# 12 Managing health risks to consumers

David Cunliffe

South Australian Department of Health, 150 Grenfell Street, Adelaide, SA 5001, Australia

## Consumer risks

Irrigation of agricultural produce by reclaimed water poses potential risks to consumers when the following three conditions are present:

1 Hazardous microorganisms or chemicals are present;
2 Concentrations of the hazardous agents are high enough to cause illness; and
3 There is a route of exposure leading to contact between consumers and the hazard in a manner that would cause illness.

This risk characterisation applies equally to any other water used for irrigation and any other material such as fertiliser used in the production of food crops.

Therefore, to ensure agriculture products are safe, control measures need to be applied to:

1 Prevent hazards from being present – one example would be to apply strict trade waste control programs to prevent hazardous chemicals being released into sewers and transported to wastewater treatment plants (WWTP). However, this approach cannot be applied to microbial hazards.
2 Reduce the concentrations of hazards below the level that would cause illness – reducing concentrations of pathogenic microorganisms is the principal function of WWTPs. The higher the level of treatment, the lower the concentrations of pathogenic microorganisms.
3 Prevent or minimise the exposure of consumers to the hazards. This can be achieved by:
   - restricting the types of crops that are irrigated (eg fruit trees, crops that are processed or cooked before consumption)
   - controlling methods of application (eg drip irrigation rather than spray irrigation); the impact of this measure will depend on the nature of the crop (eg root vegetables, salad vegetables with ground contact or crops borne on vines or trees)
   - setting withholding periods between application of water and harvesting, and sale of crops.

The various mechanisms for reducing risks, including prevention, removal and onsite control are important components of reclaimed water guidelines, which allow a balanced approach to the management of health risks. In schemes where high levels of treatment are applied, to minimise concentrations of hazards, lower levels of onsite control are required to reduce exposure to hazards. Conversely, if lower levels of treatment are applied, then methods to control exposure need to be increased.

### Pathogens

The types and concentrations of enteric pathogens present in raw sewage reflect illness in the community. For instance, in Australia the occurrence of large numbers of the highly pathogenic cholera organism, *Vibrio cholerae*, is very unlikely. In some cases, illness and occurrence of pathogens may be seasonal. For instance, infections with *Cryptosporidium* are typically more common in late summer and autumn in countries such as Australia and the United States while in other countries infections occur more commonly in spring and autumn.

Table 12.1 provides a list of the typical pathogens that can be found in raw sewage while Table 12.2 provides an indication of concentrations of organisms detected in raw sewage.

**Table 12.1 Typical pathogens found in raw sewage.**

| Pathogen type | Examples | Illness | Infectious dose |
|---|---|---|---|
| **Bacteria** | Atypical mycobacteria | Skin, respiratory infections | Unknown |
| | *Campylobacter* | Gastroenteritis, Guillain-Barre syndrome | $10^3$ |
| | *Helicobacter pylori* (?) | Peptic ulcers | Unknown |
| | Pathogenic *E. coli* | Gastroenteritis, haemolytic uremic syndrome | $10^1$–$10^8$ |
| | *Pseudomonas aeruginosa* | Skin, eye, ear infections | $>10^5$ |
| | *Salmonella* | Gastroenteritis | $10^4$–$10^7$ |
| | *Shigella* | Dysentery | $10^1$–$10^2$ |
| | *Staphylococcus aureus* | Skin, eye, ear infections, septicaemia | Unknown |
| | *Vibrio cholerae* | Cholera | $10^3$ |
| | *Yersinia* | Gastroenteritis, septicaemia | $>10^3$ |
| **Viruses** | Enterovirus | Gastroenteritis, respiratory illness, nervous disorders, myocarditis | 1–10 pfu[A] |
| | Adenovirus | Gastroenteritis, respiratory illness, eye infections | 1–10 pfu |
| | Rotavirus | Gastroenteritis | 1–10 pfu |
| | Hepatitis A | Infectious hepatitis | 1–10 pfu |
| | Calicivirus | Gastroenteritis | 1–10 pfu |
| | Astrovirus | Gastroenteritis | 1–10 pfu |
| | Coronavirus | Gastroenteritis | 1–10 pfu |
| **Protozoa** | *Cryptosporidium* | Gastroenteritis | 1–2000 oocysts |
| | *Giardia* | Gastroenteritis | 1–10 cysts |
| | *Naegleria fowleri* | Amoebic meningitis | Unknown |
| | *Entamoeba histolytica* | Amoebic dysentery | 1–10 cysts |
| **Helminths** | *Taenia* *T.saginata* | Tapeworm Beef measles | 1–10 eggs |
| | *Ascaris* | Roundworm | 1–10 eggs |
| | *Trichuris* | Whipworm | 1–10 eggs |

Source: after Feacham *et al* (1983), Geldreich (1990), Bitton (1994), National Research Council (1996).
[A] pfu = plaque forming unit.

