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US Waterborne Disease Estimate

A comprehensive summary of research aimed at estimating the extent of waterborne disease in the United States has been published as a Supplement to the Journal of Water and Health. This special issue brings together information from a range of surveillance activities, epidemiological studies and risk assessment modelling to provide an overview and discussion of the evidence linking drinking water with epidemic and endemic disease in developed nations. Many of the studies described were conducted by the US Environmental Protection Agency and the Centers for Disease Control and Prevention in response to the 1996 amendments to the US Safe Drinking Water Act. These amendments required the two agencies to jointly conduct pilot waterborne disease occurrence studies for at least five major communities or public water supply systems, prepare a report on the findings and develop a national estimate of waterborne disease. The research effort focused on acute gastrointestinal illness (AGI) as the most common disease outcome from microbial contamination of drinking water.

An introductory paper describes methods for assessing waterborne risks including an overview of epidemiological study designs, and the interpretation of their findings. This is followed by a summary of reported waterborne disease outbreaks in the US from 1920 to 2002. The next article deals with research studies that have estimated the overall rate of AGI (from all causes) in developed countries. Such studies have produced a broad range of estimates from 0.1 to 3.5 episodes of AGI per person per year. The estimate of 0.65 episodes per person per year from US FoodNet studies is considered to be the most generalisable to the US population.

Five published research studies that have assessed waterborne disease rates through randomly assigned household water quality interventions are reviewed and their results are used to estimate attributable risk (proportion of AGI caused by drinking water). A modelling exercise is then carried out with a range of assumptions about risk levels attributable to source water and water treatment versus distribution systems, and the number of people in the US served by water systems with different risk levels. This produces estimates of 4.26 to 11.69 million cases of AGI attributable to US community water systems each year (although not stated in the paper this can be calculated to correspond to 2.4% to 6.6% of all AGI in the US population served by such water supplies). The authors caution that there are uncertainties of unknown magnitude in their assumptions, but this approach could be refined if better data can be obtained and incorporated in the model.

Another approach to estimating disease risks attributable to drinking water is to observe communities where changes in water treatment are being implemented to determine whether these are accompanied by changes in disease rates or other indicators of AGI. Such studies have given mixed results with some observing a reduction in AGI coinciding with improvements in water quality while others have not. Methodologically these studies are weaker than intervention studies. A number of other epidemiological study designs have been applied to waterborne disease, including cohort studies, case-control studies, time-series analyses and ecological studies. Findings from these observational studies cannot be applied to the national estimate, although further studies of improved design may be useful.

Serological studies may be used to assess population exposures to a number of specific pathogens, and may provide an indication of the importance of water versus other routes of exposure if communities with different types of water supply are compared. A considerable number of serological studies have been carried out in relation to *Cryptosporidium* exposure from water supplies, with overall results suggesting that exposure and infection from surface water supplies may be common but clinical illness rare. This has raised the question of whether frequent low

level exposures may stimulate immunity and lower overall illness rates in immunocompetent people.

Microbial risk assessment can be used to derive estimates of waterborne infection risks for specific pathogens using information on pathogen distribution in drinking water, volumes of water ingested and dose-response parameters. Complex models can incorporate factors such as immunity, asymptomatic infection and secondary infections. Microbial risk assessment cannot be used to derive an estimate of total waterborne AGI but can provide insight on risks for specific pathogens and for different components of the water supply system.

Microbial risks from drinking water supplies must be managed in context with other risks to public health. In addition to estimating the extent of waterborne disease in terms of AGI episodes, it would be desirable to also derive some measure of the severity of disease and the impact on the healthcare system. This "burden of disease" approach can assist the prioritisation of resource allocation for diverse public health problems. A number of methods of measuring health, economic and societal impacts of disease have been developed internationally, and could be applied to waterborne disease if appropriate data are available.

The final paper in the Supplement summarises the outcomes of an expert workshop held in July 2005. The recommendations made under each topic discussed at the workshop are outlined below:

- A National Estimate - future studies should use a standard definition of AGI to ensure comparability of results, and more details should be reported on methods of identifying cases, differentiation of primary and secondary cases, and laboratory investigations. The statistical power of studies should be more clearly described, and calculations of attributable risk should be shown in detail. Future studies should include measures of illness severity such impact on normal activities or medical care required. Improved surveillance for waterborne outbreaks should be encouraged, supported by appropriate clinical, water quality and engineering investigations.

- Epidemiologic and seroprevalence studies - future household intervention studies should be conducted in systems which are highly challenged in source water quality and treatment effectiveness. Particular attention should focus on distribution system risks, and studies should be of double-blinded design. Community intervention studies should address situations that are applicable to a large percentage of the US population, and should have adequate statistical power. Nesting of household intervention studies within community intervention studies should be considered. Case-control studies of AGI (in contrast to AGI from a specific pathogen) should be considered although case identification methods would need to be defined. Additional studies should be carried to estimate the prevalence of waterborne *Cryptosporidium* infection, including the possible benefits of protective immunity. The specificity and sensitivity of serological tests and degree of cross reaction with species other than *C. parvum* need to be assessed.

- Approaches to estimating the risk - modelling of risks from information on background AGI rates could be improved by defining different categories of water systems and the AGI rate for each category. For the Bayesian-Monte Carlo approach, sensitivity analysis should be performed and an estimate should be sought from a panel of non-EPA experts. Microbial risk assessments for selected waterborne pathogens would complement the national estimate. An estimate of the proportion of AGI attributed to water should be made using surveillance data and a similar approach to that previously used for foodborne disease in the US.

- Important data gaps - particular needs were identified with respect to risks for sensitive subpopulations such the profoundly immunosuppressed, risks arising from contamination of the distribution system, risks for groundwater systems and individual systems (ie household wells, bottled water etc). Information is also needed on secondary transmission of waterborne disease, and the characteristics and prevalence of specific pathogens contributing to AGI. A system is needed to categorise key characteristics of water supplies in terms of disease risks in order to derive a national estimate.

Journal of Water and Health (2006) 4 (Suppl 2).

Recreational Water Risks

New WHO Guidelines

The World Health Organisation recently released the second volume of *Guidelines for Safe Recreational Water Environments: Volume 2 Swimming Pools and Similar Environments* (1). The document covers operational guidance and risk management for swimming pools, hot tubs (also known as spas or jacuzzis), plunge pools, physiotherapy pools and natural spas. As for other WHO documents relating to water-related health risks, a preventive management approach is promoted. In this context a “guideline” may comprise:

- a level of management;
- a concentration of a constituent that does not represent a significant risk to the health of members of significant user groups;
- a condition under which exposures with a significant risk are unlikely to occur; or
- a combination of the last two.

The document discusses and provides guidance on the following aspects of risk:

Drowning and injury prevention – the proportion of drownings attributable to recreational water use is likely to vary significantly in different countries. Figures from developed countries show that a large percentage of drowning deaths in children under 5 years of age are associated with home swimming pools and hot tubs. Alcohol consumption is a significant factor in many adolescent and adult drownings. Non-fatal near-drowning events are a likely to exceed the number of fatal events, and may cause long term neurological effects due to oxygen deprivation of brain tissues. Preventive and management measures include adequate supervision of pools, physical barriers to prevent access by young children, design measures to prevent entrapment of body parts and hair in inlets and outlets, and training in rescue and resuscitation. There is no clear evidence that swimming lessons and water safety instruction are effective in preventing drownings.

The severity of spinal injuries associated with diving into shallow water bodies or pools tends to be greater than spinal injuries from other activities as damage usually occurs high in the spine, often resulting in

quadriplegia or paraplegia. Young men under 25 years are at highest risk of sustaining such injuries. Education programs have been shown to be effective in reducing diving-related injuries. Other injuries resulting from slip, trip and fall accidents are also common in and around pools, and can be managed by good design and construction, adequate supervision, warnings and user education.

