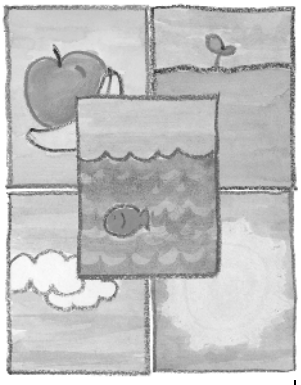
Water and the environment: a natural resource or a limited luxury?



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ABSTRACT

- The risk of contamination of drinking water supplies with microbial pathogens is minimised by modern approaches to water management, but continues to be the major public health concern.
- Chemical contaminants usually pose little health risk except at very high levels, but debate continues over the potential adverse health effects of low-level, chronic exposure to compounds such as disinfection byproducts.
- Recreational water contact can be associated with adverse health outcomes either from microbial infections or exposure to cyanobacterial toxins.
- Environmental issues such as increasing salinity and global warming are likely to affect the sustainability of our current drinking water supplies and increase the threat of waterborne disease outbreaks.
- New technologies, use of alternative water sources, such as rainwater tanks, water reuse and restrictions will undoubtedly be part of the solution to our diminishing water resources, but have the potential to introduce new health threats.

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MANY AUSTRALIANS take for granted access to as much high-quality drinking water as desired. In developed countries, water treatment technologies have eliminated most waterborne infections. However, new health threats, limited water resources and environmental changes, such as increasing salinity and global warming, along with more sensitive methods for measuring contaminants, are bringing the safety of our water supplies back into question.

Microbial contamination of drinking water

Although modern treatment processes and stringent regulations mean that tap water is generally safe to drink in developed countries, microbial pathogens remain the major public health risk associated with drinking water. Major waterborne pathogens include bacteria (eg, pathogenic *Escherichia coli* strains, *Campylobacter* and *Salmonella* spp.), protozoa (eg, *Cryptosporidium parvum* and *Giardia lamblia*), and viruses (eg, adenoviruses, enteroviruses and rotaviruses).

These organisms may be transmitted by other routes, including food and person-to-person spread, and drinking water is thought to be a minor contributor to disease in most Australian communities. For example, a recent randomised controlled trial in Melbourne found no difference in gastroenteritis rates between people who drank regular tap water and those who drank filtered, ultraviolet-treated water, suggesting that drinking water does not contribute significantly to background rates of gastroenteritis in that city.[1]

However, the potential for large populations to be exposed to pathogens via the water supply mandates vigilance against contamination of source water and failure of water treatment procedures. In addition, for many smaller and remote communities, limited resources mean that reliable provision of microbiologically safe water remains a challenge.

Microbial contaminants in Australia's drinking water supplies are reduced or eliminated through protection of water catchment, disinfection, water treatment and filtration. Treated water is then monitored for bacterial indicator organisms to satisfy guidelines for use as drinking water. However, this type of monitoring inevitably involves a timelag between sampling and availability of test results, and water contamination will seldom be detected until after consumption. Moreover, while current indicator organisms (*Escherichia coli* or faecal coliforms) are good indicators of risks from bacterial pathogens, they correlate poorly with viral and protozoal pathogens.

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Current and emerging issues

Monitoring for viral or protozoal pathogens has been suggested to improve the microbial safety of water supplies, but is technically difficult and expensive, and results are hard to interpret. For example, in Sydney in 1998, high concentrations of *Cryptosporidium* oocysts and *Giardia* cysts were reported in treated drinking water, but subsequent investigations revealed no evidence of increased disease,[2] and questions were raised about the validity of the test results.[3]

Cryptosporidium spp. and *Bacillus anthracis* are candidates for bioterrorist contamination of water supplies,[4] because of their low infectious dose. Although the high level of dilution reduces the risk of health effects, the threat cannot be dismissed. Protecting the security of water supplies is now a major focus of the Australian and international water industry.