Results from two Australian wastewater treatment plants indicate that the raw sewage contained 2000 *Cryptosporidium*, 8000 adenovirus and 7000 *Campylobacter* per litre (as a 95th percentile) (NRMMC and EPHC 2005).

# Hazard reduction

## Wastewater treatment processes

The primary purpose of wastewater treatment is protection of public health through reduction of enteric pathogens present in raw sewage. Typical reductions achieved by traditional treatment processes (see *Chapter 3*) are shown in Table 12.3.

A WWTP that incorporates primary screening, secondary treatment, coagulation, filtration and disinfection should be able to produce a high-quality reclaimed water containing <1 *E. coli*/100 mL and low numbers of enteric viruses, *Cryptosporidium* oocysts, *Giardia* cysts and helminth ova (Asano *et al* 1992; Yanko 1993; Rose *et al* 1996; National Research Council 1996; Cunliffe and Stevens 2003).

## Onsite controls

Onsite controls and restrictions on the use of reclaimed water can also be deployed to reduce the potential for hazard transmission and human exposure. Lower qualities of reclaimed water can be used to irrigate crops, providing post-treatment controls are applied to reduce human exposure to potential hazards in the water. Log reductions in exposures can be ascribed to onsite preventive measures. These log reductions can range from 0.5 log/d for withholding periods to 5–6 logs for crop processing (NRMMC and EPHC 2005).

**Table 12.2 Numbers of microorganisms detected in raw sewage.**

| Organism | Numbers in sewage (per L) |
|---|---|
| Adenoviruses | $10^1$–$10^4$ |
| *Cryptosporidium* | 0–$10^4$ |
| Enteroviruses | $10^2$–$10^6$ |
| *Escherichia coli* | $10^5$–$10^{10}$ |
| *Giardia* | $10^2$–$10^5$ |
| Helminth ova | 0–$10^4$ |
| Rotaviruses | $10^2$–$10^5$ |
| *Salmonella* | $10^3$–$10^5$ |
| *Shigella* | $10^1$–$10^4$ |

Source: after Feacham *et al* (1983), Bitton (1994), National Research Council (1996).

# Health-based targets

Health-based targets are the benchmarks that have to be achieved to ensure safety for consumers of irrigated produce. The normal benchmarks are guideline values for chemical hazards and performance targets for microbial hazards. The inputs into the calculation of health based targets are a definition of tolerable risk and the elements associated with risk assessment:

- concentrations of hazards in raw sewage;
- dose response data for these hazards; and
- exposures associated with the use.

## Tolerable risk

There are several definitions of tolerable risk including an acceptable upper limit of 1 infection per 10 000 people per year (Regli *et al* 1991) for microbial hazards. This limit has been cited as a basis for establishing microbiological limits for drinking water guidelines (Macler and Regli 1993). Other definitions exist for chemical hazards (NHMRC and NRMMC 2004).

However, the 'Draft national guidelines for water recycling' (NRMMC and EPHC 2005) have adopted disability adjusted life years (DALYs) as the best metric for describing health impacts and risks. DALYs have also been adopted in water guidelines developed by the World Health Organization (WHO 2004). A DALY is the sum of years lost through being in less than good health and premature death associated with exposures to either microbiological or chemical hazards. Determining DALYs includes considering both acute impacts (eg diarrhoeal disease) and chronic impacts (eg cancer or reactive arthritis associated with a low proportion of Campylobacter and Salmonella infections).