Microbial hazards – a wide range of pathogenic microorganisms may potentially be present in pools and their surroundings. These may arise from bathers (faecal, respiratory or dermal pathogens) or from environmental sources (opportunistic pathogens). Outdoor pools may also be subject to contamination by animal faeces. A number of pool-related outbreaks from enteric viruses, bacteria and protozoa have been reported in the literature, as well as outbreaks of pharyngo-conjunctivitis from non-faecal strains of Adenovirus. Transmission of such pathogens through pool use is also likely to occur in the absence of recognised outbreaks. Proper operation of disinfection and filtration systems is needed to minimise pathogen levels, and education of parents of young children regarding hygienic behaviour may also be useful in reducing contamination. For incidents of faecal release or vomiting in pools, the only effective management response is to close the pool until the contamination has been removed.

Non-faecal bacterial pathogens that have been associated with outbreaks in hot tubs and thermal pools include *Legionella* species, *Pseudomonas aeruginosa*, *Mycobacterium* species, *Staphylococcus aureus*, and *Leptospira* species. The protozoa *Naegleria fowleri* and *Acanthamoeba* species may also proliferate in warm water and infect bathers. Some viral and fungal infections of the skin may be spread via contaminated surfaces and objects around pools. Management measures include correct disinfection and cleaning practices, encouraging users to shower before entering hot tubs, and limiting the number of users and duration of exposure. High risk individuals (who are immunocompromised or have chronic lung disease) should be warned of the infection risks associated with pools and hot tubs.

Chemical hazards - bathers may be exposed to chemicals in pool water and the atmosphere through ingestion, inhalation or dermal absorption. Chemicals may originate from the water used to fill the pool (disinfection byproducts from tap water), from bathers themselves (urine, sweat, dirt, skin lotions), or from pool management chemicals (disinfectants, pH correction chemicals etc). Concentrations of disinfection byproducts have been reported to vary greatly among pools and may exceed drinking water guideline values. However due to the low amount of ingestion and the intermittent nature of exposure, the risks of DBP exposure from swimming are considered to be small. There have been a number of reports of significant eye and respiratory irritation associated with excessive levels of chloramines and bromamines in the air of indoor pools and hot tubs. People who suffer from asthma appear to be at higher risk of such symptoms. There are also risks associated with malfunctions of plant and equipment that may result in release of chemicals. These can be addressed by proper installation and maintenance, and use of monitoring and warning systems.

Managing air and water quality - encouraging pre-swim showering and toilet use are important measures to minimise the amount of microbial and chemical contamination introduced by bathers into pool water. The correct choice and operation of disinfection and filtration systems is essential to maintain good water quality. Prompt responses are needed for faecal release and vomiting incidents. Small pools and hot tubs should be emptied and cleaned before refilling. Draining of large pools is seldom feasible, but effective cleanup, increasing disinfectant levels or shock dosing, and several filtration cycles should reduce risks before the pool is reopened for use. Given that young children are the most likely source of such contamination incidents, they should if possible be confined to separate small pools which can be readily drained and cleaned. Air quality can be managed by proper control of water quality and adequate ventilation systems.

Guideline implementation - The process of managing and minimising health risks from pools begins with design and construction, and follows through to operation and management of the facility, provision

of ongoing public education and information, and meeting regulatory requirements. In keeping with the philosophy of preventive risk management, each facility should have a pool safety plan which describes the facility and equipment, monitoring and maintenance, normal operating procedures, and procedures for incident and emergency response. Successful implementation of the Guidelines also requires development of an appropriate public health policy and legislative framework.

Exposure Assessment

Application of quantitative risk assessment methods to microbial risks from recreational water requires an estimate of the volume of water ingested during recreational activities. To date there has been little empirical information on which to base such estimates, and current microbial risk assessments from WHO and other regulatory bodies rely on generally accepted assumptions about plausible ingested volumes. A recent pilot study performed by US researchers has provided some quantitative experimental data on recreational water ingestion for child and adult swimmers (2).

The pilot study involved 12 adults (4 male, 8 female) and 41 non-adults (20 male, 21 female) who were recruited at an outdoor community swimming pool. The age distribution of participants was not specified except that adults were 18 years and older, while non-adults ranged from 6 years to less than 18 years. The pool was disinfected with chloroisocyanate, a compound that decomposes slowly to release chlorine and cyanuric acid. Previous studies have shown that more than 98% of ingested cyanuric acid is excreted in the urine within 24 hours of ingestion without being metabolised, and that dermal absorption of this compound is minimal. However existing assay methods for cyanuric acid were cumbersome so the authors carried out preliminary research work to develop a simpler assay method and better techniques for concentrating and cleaning up samples prior to analysis.

Swimmers were asked to swim in the pool for at least 45 minutes on the observation day, and not to swim for 24 hours before and after this swim. They were also requested to void urinate before their swim then

to collect all urine for a period of 24 hours after the swim. Water samples were collected at a depth of 250mm from four locations in the pool before the start of swimming activities. Urine and pool water samples were processed and assayed for cyanuric acid, and then the volume of water ingested by each swimmer was calculated assuming 100% excretion of the ingested dose. The volume of pool water ingested during the 45 minutes of swimming ranged from 0ml to 53ml for adults (mean 16ml) and 0 to 154ml for non-adults (mean 37ml). The difference between mean ingested volumes for adults and non-adults was statistically significant ($p=0.0412$). Females tended to ingest less water than males in both the adult and non-adult groups but these differences were not statistically significant.

The authors note that these observations may not be directly transposable to natural water environments as swimming behaviour may be different, particularly in marine waters. The relatively small number of participants in this study also limits the generalisability of the results. The estimated ingested volumes from this volunteer study are in the same range as those usually assumed for quantitative microbial risk assessment (20 to 50ml per hour of swimming), suggesting that the assumed values used to date to calculate microbial risks are valid. The mean volume of water ingested during 45 minutes by adults in this study (37ml) was considerably less than an estimate (128ml) made in a study of similar methodology in five competitive long distance swimmers during the 1980s. This may reflect a difference in competitive and recreational styles of swimming. The methodology tested in this pilot study will now be applied to a larger study with a more demographically balanced group of participants to enable better characterisation of individual variability and age and gender-related variability.

(1) The Guidelines are available from the WHO website: http://www.who.int/water_sanitation_health/bathing/bathing2/en/

(2) Water ingestion during swimming activities in a pool: a pilot study. Dufour AP, Evans O, Behymer TD and Cantu R. (2006) *Journal of Water and Health* 4 425-430. doi:10.2166/wh.2006.017

IARC Evaluates Nitrate, Nitrite and Cyanobacterial Toxins

The International Agency for Research on Cancer (IARC) recently convened an expert group of toxicologists to consider the evidence for carcinogenicity in humans for nitrate, nitrite and cyanobacterial toxins. Humans may be exposed to these substances through drinking water supplies and through foodstuffs. Levels of nitrate in surface water and groundwater sources around the world have been increasing due to the use of nitrate as an agricultural fertiliser, and cyanobacterial blooms are also becoming more common in some regions due to eutrophication of surface waters and climatic changes that promote cyanobacterial growth.

Where drinking water nitrate levels are below the WHO Guideline value of 50 mg/L, the major dietary source of both nitrate and nitrite is food, particularly vegetables, cereal products and cured meats. Ingested nitrate is absorbed in the gastrointestinal tract then secreted in saliva where it is reduced to nitrite by oral bacteria. In the stomach nitrite may react with nitrogen-containing substances to form N-nitroso compounds, including some which are known carcinogens. These nitrosation reactions are inhibited by the presence of vitamin C and other antioxidants.

Based on the available evidence the expert group concluded that there was “inadequate evidence of carcinogenicity” for nitrate or nitrite in drinking water, and for nitrate in food. However for nitrite in food the group concluded that there is “limited evidence of carcinogenicity” based on the association with stomach cancer in epidemiological studies. A number of animal studies have also assessed exposure to nitrite in combination with secondary or tertiary amines or amides, and most found increased rates of benign and malignant tumours at a range of sites. On this basis, the group concluded that there was “sufficient evidence of carcinogenicity” for nitrite in combination with amines or amides.

Although epidemiological studies have not shown elevated cancer risks for nitrate in drinking water, the group specifically commented that nitrate in water might contribute to nitrosation reactions because it

may be consumed without nitrosation inhibitors. This is in contrast to nitrates from vegetables where nitrosation inhibitors (vitamin C and/or other antioxidants) would be present in the stomach at the same time. The working group also reached an overall conclusion that “ingested nitrate or nitrite under conditions that result in endogenous nitrosation is probably carcinogenic to humans”.