Use of alternative water sources, such as water reuse schemes and rainwater collection, may increase the risk of infection. New risk-management approaches or water treat-

1: Recreational waterway closed because a cyanobacterial bloom

Although cyanobacteria do not infect humans or animals, they may cause contact dermatitis, gastroenteritis and allergic symptoms (eg, rhinitis, conjunctivitis and asthma), probably through cellular endotoxins. Some blooms also produce hepatotoxins or neurotoxins.

ment methods may be needed to protect public health. For example, increasing use of rainwater or "grey" water (laundry and shower waste) in urban areas raises the possibility of cross-connection with the tap water supply, and may require more stringent plumbing regulations.

Chemical contamination of drinking water

Chemicals may enter drinking water through leaching from the environment, chemical spills and deliberate additions (eg, disinfectants), and contact with piping and plumbing materials. In addition, toxins produced by cyanobacteria (blue-green algae; Box 1) may be considered as chemical contaminants, as their health effects are mediated via intoxication rather than infection. Cyanobacterial blooms occur in warm, slow-moving rivers and lakes, and are promoted by nutrient runoff from the surrounding catchment.

Some chemicals relevant to drinking water quality and their potential health effects are summarised in Box 2. For many, there is clear evidence of adverse effects at high exposure levels, but the degree of risk at the lower levels found in drinking water is not well defined. Drinking water guideline levels for chemical contaminants incorporate safety factors, so that daily exposure at the guideline level over a lifetime poses no significant risk.

Current and emerging issues

Debate continues about the health effects of exposure to disinfection byproducts, while more recent concerns include endocrine disrupters (chemicals which mimic or interfere with the actions of endocrine hormones) and pharmaceuticals.

Disinfectants such as chlorine and chloramines react with suspended organic material to produce a large range of byproducts. Some epidemiological studies have indicated a possible association between exposure to disinfection byproducts and adverse health effects (Box 2), although evidence in this area is conflicting and inconclusive.[5] Attention has focused on chlorine-based disinfectants, with the byproducts of other chemical disinfectants less well studied. Overall, the immediate benefits of chlorination in terms of protection from microbial pathogens far outweigh theoretical long-term risks of disinfection byproducts. This was well illustrated in Peru, where inadequate or absent disinfection was a contributing factor in a major cholera outbreak.[6]

Manufactured chemicals, such as pesticides, insecticides, industrial waste products and pharmaceuticals (including antibiotics, steroids and reproductive hormones), may contaminate our water supplies. Use of recycled wastewater and biosolids from sewage increases the potential for exposure. Concern has arisen about the potential adverse effects of low-level exposures to these substances, particularly those with endocrine-disrupting activity. No impact on human health has been convincingly demonstrated so far, but research on this topic is a high priority.[7]

Many chemicals and toxins are odourless, colourless, tasteless and biologically active in microgram amounts and, as such, could serve as potential tools for bioterrorism. Possible candidates include botulinum toxin A, tetrodotoxin, ciguatoxins, arsenic, lead, mercury, pesticides and radionuclides.[4]

Recreational water sources

Potential health risks associated with exposure to swimming pools, spas, rivers, reservoirs or marine waters include gastrointestinal, skin and respiratory infections. Gastrointestinal infections transmitted by the faecal–oral route are most common. Public swimming pools have been linked with outbreaks of disease caused by *E. coli*, *Shigella*, *Cryptosporidium* and *Giardia* spp. Other illnesses related to recreational water exposure are shown in Box 3. In addition, cyanobacteria may cause contact dermatitis, gastroenteritis and allergic symptoms, possibly through endotoxins (Box 1).

Vector-borne diseases

Pools of water, uncovered containers and poorly maintained rainwater tanks can serve as breeding sites for mosquito vectors which transmit diseases such as Ross River and Barmah Forest virus infection, Murray Valley encephalitis, malaria, dengue fever and Japanese encephalitis. Global warming may increase health risks by permitting insect vectors to spread to new regions.