Both the 'Draft national guidelines on water recycling' (NRMMC and EPHC 2005) and the latest edition of the WHO's 'Guidelines for drinking-water quality' (WHO 2004) have adopted $10^{-6}$ DALYs per person per year as a tolerable level of risk. This is equivalent to an annual risk of illness of $10^{-3}$ (ie 1 illness per 1000 people) for a diarrhoea-causing pathogen such as *Cryptosporidium*. This is well below the Australian reported rate of 0.8–0.92 cases of diarrhoeal illness per person per year (OzFoodNet Working Group 2003).

## Microbial risk assessment

Sewage can contain a wide range of pathogenic microorganisms and it is not practical to undertake a risk assessment for all of these organisms. A standard approach is to select reference pathogens representing the major groups of pathogens (NRMMC and EPHC 2005). Reference pathogens need to have several properties including high occurrence and pathogenicity, and for risk assessment purposes there needs to be data on occurrence and dose response. *Cryptosporidium* is a standard choice as a reference pathogen for enteric protozoa, rotavirus can be used as a reference for viruses, and *Campylobacter* for enteric bacteria. Dose response data are available for each of these pathogens (Haas *et al* 1999; Messner *et al* 2001) and Australian data are available for occurrences of *Cryptosporidium* and *Campylobacter*. Data for adenoviruses can be used as an indicator for rotavirus concentrations (NRMMC and EPHC 2005).

**Table 12.3 Log reduction of microorganisms achieved by treatment processes.**

| | Level of treatment[A] | | | |
|---|---|---|---|---|
| | Primary | Secondary | Lagoons | Tertiary (filtration & disinfection) |
| Organism | Log reduction | | | |
| Bacteria | 0–2 | 0–2 | 1–6 | 4–6 |
| *Cryptosporidium* | 0–1 | 0–1 | 1–3 | 2–3 |
| *Enteric viruses* | 0–1 | 0–2 | 0–2 | 3–4 |
| Giardia | 0–1 | 0–2 | 3–5 | 2–4 |
| Helminth ova | 0–2 | 0–2 | 1–3 | 2–3 |

Source: after Feacham *et al* (1983), Bitton (1994), National Research Council (1996).
[A] See Chapter 3.

There is a limited range of exposure data associated with agricultural application of reclaimed water. Unrestricted spray irrigation of salad crops represents the highest potential exposure associated with agricultural irrigation. Shuval *et al* (1997) determined that 10.8 mL of water could adhere to 100 g of lettuce whereas 0.4 mL could adhere to cucumbers. These types of data can be used together with figures on consumption of salad vegetables by Australians (ABS 1995) to determine typical or average exposures to components of irrigation water.

## Calculated log reductions (performance targets)

Using the information discussed above, log reductions of pathogens in raw sewage can be calculated to ensure that health risks do not exceed the tolerable health risk of $10^{-6}$ DALYs when salad crops are irrigated with reclaimed water (NRMMC and EPHC 2005). The calculated reductions are 4.8 logs for *Cryptosporidium*, 5.9 logs for adenoviruses / rotaviruses and 4.9 logs for *Campylobacter*. These reductions equate to concentrations in reclaimed water of about 3 *Cryptosporidium*, 1 rotavirus and 10 *Campylobacter* per 100 L. These concentrations are provided as an indication of a final target. However, testing for these pathogens would not be a part of routine monitoring programs.

The required log reduction could be achieved by treatment alone or by a combination of treatments and onsite controls. For example, for commercial food crops it can typically take 36–48 hours to move from final irrigation through to harvest, transport to retail outlets and purchase. This time period would lead to about a 1 log reduction in virus numbers, hence the log reduction target for treatment would be reduced to about 5 logs.

The use of onsite controls to reduce potential exposure and, hence, to reduce required log reductions can be extended as shown in Table 12.4. This enables lower quality reclaimed water to be used as shown in Table 12.5. For example, drip irrigation of crops with no ground contact (eg tomatoes, peas, citrus and orchard fruit) reduces exposure by 4 logs while decay of organisms between final watering, harvesting and consumption reduces exposure even further. Log reductions required through treatment for this type of reclaimed water use would be less than 1 log for protozoa, viruses and bacteria. These reductions can be achieved by secondary treatment and disinfection. Processing of food crops such as cereals, wine grapes and potatoes reduces exposure by 5–6 logs, meaning that only limited treatment is required such as secondary treatment or primary treatment with lagoons.