Evidence on both microcystins and nodularins was considered in the evaluation of cyanobacterial toxins. Microcystin is produced by the freshwater cyanobacterial species *Microcystis aeruginosa* while nodularin is produced by *Nodularia spumigena* which occurs in brackish waters. Both toxins act specifically on the liver. Exposure of humans to these toxins may occur through consumption of contaminated drinking water or accidental ingestion of recreational water. In addition, cyanobacteria play an important role in many aquatic food chains, and their toxins may accumulate in the tissues of fish, crustaceans and shellfish which are subsequently consumed by people. There have also been documented instances of microcystin contamination of algal products promoted as health food supplements.

Microcystin LR is the best studied of the cyanobacterial toxins, although it has not yet been subjected to the 2-year chronic exposure bioassay in rodents that is traditionally used to assess carcinogenicity. On the basis of the available evidence, the expert group concluded that microcystin-LR is “possibly carcinogenic to humans”. The evidence for nodularins was judged inadequate to make a decision, and accordingly these toxins were regarded as “not classifiable as to their carcinogenicity”.

A detailed description of the evidence considered by the expert group and their conclusions will be published shortly as an IARC monograph:

Volume 94 Ingested nitrate and nitrite, and cyanobacterial peptide toxins. Lyon: International Agency for Research on Cancer.

Carcinogenicity of nitrate, nitrite, and cyanobacterial peptide toxins. Grosse Y, Baan R, Straif K, et al. (2006) *The Lancet Oncology* 7 628-629.

WHO Seeks Comment On NDMA

The World Health Organisation (WHO) has issued a background document on N-Nitrosodimethylamine (NDMA) in drinking-water as part of the process towards development of a guideline value for this compound. The document was developed by an expert group that met in Geneva earlier this year, and provides an update on new research on NDMA since the last review by WHO in 2002. WHO has invited comments on the document before it is finalised.

NDMA was once used as a feedstock chemical in a range of industries including the manufacture of polymers, fibres and plastics, the production of high-energy batteries, and as an additive to lubricants. It is also formed as a by-product in a variety of industrial processes that use nitrates, nitrites or amines as substrates. NDMA may also be produced as a result of naturally occurring chemical and biological reactions in the environment. Studies as far back as the 1960s and 1970s showed NDMA to be a potent carcinogen in a number of animal species through both the ingestion and inhalation routes. NDMA was shown to act directly on DNA to cause mutations and chromosome breakage, indicating that it should be regarded as a no-threshold carcinogen (ie any level of exposure is theoretically capable of causing genetic damage leading to cancer).

Recognition of the dangers of NDMA exposure led to the introduction of strict occupational health and safety regulations to protect workers, and the gradual phasing out of NDMA production as an industrial chemical in developed countries. However it is still generated as a contaminant in waste from a range of activities including rubber manufacturing, leather tanning, pesticide manufacturing, food processing, foundries, and dye manufacturing. NDMA has also been detected in manure from dairy cattle and in sewage treatment plant effluent.

Surveys of foodstuffs conducted in the 1970s and 1980s showed high levels of NDMA in a number of food items including:

- foods preserved by the addition of nitrate and/or nitrite, such as cured meat products (in particular, bacon) and cheeses
- foods preserved by smoking, such as fish and meat products
- foods dried by combustion gases, such as malt, low-fat dried milk products, and spices
- pickled and salt-preserved foods, particularly pickled vegetables and;
- foods grown or stored under humid conditions, leading to nitrosamine formation by contaminating bacteria.

In 1987 NDMA was classified as “probably carcinogenic to humans” by the International Agency for Research on Cancer. Concerns over possible cancer risks from NDMA and other nitrosamine compounds already present in foods or formed in the stomach by reaction of nitrite with amines led health regulators to introduce measures to reduce exposures from food. However due to the lack of recent surveys of NDMA content in foodstuffs, the extent of current exposure from food remains uncertain. Tobacco smoke is also a significant source of exposure to NDMA.

NDMA in water supplies came to prominence relatively recently when it was detected in Californian groundwaters in the late 1990s as a result of contamination from rocket fuel. Subsequently, NDMA was reported in treated wastewater being used to recharge drinking water aquifers, and in a range of surface water supplies. It is now known that NDMA may be formed as a consequence of both chlorination and chloramination processes depending on the conditions used and the presence of precursor substances. Polyamine coagulants can contribute to NDMA formation during drinking water treatment. Improvements in analytical methods now permit the detection of NDMA at nanogram per litre concentrations, and it has been demonstrated that a number of structurally related N-nitrosamine compounds (possibly with similar carcinogenic properties) may also be present in water. Efforts to reduce population exposures to disinfection byproducts by regulating trihalomethane (THM) levels may paradoxically result in increasing exposures to N-nitrosamine compounds as water suppliers switch from chlorination to chloramination for drinking water disinfection to achieve lower THM values.

There are few economic options for removing NDMA from drinking water. Methods such as activated carbon adsorption, reverse osmosis, air stripping, ozonation, and biodegradation have limited effectiveness for this compound. NDMA can be degraded by UV treatment, however the dose required for 90% removal is reported to be about 10-fold greater than that usually applied for virus inactivation, making this an expensive option.

The WHO expert group constructed a “worst-case” estimate of NDMA exposure from air, water and food. They concluded that in the absence of tobacco smoke an adult would be exposed to 0.005-0.016 NDMA microgram/kg body weight per day, of which 0.0003-0.001 microgram/kg body weight per day would come from drinking water and 0.0043-0.011 microgram/kg body weight per day from food. Thus drinking water is likely to comprise 10% or less of daily NDMA exposure. Consideration of tobacco smoking showed exposure would be greatly elevated if there was regular exposure to environmental tobacco smoke in the home, as this was estimated to contribute 0.05 microgram/kg body weight per day (4 to 10-fold greater than all other sources combined).

The final section of the WHO document describes the derivation of a proposed guideline value for NDMA in drinking water, based on consideration of a study of cancer in rats and using conservative (protective) assumptions. It was estimated that a guideline value of 100 nanograms/L would result in no more than one additional cancer per 100,000 people if each person in the population drank 2 litres of water containing NDMA at this level every day for 70 years. These calculations make no adjustment for possible differences between animals and humans in the kinetics of NDMA metabolism. WHO has specifically requested comment on this aspect of the calculation during its own review process. It is planned that advice on NDMA should be included in the second addendum to the 2004 WHO Guidelines for Drinking-water Quality to be released in 2007.

The NDMA document is open for comment until 30 November 2006.

http://www.who.int/water_sanitation_health/dwq/chemicals/ndma/en/index.html

Fluoridation Of Bottled Water

Bottled water containing added fluoride may soon become available on the Australian market following a surprise decision by the Australasian Bottled Water Institute (ABWI) to make an application to Food Standards Australia New Zealand to permit fluoridation of packaged waters. The ABWI, which represents about 90% of packaged water manufacturers in Australia, has previously argued that there was little consumer demand for fluoridated bottled water. At present the food standards covering packaged mineral water and spring water do not permit the addition of fluoride to such products, although naturally occurring fluoride is allowed at levels up to 2.0 mg/L. Opponents of drinking water fluoridation have criticised the move, stating that the wish to avoid fluoridated tap water was the initial motivation for many people to drink bottled water.

The ABWI has in the past issued statements recognising the benefits of drinking water fluoridation and its importance in maintaining healthy teeth, especially in Australian children, however it has consistently denied that consumption of non-fluoridated bottled water is a significant factor in poor dental health. This view is not shared by the Australian Dental Association which considers regular consumption of fluoridated water to be an important measure to prevent tooth decay. Surveys conducted by the Australian Bureau of Statistics show that 7.6% of Australian households use bottled water as their main source of drinking water.

Fluoride has been classified as being essential to human health due to its role in the prevention of dental caries. Recently this mineral was included for the first time in dietary recommendations issued jointly by the Australian National Health and Medical Research Council and the New Zealand Ministry of Health (*Nutrient Reference Values for Australia and New Zealand: Including Recommended Dietary Intakes (2006)*). The process for Food Standards Australia New Zealand to reach a decision on the application to fluoridate packaged waters may take up to two years to complete, and the process is expected to include a public consultation phase in late 2007.