Inadequate water access

Provision of safe and adequate water supplies is a major challenge in small communities in remote parts of Australia, especially Aboriginal and Torres Strait Islander communities. Insufficient water for cooking, domestic use and personal hygiene increases the risk of infections transmitted by the faecal–oral route, and skin and eye infections, including

2: Health outcomes possibly related to chemical exposures from drinking water

Chemical	Possible health outcomes	Comments
Aluminium	High levels possibly associated with Parkinsonian dementia, Alzheimer's disease and amyotrophic lateral sclerosis.	No health guideline for aluminium in water supplies set by either the World Health Organization or National Health and Medical Research Council (NHMRC), because of insufficient data. Food and other beverages are the main sources of daily intake of aluminium, with < 2% from drinking water.
Arsenic	Chronic exposure associated with increased risks of cancer (particularly of the skin, lung, and genitourinary tract), skin changes, organomegaly, vascular changes (including hypertension) and neurotoxicity.	Chronic arsenic toxicity is a current major health concern in Bangladesh and West Bengal. In Australia, arsenic contamination of groundwater may occur from past gold mining, sheep dipping or timber treatment practices, or natural geological sources. Levels recorded in Australia are 10–30 times lower than those associated with adverse effects documented from epidemiological studies.
Copper	High intake is associated with acute gastrointestinal symptoms (nausea, vomiting and abdominal pain) and chronic exposure can result in cirrhosis.	Many cases of acute poisoning reported worldwide, but only two cases of liver failure in Australian children have been reported (associated with exposure to acidic bore water with high levels of copper from pipes).[15] Food is the main source of copper intake, with < 10% contribution from drinking water.
Disinfection byproducts (DBPs)	Chronic exposure possibly associated with increased risk of cancer, particularly of the bladder and bowel. More recent attention focused on possible increased risks of miscarriage and birth defects.	It is difficult to measure DBP exposure accurately and to account for potential confounding effects from other exposures. Evidence for adverse health effects from DBPs in drinking water is currently considered inconsistent and inconclusive,[16-18] but this remains an area of active research.
Lead	Lead exposure can have central nervous system effects. Epidemiological evidence suggests cumulative exposure in children affects intellectual development. Carcinogenicity suggested by animal studies, but not documented in humans.	Lead piping was used extensively for domestic plumbing in Europe and North America, but seldom in Australia. Most lead intake is from food and other sources, such as old paintwork.
Nitrate	Methaemoglobinaemia in infants aged under three months may occur if baby formula is made with water with raised nitrate concentrations (> 50 mg/L).	Nitrate from natural and man-made sources (eg, agricultural fertilisers) may affect groundwater supplies. In several Western Australian towns, bottled water is supplied for making baby formula because of high nitrate levels in tap water.
Fluoride	Possible effects on bone (skeletal fluorosis, osteosarcomas, osteoporosis and fractures). High levels in children can lead to dental fluorosis.	Levels of fluoride added to drinking water in Australia do not appear to have an adverse effect on bone mineral density or fracture incidence.[19] NHMRC reviews have supported the dental health benefits and safety of water fluoridation.[20]
Cyano-bacterial toxins	Some species produce endotoxins (causing allergic reactions, skin rashes, eye irritation, gastroenteritis), neurotoxins and hepatotoxins.	High levels are very unlikely in drinking water supplies. The only significant human cyanobacterial poisoning recorded in Australia occurred on Palm Island in 1979, when use of copper sulfate to kill a cyanobacterial bloom in a reservoir released large amounts of hepatotoxin. About 140 children and 10 adults were hospitalised with hepatitis-like symptoms.[21]

trachoma. Low water intake may also contribute to renal disease. With increasing depletion of water resources caused by increasing demand and changing rainfall patterns, limited water supply may become a more widespread problem.

Environmental issues

Major problems facing water resources and urban supplies in Australia include:

Competing activities and contamination in catchment areas: The quality and quantity of water sources are at risk from activities such as logging, farming, mining, residential and industrial development, recreation and tourism. Sewage and wastewater runoff also contribute to source water contamination.

Salinity: In some areas of Australia, groundwater supplies contain high levels of dissolved salts, which make water unpalatable. As areas affected by salinity increase, additional drinking water sources or treatment methods will be needed (Box 4).