**Table 12.4 Log reductions provided by onsite controls.**

| Control measure | Log reduction in exposure to pathogens |
|---|---|
| Cooking or processing of crops (eg potatoes, wine grapes) | 5–6 |
| Removal of skins from produce before consumption | 2 |
| Drip irrigation | 2 |
| Drip irrigation of crops with no ground contact | 4 |
| Subsurface irrigation of above-ground crops | 4 |
| Withholding periods | 0.5 per day (viruses and bacteria) |

These calculations err on the side of caution. The calculated log reductions assume that all organisms detected are infectious for humans through ingestion but this is unlikely to be the case. For example, it is doubtful that all of the *Cryptosporidium* and *Giardia* detected in treated effluent are infectious. Most analyses of these organisms base assessments of viability on dye exclusion (US EPA 1999b), but the relationship of this to infectivity is uncertain (eg see Clancy *et al* 1998). Analysis of adenovirus excreted by humans has shown that only a small proportion belongs to the serotypes generally associated with enteric illness (for a review of serotypes see Hierholzer 1991). Human behaviour such as washing of produce before use and consumption has also not been considered.

This caution and conservatism is probably necessary to achieve acceptance by consumers and wholesalers (see *Chapter 13*).

There are at least two examples where unrestricted irrigation of food crops with reclaimed water has been practised. The first is the Monterey Scheme (California, USA) which has been operating for almost 20 years and the second is the Virginia Pipeline Scheme (South Australia) which has operated since 1999. Microbiological and chemical testing of crops grown in these schemes has not detected any differences between produce irrigated with bore water and reclaimed water (Sheikh *et al* 1990, Kelly and Stevens 2002).

# Cyanobacteria

Cyanobacteria or blue-green algae are common in surface waters including farm dams used for agricultural irrigation in Australia. Some species produce toxins. The possibility that cyanobacterial blooms may affect crop quality has been raised as a research need but there has

**Table 12.5 Reclaimed water quality requirements for specific food crops.**

| Type of crop | Application method | Treatment log reductions | Onsite control reductions |
|---|---|---|---|
| Large surface area grown on or near the ground and consumed raw (eg broccoli, cabbage, cauliflower, celery, lettuce) | Spray | Secondary, filtration disinfection<br>4–5 log protozoa<br>6 log viruses<br>> 6 log bacteria | 1.0 log virus and bacteria due to decay prior to sale |
| Crops without ground contact (eg tomatoes, peas, beans, capsicums, non-citrus orchard fruit, non-wine grapes) | Drip | Secondary and disinfection<br>0.5–1 log protozoa<br>1–3 log viruses<br>>6 log bacteria | 4 log (drip)<br>1.0 log virus and bacteria due to decay prior to sale |
| Crops without ground contact and skin that is removed before consumption (eg citrus and nuts) | Spray<br><br>Drip | Secondary and disinfection<br>0.5–1 log protozoa<br>1–3 log viruses<br>>6 log bacteria | 3 log (spray)<br>5 log (drip)<br>1.0 log virus and bacteria due to decay prior to sale |
| Crops processed before consumption (eg potatoes, brussel sprouts, cereals, grapes for wine making) | Spray, drip | Secondary treatment<br>0.5–1 log protozoa<br>0–2 log viruses<br>1–3 log bacteria | 5–6 log cooking/processing |
| Crops not for human consumption Silviculture, turf growing | Any | Secondary treatment<br>0.5–1 log protozoa<br>0–2 log viruses<br>1–3 log bacteria | >6 log |

been very limited work undertaken. The potential for public health impacts would require the presence of significant numbers of toxic cyanobacteria, uptake or irreversible attachment of toxins to crops and limited environmental degradation. Uptake of cyanobacterial toxins into cellular material is problematic, and, although it is known that environmental microorganisms can degrade toxins, the rate at which this would occur for the range of identified cyanobacterial toxins is unknown (see Chorus and Bartram 1999). Codd *et al* (1999) demonstrated physical carriage of *Microcystis aeruginosa* and the associated toxin microcystin on lettuce leaves due to spray irrigation, but the initial concentrations of the organism in the irrigation water was not reported. There was no attempt to assess the potential risks to human health from consuming these leaves.