Call For Recycled Water Ban

A Californian Senator has called for a ban on the use of recycled water on organic crops and possibly all crops following a multi-state outbreak of *E. coli* O157:H7 linked to fresh baby spinach grown in the Salinas Valley. The outbreak has affected at least 187 people in 26 states across the US, with 97 people hospitalised and one death attributed to the outbreak. Twenty-nine of those hospitalised have developed haemolytic-uremic syndrome. A number of other cases and two additional deaths are also under investigation but have not yet been confirmed as attributable to the outbreak strain. The high rate of hospitalisations has led health officials to speculate that this outbreak strain may be a more virulent strain of the pathogen than usually encountered.

The Salinas Valley is a major producer of spinach and other green vegetables and is commonly known as the “salad bowl of America”. The current outbreak of *E. coli* O157 is the ninth outbreak linked to fresh salad vegetables grown in the area over the last decade. Health investigators have been unable to trace the specific source of any of the previous outbreaks. In the current outbreak, several contaminated bags of spinach have been traced back to one company in San Juan Bautista. At present there is no evidence linking this outbreak or any of the previous outbreaks to recycled water from sewage effluent. Advocates of recycled water have pointed out that the treatment and monitoring requirements for recycled water mean that its quality is better controlled and characterised than many other irrigation water sources. Surface water supplies in the region are of poor microbial quality, and most vegetable growers use deep groundwater for irrigation. Some have speculated that local contamination of the aquifer or surface water flooding may be the source of the *E. coli*, and contamination at the packaging stage has not yet been ruled out. The Californian legislature has announced it will hold an inquiry into the outbreak, and will work with industry and the Food and Drug Administration to develop management plans to minimise the risks of further outbreaks.

News Items

House of Lords dismisses arsenic suit

The British House of Lords has dismissed a lawsuit brought against the British Geological Survey (BGS) by a victim of arsenic poisoning in Bangladesh. The plaintiff claimed that the BGS was negligent in not testing well water for arsenic when it carried out a survey of groundwater in central and north east Bangladesh in 1991. Millions of people were subsequently exposed to high levels of arsenic from tubewells constructed by aid agencies in an effort to provide microbiologically safe water. The July ruling by the House of Lords, Britain’s highest court, marks the end of a prolonged series of court cases seeking compensation on behalf of those who have suffered chronic arsenic poisoning from contaminated well water.

Tap water safe to clean wounds

A review of the scientific evidence comparing sterile saline with tap water for washing uninfected wounds has found that there was no significant difference between the two in terms of rates of infection or wound healing. The review was carried out by the Centre for Applied Nursing at the University of Western Sydney for the Cochrane Collaboration, an international collaboration to promote evidence-based healthcare.

Dispute over recycled water ends

A protracted dispute over the use of recycled water at a major industrial complex in Port Kembla, New South Wales has been resolved by a statement issued by the state Minister for Water that the recycled water was no less safe than the current water supply. Commissioning of the 20 megalitres/day recycled water supply for industrial uses at the complex was delayed for nearly a year when the Fire Brigade Employees Union refused to allow its members to use the water for firefighting unless it received a written safety guarantee. During the ban the complex continued to use water from the Avon Dam, part of the Sydney drinking water supply. Experts have pointed out that the recycled water is treated by microfiltration and reverse osmosis, and is of a quality equivalent to drinking water.

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

Cytogenetic damage and genetic variants in the individuals susceptible to arsenic-induced cancer through drinking water.

Ghosh, P., Basu, A., Mahata, J et al. (2006) International Journal of Cancer, **118**(10); 2470-8.

Investigating vomiting and/or bloody diarrhoea in Campylobacter jejuni infection.

Gillespie, I.A., O'Brien S, J., Frost, J.A., et al. (2006) Journal of Medical Microbiology, **55**(Pt 6); 741-6.

Effects of indoor drinking water handling on trihalomethanes and haloacetic acids.

Levesque, S., Rodriguez, M.J., Serodes, J., Beaulieu, C. and Proulx, F. (2006) Water Research, **40**:2921-30.

Daily intakes of copper, zinc and arsenic in drinking water by population of Shanghai, China.

Xu, P., Huang, S., Wang, Z. and Lagos, G. (2006) Science of the Total Environment, **362**(1-3); 50-5.

Development of a health-protective drinking water level for perchlorate.

Ting, D., Howd, R.A., Fan, A.M. and Alexeeff, G.V. (2006) Environmental Health Perspectives, **114**(6); 881-6.

Social perceptions of the impacts of Colombo water supply projects.

Biswas, A.K., Jayatilaka, R. and Tortajada, C. (2005) Ambio, **34**(8); 639-44.

Waterborne microbial risk assessment: a population-based dose-response function for Giardia spp. (E.M.I.R.A study).

Zmirou-Navier, D., Gofti-Laroche, L. and Hartemann, P. (2006) BMC Public Health, **6**:122.

Detection and characterization of hepatitis A virus in water samples in Thailand.

Kittigul, L., Uthaisin, A., Ekchaloemkiet, S, et al. (2006) Journal of Applied Microbiology, **100**(6); 1318-23.

A large outbreak of hepatitis E among a displaced population in Darfur, Sudan, 2004: The role of water treatment methods.

Guthmann, J.-P., Klovstad, H., Boccia, D, et al. (2006) Clinical Infectious Diseases, **42**(12); 1685-91.

Alternative indicators of fecal pollution: Relations with pathogens and conventional indicators, current methodologies for direct pathogen monitoring and future application perspectives.

Savichtcheva, O. and Okabe, S. (2006) Water Research, **40**: 2463-76.

Arsenic

Arsenic exposure from drinking water and risk of premalignant skin lesions in Bangladesh: baseline results from the Health Effects of Arsenic Longitudinal Study

Ahsan, H., Chen, Y., Parvez, F., Zablotska, L., Argos, M., Hussain, I., Momotaj, H., Levy, D., Cheng, Z., Slavkovich, V., van Geen, A., Howe, G.R. and Graziano, J.H. (2006) American Journal of Epidemiology, **163**(12); 1138-48.

Arsenic is recognised as a human carcinogen and there is abundant evidence of cancer and other adverse effects from chronic exposures to high levels in drinking water. However there is little scientific evidence regarding the health effects of low-level arsenic exposure, and estimates of health effects at doses less than 100 microg/L are mainly based on extrapolations from high-dose studies. A prospective cohort study was recently established, the Health Effects of Arsenic Longitudinal Study (HEALS), to investigate the health effects of arsenic exposure for doses ranging from very high to very low in nearly 12,000 men and women in Araidhazar, Bangladesh using individual level exposure assessment. This paper reports on the dose-response relations of exposure to arsenic in drinking water on risk of premalignant skin lesions at the time of recruitment.

Cohort participants were recruited from a population exposed to the full-dose range of arsenic (0.1-864 microg/L) in a 25 km² area southeast of the capital. Potential study participants were visited in their homes by trained study teams and interviewed, including a full dietary instrument. The visit included clinical assessment for skin lesions and other health conditions and collection of blood and urine samples. Subjects were given detailed arsenic exposure information and relevant health education information. Between October 2000 and May 2002 a total of 11,746 participants were recruited. Water samples were collected from all 5,966 tube wells in the study area and analysed for arsenic, and well water usage data was also collected. Urine samples were provided by 11,224 participants for measurement of total urinary arsenic concentration. A structured protocol was followed to ensure

uniformity in the clinical examination of skin lesions on the entire body. There were 714 confirmed cases of premalignant skin lesions identified. Various statistical regression models were used in the analysis. Adjustment was made in all analyses for age, gender, cigarette smoking, socioeconomic status indicators, sun exposure and body mass index.