Climate change: Climate change, particularly rising temperatures and changes in rainfall, will affect our water supplies (Box 5). Weather pattern changes, with more prolonged droughts alternating with high-intensity rainfall events, may alter disease transmission patterns. Waterborne outbreaks are significantly associated with high-rainfall events, which flush large quantities of contaminants into water sources and overwhelm water treatment systems.[8] Falling water levels and reduced river flows during droughts increase the risk of cyanobacterial blooms, and also make water treatment more

3: Non-gastrointestinal illnesses associated with recreational water exposure, and their causes

Skin diseases
Pseudomonas aeruginosa (eg, "spa" folliculitis)
Atypical mycobacteria, especially *Mycobacterium marinum*, *Mycobacterium ulcerans* (skin ulcers, common in southern Australia)

Respiratory diseases
Viruses, particularly adenovirus
Legionella spp. (may be associated with spas or whirlpools)
Environmental mycobacteria, especially *Mycobacterium kansasii, Mycobacterium avium* complex (lung disease, particularly in immunosuppressed people)

Ear infections
P. aeruginosa, *Staphylococcus aureus* (otitis externa and media)

Liver or renal disease
Leptospira spp. (via skin contact with water contaminated with animal or rodent urine, often in association with water sports and adventure travel;[23] a recent large outbreak occurred among participants in a Malaysian triathlon[24]).

Central nervous system infections
Naegleria fowleri fulminant, usually fatal, amoebic meningoencephalitis, after swimming in contaminated ponds; cases recorded in several Australian states
Acanthamoeba spp. (universally fatal granulomatous encephalitis which can occur in immunosuppressed people after exposure to fresh or sea water or chlorinated swimming pools)

Keratitis
Acanthamoeba spp. (in people with corneal abrasions)

difficult as levels of sediment and organic material increase. Global warming is also predicted to extend the geographic range of many insect-borne diseases.[9,10]

Sustainability: Australia's water use has increased 65% since the early 1980s. Many rivers, wetlands and bays are already degraded because of the high levels of water extracted and runoff of polluted surface water and stormwater. As few sources of surface and groundwater remain unexploited, new strategies to match supply and demand are needed.

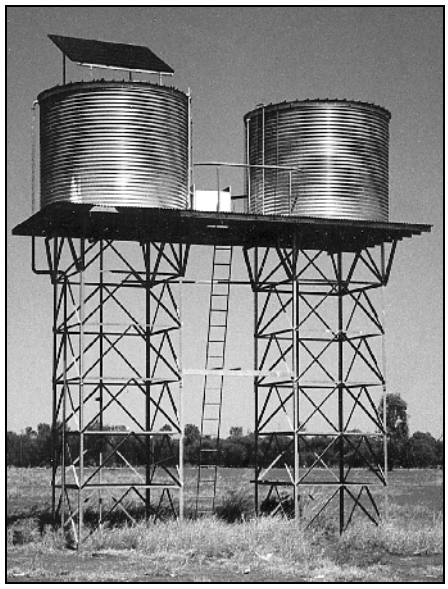
Role of clinicians

Although drinking and recreational water supplies are unlikely to be major sources of illness in Australian communities, they pose a potential risk. Clinicians have a role in diagnosis of waterborne disease and prevention:

- Physicians should be aware of local waterborne health problems in high-risk geographical areas (eg, nitrate in groundwater sources).
- A disease cluster or outbreak suggested by a common history of exposure to drinking or recreational water should be immediately reported to the local health department. Faecal specimens should be collected to identify a pathogen, if warranted clinically. However, diagnosis of a specific pathogen does not identify the source, as multiple routes of transmission are possible. For example, although outbreaks of giardiasis and cryptosporidiosis have been related to contaminated drinking water overseas, no outbreaks have been associated with municipal water supplies in Australia, and most sporadic cases of diarrhoea caused by these pathogens are not caused by contaminated water supplies.
- Preventive advice, particularly in the immunocompromised or other vulnerable groups, or during periods of suspected high health risk, may include the following:

- use an appropriate tap filter for drinking water;
- use alternative sources for drinking water;
- bring water to a rolling boil before use; and
- avoid recreational water exposures.

