. Larger intervention studies are needed in other locations that generate a more distinct effect on diarrhoeal disease, use additional and improved serologic assays and collect serum samples at more frequent intervals.

Comment  Infection may not always lead to detectable seroconversion - for example volunteer studies of Cryptosporidium parvum infection have shown that not all infected individuals will develop circulating IgG antibodies.