Males were four times more likely than females to have skin lesions. Older age was positively associated with the risk of skin lesions. A general inverse trend was found for the association between body mass index and skin lesion risk. Risk of skin lesions was also associated with cigarette smoking, hukka smoking (tobacco smoking using water pipes), and markers of socioeconomic status in the rural Bangladeshi population when arsenic exposure was held constant in the analysis. Compared with drinking water containing less than 8.1 microg/L of arsenic, drinking water containing 8.1-40, 40.1-91, 91.1-175 and 175.1-864 microg/L of arsenic was associated with adjusted prevalence odds ratios of skin lesions of 1.91 (95% CI: 1.26, 2.89), 3.03 (95% CI: 2.05, 4.50), 3.71 (95% CI: 2.53, 5.44) and 5.39 (95% CI: 3.69, 7.86) respectively. It was estimated that those exposed to water with an arsenic concentration of 10 microg/L would have a 1.22 times higher risk of developing skin lesions compared with those whose dose was zero. In a cohort of 10,000 people over one year, exposure to 10 microg/L of arsenic from well water could lead to 14 excess cases of nonmalignant skin lesions above the background occurrence typical for this population. Water consumption in this population is high (2.5 to 3 litres/day), and lower risks would be expected for lower consumption levels.

This dose-response effect between arsenic and skin lesion risk was evident in several statistical models used for analysing cross-sectional data. Even those consuming water containing less than 50 microg/L of arsenic (the current permissible limit in Bangladesh and some other countries) had an increased risk of non-malignant skin lesions. The risk seemed to be influenced by gender, age and body mass index for at least a subset of persons. The authors note that gender differences in the risk of skin lesions may reflect differences in sun exposure between men and

women, although gender differences in the metabolism of arsenic cannot be ruled out. Body mass index is an indicator of nutritional status in this population and the association with skin lesions may reflect a mitigating effect of dietary components on arsenic induced damage.

Disinfection Byproducts

Assessment of lifetime exposure to trihalomethanes through different routes

Villanueva, C.M., Cantor, K.P., Grimalt, J.O., Castano-Vinyals, G., Malats, N., Silverman, D., Tardon, A., Garcia-Closas, R., Serra, C., Carrato, A., Rothman, N., Real, F.X., Dosemeci, M. and Kogevinas, M. (2006) *Occupational & Environmental Medicine*, **63**(4); 273-7.

This paper presents data on the exposure assessment component of a multicentre case-control study of bladder cancer conducted in Spain from 1998 to 2001. The study evaluated lifetime exposure to THM through ingestion, inhalation and dermal absorption. Subjects were from 18 hospitals from five areas in Spain. Cases were patients aged 20-80 who were diagnosed with primary bladder cancer who lived in the catchment area of the study hospitals. Controls were hospital patients whose diagnoses were not related to the known risk factors for bladder cancer. Each case was matched to a control by gender, age group and residence area. There were 1219 cases and 1271 controls in the study.

A questionnaire was sent to about 200 water utilities and local authorities requesting current and historical information on DBPs and water treatment. Current and past THM levels were estimated using data on THM levels, water source history (proportion of ground/surface over the years) and the year chlorination was initiated. A computer assisted personal interview was conducted of subjects in hospitals. Information collected included residential history from birth, occupational history from age 16, water source at each residence and job, average daily water consumption, frequency, duration and water temperature of bathing/showering and frequency, duration and location (indoor/outdoor) of swimming pool attendance.

There were four indices of exposure to DBP calculated for the period between age 15 and the time of interview. These included: residential THM exposure, ingestion THM level, THM exposure from bathing and showering, and exposure to DBP from swimming in pools. Estimates of THM levels included 79% of the subjects' person-years of exposure.

The drinking water source at the last residence for controls was municipal water (63%), private well water (2%), bottled water (22%) and water from other sources such as springs, rain water, streams (13%). It was found that 79% of control subjects usually showered, 16% usually took a bath, 4% had a shower or a bath and 1% usually washed using a washbowl. There were 13% of control subjects who reported ever swimming in a pool. The average frequency of swimming pool attendance was 5 times a month with the average swimming duration of 30 minutes.

The average residential THM level was 32.2 microg/L and levels varied by area. Of those subjects considered as unexposed to THM through ingestion in the household, 46% were classified as medium-highly exposed through showering or bathing and 10% were classified as exposed through swimming in pools. There were 80% of subjects who were highly exposed through ingestion in the home who were also evaluated a medium-highly exposed through baths or showers. Average ingestion THM exposures at home and in the workplace were correlated with a Pearson correlation coefficient of 0.61 (based on 524 controls). Correlation restricted to subjects who never drank bottled water was 0.74 (based on 304 controls).

In this population with a relatively stable residential history, the level of individual exposure to these DBP compounds depended on the route of exposure. When evaluating only a single exposure route or situation (e.g. ingestion), misclassification of the total THM exposure may occur. When assessing total DBP exposure, epidemiological studies need to collect individual data on different exposures as well as extensive data on DBP levels in water in order to assess total DBP exposure.

Hardness

Calcium and magnesium in drinking water and risk of death from acute myocardial infarction in Taiwan

Yang, C.Y., Chang, C.C., Tsai, S.S. and Chiu, H.F. (2006) *Environmental Research*, **101**(3); 407-11.

An inverse relationship has been reported between water hardness and cardiovascular diseases (CVD) in several epidemiological studies however the results have not been consistent. This study was undertaken to study the relationship between the level of calcium and magnesium (the main determinants of water hardness) in drinking water and death from acute myocardial infarction (AMI).

There were 322 municipalities in Taiwan suitable to be included in the analysis. Data was obtained from the Bureau of Vital Statistics of the Taiwan Provincial Department of Health in Taiwan on all deaths of Taiwan residents' from 1994 to 2003. The case group consisted of all eligible AMI deaths occurring in people between 50 and 69 years of age. Controls were obtained from other deaths excluding those deaths caused by a variety of other causes which have been previously reported as having negative correlations with hardness levels in drinking water. Control subjects were pair-matched to the cases by sex, year of birth and year of death. Matched controls were selected randomly from a set of possible controls. To be eligible for the study subjects had to have residence and place of death in the same municipality. The Taiwan Water Supply Corporation provided information on levels of calcium and magnesium in each municipality's treated drinking water supply. Four finished water samples, one for each season were collected from each waterworks. For all cases and controls, the municipalities of residence were identified from their death certificate and assumed to be the sources of the subject's calcium and magnesium exposure via drinking water.

There were 10,094 AMI cases included in the study. The mean calcium concentration in the drinking water of cases was 33.6 mg/L (SD=19.5) and the mean magnesium concentration was 11.3 mg/L

(SD=7.6). For controls the mean calcium concentration in the drinking water was 36.3 mg/L (SD=19.1) and the mean magnesium concentration was 11.8 mg/L (SD=7.7). The odds ratios (ORs) for death from AMI were significantly lower for the two groups with high levels of calcium in their drinking water. ORs were only slightly altered by adjustment for confounders. Adjusted ORs (95% CI) were 0.79 (0.73-0.86) for the group with water calcium levels between 25.1 and 42.4 mg/L and 0.71 (0.65-0.77) for the group with calcium levels of 42.6 mg/L or more. The crude ORs for death from AMI were significantly lower than 1, however after adjustment for possible confounders, magnesium intake from drinking water was positively, although not significantly associated with increased risk for death from AMI.

The results from this study show a significant protective effect of calcium intake from drinking water on the risk of death from AMI. Data on an individual's exposure in this study lacked precision as no information was available on water intake (or indeed whether people drank tap water), or calcium and magnesium intake from food. In addition other risk factors for AMI such as socioeconomic factors, access to care, smoking habits, fat consumption, obesity and cholesterol levels were not assessed in this analysis.

Microsporidia

Microsporidian species known to infect humans are present in aquatic birds: Implications for transmission via water?

Slodkiewicz-Kowalska, A., Graczyk, T.K., Tamang, L., Jedrzejewski, S., Nowosad, A., Zduniak, P., Solarczyk, P., Girouard, A.S. and Majewska, A.C. (2006) *Applied and Environmental Microbiology*, **72**(7); 4540-4.