4: Bore water tanks with filter systems



These tanks are fitted with solar-powered reverse-osmosis filter systems to reduce levels of dissolved solids and render the water palatable.

Potential future solutions

Water restrictions, increasing use of alternative water sources and more water-efficient appliances will be important elements in reducing our demand for drinking water, but may also present potential health risks. Solutions will include:

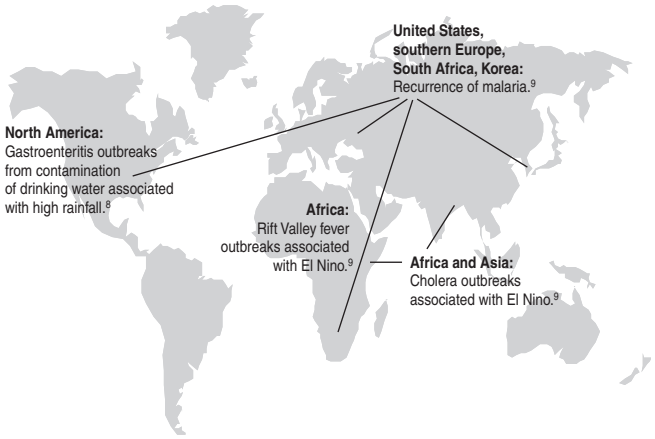
Risk management systems: The Australian Drinking Water Guidelines are currently being revised to incorporate a preventive risk management approach.[11] This emphasises the need for multiple barriers to microbial and chemical contamination throughout water supply systems and for real-time monitoring to detect and rectify problems before they affect water quality.

Rainwater tanks: These have a long history of use for domestic drinking water in rural and remote areas of Australia and are being increasingly used in urban areas to conserve tap water supplies. While drinking water from these tanks is not believed to pose a major risk if systems are well designed and maintained,[12] health authorities are generally not prepared to endorse the use of untreated rainwater for public consumption because of potential contamination and a lack of health outcome data.

Water reuse: Water is already recycled in agriculture and industry, which use most of our water supplies. Guidelines exist to control potential health risks from microbial and chemical contamination for different applications.[13] It is technically feasible to raise the quality of recycled water to drinking water standard, but cost and public perception are obstacles.

Dual water supplies: To reduce the demand for high-quality water, it is

5: Outbreaks of waterborne disease potentially attributable to environmental change



** El Nino events are caused by extensive warming of the central and eastern Pacific Ocean, leading to a major shift in weather patterns across the Pacific.*

possible that communities will be supplied with water of two qualities — drinking water and water for outdoor use and purposes such as toilet flushing. Such dual systems are used overseas and have recently undergone trials in housing developments in Australia (eg, Rouse Hill in Sydney). Adequate safeguards are required to address the threat of cross-connection and supply of substandard water from taps.

Conclusions

Agriculture, industry and urban populations will continue to compete for land and water. Disease outbreaks and contamination events have often provided the impetus for upgrading drinking water technology, protecting watersheds, improving distribution and regulatory systems overseas,[14] but water quality has not been seen as a major public health issue in Australia to date. We need new technologies and responses to ensure sustainability of our water supply, but new public health questions will undoubtedly arise. We should not expect limitless water supplies and should not take safe and clean water for granted (Box 6).

6: Reflections and predictions

Circa *1900*

- Cholera known to be transmitted by drinking water.
- Water supplies not yet routinely chlorinated, filtered or protected from sewage pollution.
- No routine microbial monitoring of water.
- Waterborne outbreaks, including cholera and typhoid, occurring in Australia.

Circa *2100*

- Water has re-emerged as a major public health concern.
- Many natural water resources are depleted, and water restrictions are common.
- Domestic water use has been greatly reduced by efficient conservation practices.
- Water supplies are dual, with lower quality water for non-drinking purposes.
- Rainwater tanks are compulsory for new developments.
- More variable weather patterns have increased the risk of outbreaks of waterborne disease.
- Global warming has increased rates of vector-borne disease.

Competing interests

None identified.

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