Studies of open storages associated with the Virginia Pipeline Scheme demonstrated that most of the species of cyanobacteria detected were non-toxic (Kelly and Stevens 2002). Although possible impacts of cyanobacterial blooms on crop quality have not been established, such blooms can cause problems with blocking of irrigation systems and decaying blooms can cause odour problems. One mechanism for reducing cyanobacterial blooms is to maintain rapid turnover of water. Cyanobacteria prefer still and stable conditions. Dams with long retention times are more likely to support the growth of blooms.

# Chemical quality

## Heavy metals

The concentrations of individual chemicals in domestic wastewaters, especially heavy metals, are generally below guideline values recommended for crop irrigation (ANZECC and ARMCANZ 2000) and also below those specified for safe drinking water (NHMRC and NRMMC 2004). The principal cause for concern is the discharge of industrial wastes into sewerage systems. Most jurisdictions have policies against this practice. However, ongoing policing needs to be maintained to protect the quality of reclaimed water used for irrigation and, for that matter, the alternative of discharge to fresh or marine waters.

An assessment should be undertaken of industrial activities within the areas served by sewerage systems to assist the monitoring of trade waste restrictions and to provide a better understanding of worst case scenarios for reclaimed water schemes. As previously discussed, testing of crops grown at Monterey and Virginia has detected no exceedances of chemical requirements for food quality associated with the use of reclaimed water (Sheikh *et al* 1990; Kelly *pers comm* 2004).

## Pesticides and other organic chemicals

In well-managed systems with sound trade waste monitoring there should be few, if any, detections of pesticides or significant concentrations of organic chemicals. Long-term monitoring of the four metropolitan WWTPs in South Australia has not detected the presence of pesticides and the concentrations of organic chemicals have all been very low (see *Chapter 10*).

### Endocrine disruptors (xenoestrogens)

Although there has been little evidence of human health effects from environmental exposure, there has been a lot of discussion in both the scientific and popular press about the issue of potential endocrine disrupting chemicals (Safe 2000; see *Chapter 10*). Reviews have been published by the World Health Organization (WHO 2002) and the CRC for Water Quality and Treatment (CRCWQT 2003). Even the term used to define these chemicals has been a subject of debate and various labels have been used including xenoestrogens and hormonally active agents. For simplicity, the term 'endocrine disruptor' will be used here to refer to the group of chemicals with the potential to interfere with the normal function of the endocrine system.

Hundreds and thousands of possible endocrine disruptors have been identified including pesticides, non-pesticide organics, inorganic chemicals (eg lead and cadmium), plasticisers and pharmaceuticals (eg female contraceptive hormones). The US EPA has estimated that 87 000 chemicals could be considered as potential endocrine disruptors (US EPA 1999a).

There are several issues that need to be borne in mind when considering the possible impact of endocrine disruptors:

- at this stage, there is no compelling evidence of impacts on human health from exposure to these chemicals from environmental sources (Safe 2000);
- the ever increasing list of potential endocrine disruptors is almost ubiquitous (eg phthalates, which have been identified as a cause of concern, are a normal component of plastics commonly used to wrap foods after production) (Jobling *et al* 1995);
- human exposure to natural compounds, with the potential to be endocrine disruptors, far outweighs the small amounts of manufactured compounds that may or may not be present in water (eg some plants such as soybeans contain very high concentrations of phytoestrogens) (Mazur and Adlercreutz 1998; Safe 2000); phytoestrogens have been shown to cause infertility and developmental toxicology in some animals including sheep clover infertility reported in Western Australia (Adams 1998).

There have been several reports that discharge of treated wastewater into streams can affect aquatic species including fish (Safe 2000). However, extrapolating these data to humans is very difficult for several reasons including important differences in the pharmokinetics and metabolism of fish compared to humans and consideration of the mechanisms of exposure. Fish exposure entails continuous full body immersion while human exposure is indirect through ingestion of irrigated produce.

The question that must be asked in regard to the use of reclaimed water to irrigate food crops is, does this source of irrigation water significantly increase exposure to potential endocrine disruptors? For this to occur the compound would need to be present in significant concentrations and taken up into irrigated plants and retained during growth. At this stage, for reclaimed water that is sourced predominantly from domestic wastewater, there is no evidence that these conditions are fulfilled.