Microsporidians are emerging opportunistic pathogens that infect immunocompromised and immunocompetent people. There is considerable evidence to suggest that water is involved in the epidemiology of human microsporidiosis, however this epidemiological link has not been conclusively established. It is possible that waterborne

microsporidian spores can originate from aquatic birds however this has not previously been investigated. An intensive, long-term monitoring study of a variety of ecologically diverse groups of free-ranging, captive and domestic livestock birds was undertaken to characterise the potential input of human-infectious microsporidian spores from avian hosts.

There were 570 faecal samples collected from randomly selected birds in northwest Poland. The birds represented 57 species, including 13 free-ranging, 45 captive species and three domestic species. To identify species known to infect humans (*Encephalitozoon intestinalis*, *E. hellem*, *E. cuniculi* and *E. bieneusi*), multiplex fluorescently labelled in situ hybridization (FISH) assay was used. This method employs fluorescently labelled oligonucleotide probes targeted to species-specific sequences of 18SrRNA.

Spores of *E. hellem* were identified in 20 of the 570 (3.5%) faecal samples and *E. intestinalis* was identified in one faecal sample (0.2%). Spores of these potentially human-infective species were found in 13 of 224 (5.8%) samples from free-ranging bird, 7 of the 115 (6.1%) samples from captive birds and 1 of the 231 (0.4%) samples from livestock birds. Of the 11 bird species that had potentially human-infective microsporidian spores, 8 were aquatic bird species (common waterfowl species). The prevalence of microsporidian infection in waterfowl (8.6%) was significantly higher than the prevalence of microsporidian infection in other birds (1.1%). The presence of microsporidian spores in the faecal samples was statistically strongly associated with the aquatic status of the avian host species. The overall concentration of human-infectious microsporidian spores in bird faeces was found to be $3.1 \times 10^5 \pm 1.9 \times 10^5$ spores per g. Faeces from waterfowl contained significantly more spores (mean, 2.6×10^5 spores per g) than faeces from nonaquatic birds (mean, 4.4×10^4 spores per g). A model was used to predict the impact of a single waterfowl visitation on surface water. It was estimated that a single visit of a waterfowl flock could introduce approximately 9.1×10^8 microsporidian spores of species known to infect humans.

This study showed that waterborne microsporidian spores of species known to infect humans can originate from common waterfowl. These bird species are often protected by environmental laws and occur in large numbers, have unlimited access to surface waters (including waters used for drinking water) and usually migrate quite long distances. The authors suggest that waterborne transmission of microsporidian spores should be seriously considered in the epidemiology of human microsporidiosis and should be addressed by appropriate agencies and institutions concerned with drinking water quality.

Nitrates

A review of nitrates in drinking water: maternal exposure and adverse reproductive and developmental outcomes

Manassaram, D.M., Backer, L.C. and Moll, D.M. (2006) *Environmental Health Perspectives*, **114**(3); 320-7.

The health hazards from consuming drinking water with nitrate are related to the direct toxicity of nitrate. Nitrate has the ability to directly oxidise haemoglobin, changing it to methemoglobin, which cannot bind oxygen. If the oxidation process overwhelms the protective reduction capacity of the cells then accumulation of methemoglobin occurs. Another concern relating to the metabolism of dietary nitrate is the potential *in vivo* formation of *N*-nitroso compounds from nitrite. Animal studies have demonstrated that nitrate, nitrite and *N*-nitroso compounds may traverse the placenta and have an affect on the foetus *in utero*. This review summarises the experimental and epidemiologic studies on nitrates in drinking water in relation to maternal exposure and adverse reproductive and developmental effects. Sources and occurrence of nitrates in United States drinking water are also discussed.

Experimental animal studies on nitrate or nitrite and adverse reproductive outcomes show some evidence for an association between exposure to nitrate and foetal loss, neonatal mortality, maternal toxicity and decrease in number of litters and live births. The epidemiological evidence for a relationship between

increased risk of adverse reproductive and developmental outcomes in humans and exposure to nitrate in drinking water is sparse and equivocal. Some studies have shown relationships between exposure to nitrates in water and spontaneous abortion, intrauterine growth restriction and various birth defects. However exposure assessment was of poor quality in most studies, and the possible effects of other water contaminants or non-water exposures such as smoking on reproductive outcomes were not controlled for.

The review showed the current literature does not provide sufficient evidence to conclude that a causal relationship exists between exposure to nitrates in drinking water and adverse reproductive effects. Further studies are needed that include individual exposure assessment for drinking water and other sources of nitrate exposure. Studies also need to have an adequate sample size and to evaluate other possible contaminants that may also be associated with reproductive outcomes. Private well users where groundwater is vulnerable to contamination need to be encouraged to increase monitoring or surveillance of such systems, and studies also need to be conducted at an individual level on these private well users. More information is needed to determine whether nitrates in drinking water at the current MCL increase the risk of reproductive and developmental effects.

Perchlorate

Estimates of exposures to perchlorate from consumption of human milk, dairy milk, and water, and comparison to current reference dose

Baier-Anderson, C., Blount, B.C., Lakind, J.S., Naiman, D.Q., Wilbur, S.B. and Tan, S. (2006) *Journal of Toxicology & Environmental Health Part A*, **69**(3-4); 319-30.

There are several sources of human exposure to perchlorate in the environment including ammonium perchlorate, an oxidizing agent in solid rock fuel, air bag inflators, fireworks, and flares. There are also naturally occurring sources of perchlorate such as potash fertiliser, evaporite soils and atmospheric sources. The US Environmental Protection Agency

(EPA) has reported that over 11 million people have perchlorate in their drinking water at levels of 4 ppb or greater. Perchlorate has also been detected in dairy milk and human milk as well as in a variety of other foods. Perchlorate competes with iodine for the sodium (Na^+) iodide (I^-) symporter (NIS), an ion channel in the basal membrane of thyroid follicular cells. If iodide uptake is significantly inhibited then there is decreased production of thyroid hormones T_3 and T_4 . For pregnant women and neonates adequate thyroid hormone production is critical and a relationship has been shown between thyroid hormone adequacy and children's mental development, visual attention, motor skills, perceptual abilities, hearing ability, selective learning and IQ in offspring.

The National Research Council (NRC) recently recommended a reference dose (RfD) for perchlorate of 0.0007 mg/kg-day, based on results of a 2-week human exposure study with 37 health adults. This RfD was recently accepted by the U.S. EPA. Drinking water is not the only source of perchlorate exposure and therefore the evaluation of potential values for the development of a maximum contaminant level (MCL) should be based on the consideration of the relative source contribution of additional exposure routes. This study was undertaken to estimate potential perchlorate daily doses from drinking water, dairy milk and human milk using selected MCL values, and previously published data.

Hypothetical perchlorate daily exposures were estimated using six different scenarios: (1) infants breastfed for 6 months, (2) infants fed formula prepared with tap water over 6 months, (3) 1-year-old children drinking dairy milk for 1 year, (4) 1-year-old children drinking tap water for 1 year, (5) women of child-bearing age consuming dairy milk for 1 year and (6) women of childbearing age consuming tap water for 1 year. Four different perchlorate concentrations were assessed for drinking water (1, 5, 18 and 24 microg/L). As there was no published data describing perchlorate levels in infant formula it was assumed that tap water was the sole source of perchlorate in infant formula.

Infants ingesting either human milk or infant formula made with tap water containing perchlorate at 18 $\mu\text{g/L}$ or higher may have daily perchlorate exposure exceeding the RfD. At some point above this RfD, inhibition of iodine uptake may occur depending on the amount of milk or formula actually ingested, the concentration of perchlorate in each meal, iodine intake and other nutritional factors and many other physiological factors. The consumption of dairy milk by women of childbearing age and by children 1-year-old did not result in the RfD being exceeded, nor did the consumption of tap water containing perchlorate at concentrations ranging from 1 to 24 ppb. However, by adding the estimated daily exposure for 1-year-old children consuming dairy milk containing 9.38 microg/L perchlorate to the estimated daily exposure for 1-year-old children consuming tap water containing 24 microg/L perchlorate, the cumulated estimated daily exposure of 7.55×10^{-4} would be greater than the RfD. Ingestion of perchlorate from other sources such as food could also result in an estimated daily exposure above the RfD. If lower estimates for perchlorate in dairy milk and tap water are used, then the daily exposure would be below the RfD.