### Pharmaceutical chemicals

Issues raised for pharmaceuticals have been similar to those for endocrine disruptors. Low concentrations of pharmaceutical compounds have been detected in waters that receive discharges of sewage effluent (Kolpin *et al* 2002). However, the relatively low human exposures to reclaimed water through agricultural use mean that the likelihood of health impacts is minimal. In addition, there is uncertainty concerning plant uptake and retention of these chemicals.

## Conclusions

There are advantages for using reclaimed water to irrigate food crops. Where highly treated reclaimed water is used for purposes such as spray irrigation of salad crops, the quality is measured continuously, and, at least microbiologically and physically, reclaimed water is generally superior in quality to surface waters used across Australia for unrestricted irrigation of food crops. Reclaimed water quality is also routinely tested for compliance with established Australian guidelines for agricultural uses. Other sources of water used for the same purpose are tested far less frequently, if at all. Some emerging issues such as endocrine disruptors, pharmaceutical chemicals and cyanobacteria have been identified (see *Chapter 10*). Although the likelihood of health impacts through irrigation of agricultural produce seems minimal, further research is required on concentrations of these hazards in recycled water and their survival, fate and transport in irrigated produce. Finally, Australian guidelines applied to the use of reclaimed water in agriculture are conservative and are designed to be protective of human health.

## References


ABS (1995) National Nutrition Survey: Foods eaten. Commonwealth of Australia.

Adams, NR (1998) Natural and anthropogenic environmental oestrogens: the scientific basis for risk assessment. Clover phyto-oestrogens in sheep in Western Australia. *Pure and Applied Chemistry* **70**, 1855–1862.

ANZECC and ARMCANZ (2000) Australian and New Zealand guidelines for fresh and marine water quality 2000. National water quality management strategy, Paper No. 4. Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand, Canberra, ACT.

Asano T, Leong LYC, Rigby MG and Sakaji RH (1992) Evaluation of the California wastewater reclamation criteria using enteric virus monitoring data. *Water Science and Technology* **26**, 1513–1524.

Bitton G (1994) 'Wastewater microbiology.' Wiley-Liss, New York.

Blumenthal UJ, Mara DD, Peasey A, Ruiz-Palacios G and Stott R (2000) Guidelines for the microbiological quality of treated wastewater used in agriculture: recommendations for revising WHO guidelines. *Bulletin of the World Health Organization* **78**(9), 1104–1116.

Chorus I and Bartram J (Eds) (1999) 'Toxic cyanobacteria in water. A guide to their public health consequences, monitoring and management.' E & FN Spon, London.

Clancy JL, Hargy TM, Marshall MM and Dyksen JE (1998) UV light inactivation of Cryptosporidium oocysts. *Journal of the American Waterworks Association* **90** (9), 92–102.

Codd GA, Metcalf JS and KA Beattie (1999) Retention of Microcystis aeruginosa and microcystin by salad lettuce (*Lactuca sativa*) after spray irrigation with water containing cyanobacteria. *Toxicon* **37**, 1181–1185.

CRCWQT (2003) 'Endocrine disruptors in the context of Australian drinking water.' Cooperative Research Centre for Water Quality and Centre, Occasional Paper 7.

Cunliffe DA and Stevens M (2003) Success of HACCP in the drinking water industry – can it be adapted to reuse schemes? Water Recycling Australia, Second National Conference Brisbane, September 2003. AWA, Sydney.

DHS SA and EPA SA (1999) South Australian reclaimed water guidelines. Department of Human Services and Environment Protection Agency, Government of South Australia, Adelaide, South Australia. http://www.epa.sa.gov.au/pdfs/reclaimed.pdf [Verified November 2005].

Feacham RG, Bradley DJ, Garelick H and DD Mara (1983). 'Sanitation and disease. health aspects of excreta and wastewater management.' John Wiley and Sons, Chichester.

Geldreich EE (1990) Microbiological quality of source waters for water supply. In 'Drinking water microbiology: progress and recent developments.' (Ed. GA McFeters) pp. 3–31. Springer-Verlag, New York.

Haas CN (1996) Acceptable microbial risk. *Journal of the American Waterworks Association* **88**, 8.

Haas CN, Rose JB and Gerba CP (1999) 'Quantitative microbial risk assessment.' John Wiley and Sons, New York.