Even though the results of this preliminary risk assessment show that the perchlorate RfD may be exceeded for certain breastfed infants it is not suggested that the public health recommendation for breastfeeding be changed. More research is needed to assess the relationship between perchlorate exposure and iodine availability and uptake in the developing foetus.

Uranium

Kidney toxicity of ingested uranium from drinking water.

Kurttio, P., Harmoinen, A., Saha, H., Salonen, L., Karpas, Z., Komulainen, H. and Auvinen, A. (2006) *American Journal of Kidney Diseases*, **47**(6); 972-82.

High natural uranium concentrations can be found in wells drilled in bedrock in certain parts of the world. Ingesting water from these wells may expose populations to high uranium levels. There is some evidence that continuous uranium exposure may

affect the human kidney, particularly the proximal tubular function, and cause kidney damage. This study is an extension of an investigation of kidney effects of ingested uranium from drinking water in Finnish drilled-well users who still use the same drinking water source. This present study aimed to further evaluate the effects of long-term exposure to uranium through drinking water by using more sensitive indicators of nephrotoxicity.

The study group comprises 95 men and 98 women aged from 18 to 81 years who had used wells as the main source of drinking water for an average of 16 years. Samples of water, urine, hair, toenail and non-fasting blood samples were collected between January and April 2003. Uranium in drinking water, urine, hair and nail samples was analysed by using inductively coupled plasma mass spectrometry. Concentrations of *N*-acetyl- γ -D-glucosaminidase (NAD), lactate dehydrogenase (LDH), alkaline phosphatase (ALP), γ -glutamyltransferase (GGT), α -glutathione-S-transferase (GST), creatinine, calcium, phosphate and glucose were measured from urine and cystatin C (CysC), creatinine, calcium, phosphate and glucose were measured from serum. These outcome measures were chosen to evaluate kidney function and cytotoxicity. The associations between uranium exposure and the outcome variables were modelled using linear regression with adjustment for age, sex, body mass index, smoking and analgesic use.

Uranium concentrations in water samples were found to range from 0.03 to 1,500 microg/L, with 31% above 100 microg /L and 55% above 15 microg /L. Median daily and cumulative intakes of uranium from drinking water were 36 microg /d and 180 mg, respectively. Indicators of kidney function and damage were overall mostly within reference values. Uranium concentrations in urine were not statistically significantly associated with indicators of cytotoxicity or tissue damage, renal proximal tubule function or glomerular function. The results were similar for the other uranium exposure indicators (uranium in drinking water, hair, toenail and daily uranium intake). There was a statistically significant association between cumulative uranium intake and glucose excretion in urine, and uranium exposure was statistically significantly associated with increased

diastolic and systolic blood pressures. However the increases on blood pressure were small and no clear hypertension was seen.

Even though this study population had high-level long-term uranium exposure, indicators of cytotoxicity, renal tubular function and glomerular function were within normal ranges and indicated no kidney damage. The lack of effects found in this study may in part be explained by adaptation of kidneys for long-term uranium exposure.

Viruses

Effect of adenovirus resistance on UV disinfection requirements: A report on the state of adenovirus science.

Yates, M.V., Malley, J., Rochelle, P. and Hoffman, R. (2006) *JAWWA*, **98**(6); 93-106.

The US Environmental Protection Agency promulgated the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) in January 5, 2006. The intention of this rule is to reduce the disease incidence associated with the protozoan parasite *Cryptosporidium* and other pathogenic microorganisms in drinking water. The LT2EWTR includes ultraviolet light (UV) dosing. The dosage of UV light required for virus inactions was identified using the most UV-resistant group of viruses currently known; the adenoviruses. Under the LT2ESWTR the UV dose required for 4-log virus removal has been increased from 40 to 186 mJ/cm². This has considerable implications for the cost of UV disinfection which is likely to impact most severely on smaller water supply systems. Concerns have been expressed that the increased UV dose may be overly protective and that use of an exceptionally resistant organism is not appropriate for setting a regulatory standard. This paper summarises discussions from an expert workshop on the issue.

Topics considered included the health effects of adenovirus infection, mechanisms of UV resistance, analytical methods for detection of these viruses, their occurrence in water sources and treated water supplies, and evidence for transmission by water. The authors conclude that considerably more work is

required in order to make a scientific evaluation of the public health significance of adenovirus in terms of drinking water regulation. While use of a “worst case” scenario (a highly UV resistant virus) may appear desirable for public health protection, there may not have been sufficient consideration of the impacts of adopting the new UV regulation on water treatment options for small groundwater systems. Many significant data gaps remain to be filled before the role of drinking water in adenovirus transmission can be adequately evaluated.

The effect of coagulation with MF/UF membrane filtration for the removal of virus in drinking water.

Fiksdal, L. and Leiknes, T. (2006) *Journal of Membrane Science*, **279**(1-2); 364-71.

Low pressure membrane filtration (microfiltration (MF) and ultrafiltration (UF)) are used currently used worldwide for the reduction of particle concentration and natural organic material (NOM) in drinking water. The effectiveness of low-pressure MF/UF as hygienic barriers in drinking water production depends on their ability to retain different types of pathogens and in particular viruses. UF technology has the ability to meet current water regulations for turbidity and *Giardia* however the retention of virus depends on the type of membrane, the membrane characteristics, the module design and operating conditions. If pre-coagulation/flocculation is combined with UF or MF membrane filtration then more efficient virus retention may be expected as viruses are adsorbed to or included in larger flocks that are retained by the membrane. This study investigated the effectiveness of pre-coagulation/flocculation combined with low pressure membrane filtration through polymer UF and MF membranes for virus and NOM removal in drinking water production.

To measure virus retention, the bacteriophage MS2 (ATCC 15597-B1) was seeded to autoclaved tap water. Bacteriophage MS2 is similar in structure to the human enteric viruses hepatitis A and poliovirus. Two commercial aluminium-based coagulants were used in this study (ALG and PAX). Experiments were conducted with two types of raw water, tap

water and NOM enriched tap water. Experiments were conducted in a closed loop where the membrane was continuously fed with virus solution from the reservoir. The efficiency of the virus removal process was defined by a log reduction value (LRV).

Initial virus concentrations ($C_{r \text{ init}}$) in the reservoir were $10^{7.0} - 10^{8.1}$ pfu/mL. Without pre-coagulation/flocculation, virus concentrations in the reservoir ($C_{r \text{ init}}$) and the permeate (C_p) were found to be the same during MF membrane filtration, indicating that virus passed freely through the membrane. When using UF membrane filtration only a minor difference between $C_{r \text{ init}}$ and C_p was found, i.e. an average LRV of 0.5 log after 60 min filtration time. With pre-coagulation/flocculation with ALG and PAX, the average LRV during the filtration period increased to at least 7.1 with a dose of 3 mg Al/L and more than 7.4 with a dose of 5 mg Al/L with UF membrane. High LRV were also found when using the MF membrane with coagulation. Average LRVs were more than 7.2, 6.7, more than 7.4 and more than 7.5 after pre-coagulation/flocculation with dosages ALG3, PAX3, ALG5 and PAX5, respectively using MF membrane filtration. The combined results show there was essentially no virus removal without pre-coagulation/flocculation however when 3-5mg Al/dosages were used for pre-coagulation/flocculation, from 6.7 logs to more than 7.5 logs of virus removal were seen. Apart from the dose PAX3, no virus was detected in the permeate after pre-coagulation and MF membrane filtration. Using UF membrane filtration, the virus concentration in the permeate was 30 pfu/mL or less, but only the PAX5 dose consistently showed no detectable virus in the permeate during the 60 min.

A test was also conducted to evaluate effectiveness of the coagulant-membrane system for combined NOM and virus removal. NOM concentrate from an ion exchange water treatment plant was used to make NOM enriched water representative of Norwegian water sources. The results indicated that low-pressure MF filtration in combination with pre-coagulation/flocculation is potentially an efficient technology for combining removal of virus and colour in drinking water production.

These experiments demonstrate that pre-coagulation/flocculation in combination with UF and MF membrane filtration is an effective hygienic barrier against MS2 virus. Results from MF membrane retained the virus to a similar degree as the UF membrane. Low-pressure MF filtration in combination with pre-coagulation/flocculation was also found to be efficient for combined removal of virus and colour in drinking water.