Hierholzer JC (1991) Adenoviruses. In 'Manual of clinical microbiology.' (Eds A Balows, WJ Hausler Jr, KL Herrman, HD Isenberg and HJ Shadomer) pp. 896–903. 5th edn. American Society for Microbiology, Washington, DC.

Jobling S, Reynolds T, White R, Parker MG and Sumpter JP (1995) A variety of environmentally persistent chemicals, including some phthalate plasticizers, are weakly estrogenic. *Environmental Health Perspectives* **103**, 582–587.

Kelly J and Stevens DP (2002) 'Increasing acceptance and use of reclaimed water. A comparison of algae in bore and reclaimed water storage dams, and microbial contamination of vegetables irrigated with these water sources.' For the Northern Adelaide Hill Catchment Water Management Board, Salsibury, South Australia.

Kolpin DW, Furlong ET, Meyer MT, Thurman EM, Zaugg SD, Barber LB and Buxton HT (2002). Pharmaceuticals, hormones and other organic wastewater contaminants in US streams, 1999–2000: a national reconnaissance. *Environmental Science and Technology* **36**, 1202–1211.

Macler BA and Regli S (1993) Use of microbial risk assessment in setting US drinking water standards. *International Journal of Food Microbiology* **18**, 245–256.

Mazur W and Aldercreutz H (1998) Natural and anthropogenic environmental oestrogens: the scientific basis for risk assessment. Naturally occurring oestrogens in food. *Pure and Applied Chemistry* **70**, 1759–1776.

Messner MJ, Chappell CL and Okhuysen PC (2001) Risk assessment for Cryptosporidium: a hierarchical Bayesian analysis of human response data. *Water Research* **35**, 3934–3940.

National Research Council (1996) 'Use of reclaimed water and sludge in food crop production.' National Academies Press, Washington DC, USA.

NHMRC and NRMMC (2004) Australian drinking water guidelines, National Health and Medical Research Council and the Natural Resource Management Ministerial Council, Canberra.

NRMMC and EPHC (2005, draft) National guidelines for water recycling: managing health and environmental risks. Natural Resource Management Ministerial Council and Environment Protection and Heritage Council, Canberra. www.ephc.gov.au/ephc/water_recycling.html

OzFoodNet Working Group (2003) 'Foodborne Disease in Australia: Incidence Notifications and Outbreaks.' Annual report of the OzFoodNet Network, 2002. *Communicable Disease Intelligence* **27**(2), 209–243.

Regli S, Rose JB, Haas CN and Gerba CP (1991) Modelling the risk from Giardia and viruses in drinking water. *Journal of the American Water Works Association* **83**, 76.

Rose JB, Dickson LJ, Farrah SR and Carnahan RP (1996) Removal of pathogenic and indicator microorganisms by a full scale water reclamation facility. *Water Research* **30**, 2785–2797.

Safe S (2000) Endocrine disruptors and human health – is there a problem? An update. *Environmental Health Perspectives* **108**, 487–493.

Sheikh B, Cort R, Kirkpatrick W, Jacques R and Asano T (1990) Monterey wastewater reclamation study for agriculture. *Research Journal of the Water Pollution Control Federation* **52**, 216–226.

Shuval H, Lampert Y and Fattal B (1997). Development of a risk assessment approach for evaluating wastewater reuse standards for agriculture. *Water Science and Technology* **35** (11–12), 15–20.

Tanaka H, Asano T, Schroeder ED and Tchobanoglous G (1998) Estimating the safety of wastewater reclamation and reuse using enteric virus monitoring data. *Water Environment Research* **70**, 39–51.

US EPA (1999a) Endocrine disruptor screening and testing advisory committee (EDSTAC) final report. Office of Prevention, Pesticides and Toxic Substances, January 1999, Washington DC.

US EPA (1999b) Method 1623: Cryptosporidium and Giardia in water by filtration/IMS/FA. EPA–821-R–99–006, US EPA Office of Water, Washington DC.

WHO (2002) 'Global assessment of the state-of-science of endocrine disruptors.' International programme on chemical safety. World Health Organization, Geneva.

WHO (2004) 'Guidelines for drinking-water quality.' 3rd edn. World Health Organization, Geneva.

Yanko WA (1993) Analysis of 10 years virus monitoring data from Los Angeles County treatment plants meeting California reclamation criteria. *Water Environment Research* **65**, 221–226.