Comment These experiments ran for only one hour with negligible fouling of the membrane, and further studies with extended run times would be needed to determine whether virus removal remains high under operating conditions applicable to water treatment plants.

Water Disinfection

Sodium dichloroisocyanurate (NaDCC) tablets as an alternative to sodium hypochlorite for the routine treatment of drinking water at the household level

Clasen, T. and Edmondson, P. (2006) International Journal of Hygiene & Environmental Health, **209**(2); 173-81.

It is estimated that 1.1 billion people lack access to improved water supplies with many forced to use supplies that are microbiologically unsafe. The World Health Organization (WHO) is promoting the treatment of water at the household level to accelerate the health gains associated with safe drinking water. Chlorination has been found to be among the most effective, affordable and sustainable way of treating water at the household level. Household bleach, sodium hypochlorite (NaOCl) is probably the most accessible and potentially sustainable of the drinking water disinfectants. However uptake outside an epidemic situation has proved challenging and alternatives that may be more likely to be adopted are being sought. One possible alternative is dichloroisocyanurate (NaDCC) which is widely used for emergency treatment of water. This review compares NaDCC with NaOCl and examines the evidence available concerning its use as a possible alternative for routine drinking water treatment by households in low-income settings.

There are important differences in the performance of the two compounds. Both NaOCl and NaDCC rely on hypochlorous acid (HOCl) as the active agent however unlike NaOCl which releases all of its chlorine as free available chlorine (FAC), NaDCC releases only about 50% of the chlorine as FAC and the rest remains as “reservoir chlorine” in the form of chlorinated isocyanurates. As the FAC is consumed by reaction with organic matter further FAC is immediately released from the reservoir until the total available is used up. When water is subject to high or variable organic loads, the reservoir of FAC also enhances the biocidal protection over NaOCl. NaDCC can also operate at a wider pH range than NaOCl and as NaDCC tablets are acidic in solution they tend to reduce the pH of water favouring the formation of undissociated HOCl. The shelf life of tabulated and strip-packaged NaDCC is 5 years in temperate and tropical climates whereas NaOCl has a recommended life of only 6 months after opening. Effervescent (self-dissolving) NaDCC tablets are considerably more convenient to use than NaOCl which is a corrosive liquid subject to spillage. The potential for mis-dosing is also minimised using the tablets. NaDCC has been found to be advantageous over NaOCl in the production of trihalomethanes.

NaDCC has recently been approved by the U.S. Environmental Protection Agency and the World Health Organisation for routine treatment of drinking water. The microbiological effectiveness of NaDCC tablets to treat household drinking water was assessed in a study in Dhaka, Bangladesh. It was found that 84% of samples from households using NaDCC tablets to treat their water were free of faecal coliforms and the maximum level was 23 FC/100 ml compared to 1000-2400 FC/100 ml in the pre-intervention source water. In this study 78% of mothers expressed satisfaction with the tablets because they were easy and safe to use, dissolved quickly and left no objectionable smell or taste. In recently conducted focus groups in Tanzania to compare household preferences between NaOCl and NaDCC tablets, 70% of participants also preferred the tablets to liquid bleach. A number of studies have shown a significant reduction in diarrhoeal diseases for household interventions with NaOCl, but

no studies have adequately examined the health impact of treating water with NaDCC.

When calculating the actual cost of the water disinfection intervention, the cost of the chemical agents and also the initial and recurrent programmatic costs must be considered. If the NaDCC tablets are accepted more readily by the target population than NaOCl and this translates into higher uptake, then NaDCC tablets may require less programmatic costs to optimise their use and therefore be more cost-effective and cost-beneficial than NaOCl even if the cost per dose is greater. These advantages of NaDCC have to be weighed against its relative lack of availability compared to NaOCl and the issues this raises about its scalability and sustainability. Manufacture of NaDCC tablets requires specialised facilities and adequate quality control to minimise contamination, whereas conditions for production of NaOCl are less demanding and more readily available in developing regions of the world.

NaDCC appears to be a promising alternative to NaOCl in household-based water treatment interventions, however. long-term randomised controlled trials in differing settings need to be undertaken comparing NaDCC to a control group without access to water treatment and also to an intervention group using NaOCl. Such research would help answer questions on its potential benefits including microbiological effectiveness, compliance, acceptability and affordability. The programmatic support needed to achieve a given level of coverage also needs to be determined to assess its cost-effectiveness compared to other methods of household water treatment.

Water Quality

Coliphage as a potential indicator of distribution system integrity.

LeChevallier, M.W., Karim, M.R., Weihe, J., Rosen, J.S. and Sobrinho, J. (2006) *JAWWA*, **98**(7); 87-96.

Protecting the water quality in the distribution system is one of the most important objectives for a community water system. Monitoring of the

distribution system water quality normally relies on measurements of disinfectant residuals, total or faecal coliform bacteria, or *Escherichia coli*. Viral indicators are not typically included. This study of the distribution system in Davenport, Iowa was undertaken to attempt to demonstrate the benefits of coliphage monitoring. Coliphages are viruses that infect *E. coli* and are similar in size, structure, morphology, and composition to human enteric viruses, but are more easily and rapidly detected in environmental samples and are found in higher numbers in wastewater and other environments. Coliphages are also useful indicators of faecal pollution as they are constantly present in faeces, sewage and polluted waters. Coliphages are more resistant to chloramines than free chlorine and therefore may be particularly suited for use in chloraminated systems. Coliphage testing is not normally applied to distribution systems.

The monitoring of the Davenport distribution system was based on an existing coliform monitoring plan in which about 120 samples are collected per month. Normally 6-8 samples are collected daily and analysed for total coliforms, heterotrophic plate count (HPC) bacteria, and total chlorine. Sampling locations are public buildings and mostly comprise restrooms or utility rooms of gas stations, restaurants, schools, hotels or businesses. Hospitals located centrally within the system had more comprehensive tests performed including temperature, pH, phosphate, free and total chlorine, male-specific and somatic coliphages as well as total coliform and HPC analysis. All of the water quality parameters were evaluated using procedures approved by the state of Iowa (*Standard Methods*, 1998).

There were 2,471 coliform samples collected and only two of these tested positive for total coliform bacteria. There was no evidence that mains breaks in the distribution system resulted in coliform contamination. There were 2,430 samples examined for HPC bacteria, the average HPC was 230 cfu/mL (range 0-2,300 cfu/mL), there was some evidence of limited bacterial regrowth within the distribution system. All samples were free of *E. coli*. The average distribution system total chlorine residual was 2.08 mg/L (range of 0.59-3.60 mg/L), and the

average free chlorine level was 0.06mg/L. There were no correlations found between the concentration of HPC bacteria and total chlorine residuals, and no seasonal pattern in HPC was found. Somatic coliphages were not detected in 69 samples of treatment plant effluent or 399 samples from the distribution system. Male-specific coliphages were found in 22 of the 393 (5.6%) distribution system samples tested with an average concentration of 0.1 pfu/100 mL (range of 0-5 pfu/100 mL).

More than 77% of positive coliphage samples occurred within 72 hours of a main break during the winter months. In the week prior to a positive coliphage result, between 2 and 13 main breaks occurred, suggests that contaminated may have come from multiple locations. All coliphages belonged to serogroup I, usually found in animal faeces. Male-specific coliphages were detected in the treatment plant effluent on three occasions. The authors comment that these may have been associated with dirt or debris from commissioning of a new clearwell although this cannot be conclusively demonstrated.

Disinfection levels at the plant exceeded regulatory requirements for inactivation of *Giardia*, and would have been expected to inactivate coliphage. The authors suggest that occurrence of coliphage in the distribution system originates predominantly from mains breaks, either at the site of the break or at distal sites where ingress occurs due to negative pressure events generated by the break.

The results suggest that coliphage monitoring of the distribution system could be useful for tracking and controlling low levels of contamination, particularly in chloraminated water systems. More studies of coliphage occurrence and survival in drinking water need to be conducted to better assess the potential for using these organisms as indicators of distribution system contamination.

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