

## Application and refinement of the WHO risk framework for recreational waters in Sydney, Australia

N. J. Ashbolt and M. Bruno

### ABSTRACT

Local adaptation of the World Health Organisation (WHO) Farnham approach to managing pathogen risk in recreational waters was readily achieved given the extensive microbiological beach data for Sydney, and a clear understanding of applying the 'Annapolis Protocol' sanitary survey component to beach classification. Daily enterococci counts were predicted by rainfall (>10 mm in 24 h or >5 mm over 4–5 days), or by wind direction/speed, sunlight and tide during dry periods. Quantitative microbial risk assessment models (maximum risk exponential model for gastroenteritis and adenovirus exponential model for respiratory illness) fitted the United Kingdom epidemiological data and show potential for use. Flexibility in interpreting what is important for local conditions is essential, illustrated by replacing the general descriptions in the Farnham report with more ridged values for stormwater-impacted beaches. Hence, a user-friendly format for bather risk management, based on key environmental predictors of faecal pollution (such as rainfall, wind direction and tide) should largely replace the need for regular and costly microbiological testing; providing risk estimates in real time and allowing immediate control measures, such as signage or temporary beach closures. Ongoing testing resources should be directed to understanding the source(s) of faecal contamination, comparing enterococci/enteric virus survival under warm Australian conditions and spot checks for recalibration of environmental factors.

**Key words** | Annapolis Protocol, bathing water, enterococci, microbial risk assessment

**N. J. Ashbolt** (corresponding author)  
**M. Bruno**  
School of Civil and Environmental Engineering,  
UNSW-Sydney,  
NSW 2052,  
Australia  
Tel: +61-2 9385 5946  
Fax: +61-2 9385 6139  
E-mail: [N.Ashbolt@unsw.edu.au](mailto:N.Ashbolt@unsw.edu.au)

### INTRODUCTION

Enterococci were the first faecal indicators described by epidemiological studies to be strongly linked to bather health following exposure to marine waters (Cabelli *et al.* 1983). It was not until randomised control studies in England during the early 1990s, however, that sound justification for setting thresholds for gastrointestinal illness (GI, 32 CFU·100 ml<sup>-1</sup>) (Kay *et al.* 1994) and acute febrile respiratory illness (AFRI, 60 CFU·100 ml<sup>-1</sup>) (Fleisher *et al.* 1996) were generally acknowledged (Prüss 1998). As a consequence, the World Health Organisation (WHO) are developing new guidelines, which advocate 95th percentiles (with corresponding GI and AFRI risks respectively) for intestinal enterococci per 100 ml of 40 (<1%, <0.3%), 200 (1–<5%, 0.3–<1.9%) and 500

(5–10%, 1.9–3.9%) (WHO 2001; Kay *et al.* 2003). The faecal indicator group, (intestinal) enterococci, therefore appears to be a good index of enteric viruses, such as the ubiquitous Norwalk-like viruses (*Norovirus*) (Wyn-Jones *et al.* 2000) and possibly *Giardia* (Stuart *et al.* 2003), that are considered to be major aetiological agents for non-pool bathers (WHO 2001). In addition to the end-point values based on a lognormal distribution of enterococci, WHO and US-EPA have further developed the 'Annapolis Protocol' approach (WHO 1999), which introduced a second dimension to recreational water management, that of a risk scaling based on likely faecal contamination within the bathing water catchment (Table 1).

**Table 1** | Classification matrix for recreational water environments (WHO 2001)

Risk category identified by sanitary inspection (susceptibility to faecal influence)	Microbiological assessment category (intestinal enterococci/100 ml)				
	A 40	B 41–200	C 201–500	D >500	Exceptional circumstance‡
Very low	Very good	Very good	Follow up†	Follow up†	Action
Low	Very good	Good	Fair	Follow up†	Action
Moderate	Follow up*	Good	Fair	Poor	Action
High	Follow up*	Follow up*	Poor	Very poor	Action
Very high	Follow up*	Follow up*	Poor	Very poor	Action
Exceptional circumstance‡	Action	Action	Action	Action	Action

\*Indicates unexpected results requiring investigation.

†Implies non-sewage sources of faecal indicators (e.g. livestock), and this should be verified.

‡Exceptional circumstances relate to known periods of higher risk, such as during an outbreak with a pathogen that may be waterborne, trunk sewer/combined sewer rupture in the beach catchment, etc. Under such circumstances, the classification matrix would be superseded.

The WHO (and draft European Union Directive) now advocate that recreational water should not only be assessed by estimates from large (over 100) samples of enterococci counts (to describe 95th percentiles), but to also consider information from progressive sanitary surveys (WHO 2001). Sydney's recreational waters are assessed every 6 days for thermotolerant coliforms and enterococci, irrespective of the catchment risk to faecal pollution. Here we present an interpretation of how to use the new WHO framework, providing an additional level of detail to manage pathogen risk, which is appropriate for the conditions and level of knowledge associated with Sydney's bathing waters.

Therefore, the aims of this study were to:

1. Assess environmental factors that may be used to predict enterococci counts in various recreational waters in Sydney.
2. Investigate viral infection risks with quantitative microbial risk assessment models and compare with illness rates reported in the United Kingdom randomised studies.
3. Adapt the WHO framework by way of a case study.

## METHODS

Three coastal Sydney beaches were chosen on the basis of likely differing environmental effects and sources of faecal contamination (Table 2). Counts of thermotolerant coliforms (ThC) and enterococci every 6 days from 1997–2000 (NSW-EPA 2000) were compared against daily rainfall data (Bureau of Meteorology, averaged over three sites in each beach catchment), wind (speed and direction), sunlight hours and tidal state using SigmaStat (V2.03, SPSS Inc.). The prevailing wind direction on the day of sampling was averaged from the north/south component (cosine) and east/west component (cosine), based on 5-min interval data, calculated by multiplying the speed of the wind ( $\text{m}\cdot\text{s}^{-1}$ ) by the sine or cosine of the compass angle.

While thermotolerant coliforms increased following rainfall, counts readily returned to local compliance (Table 2), in contrast to the greater persistent and subsequently higher counts of enterococci, hence as suggested by WHO (2001), only enterococci data were analysed further.

**Table 2** | Sydney beaches' compliance, major pollution sources and rainfall response

Beach	Season	Percent compliance* to:		Pollution sources	Rainfall threshold
		Enterococci	ThC		
Bondi	96–97 summer	90	100	3 stormwater drains, bather shedding	> 10–15 mm/24 h (major peaks if > 2 events of 15 mm/24 h)
	98–99 summer	50	86		
Collaroy	96–97 summer	94	100	2 stormwater drains, Narrabeen lagoon discharge after heavy rain, sewer overflows	> 20 mm/24 h (major peaks if > 50 mm/24 h; smaller peaks if 5–10 mm over days to weeks)
	97–98 summer	84	100		
	98–99 winter/summer	45/81	100		
	99–00 winter/summer	68/87	100		
South Cronulla	96–97 winter/summer	52/87	100	7 stormwater drains and cliff face outfall (changed in April 2001)	> 10 mm in 24 h (4–5 days > 5 mm provided longer duration peaks)
	97–98 winter/summer	86/67	100		
	98–99 winter/summer	36/13	100		
	99–00 winter/summer	36/10	100		

\*NSW compliance is based on median <33 enterococci/100 ml or <150 thermotolerant coliforms (ThC)/100 ml. Rainfall threshold was the point on plots of faecal indicator versus rainfall where a strong association was first observed beyond the origin.

A comparison of the dose–response curves (exponential and  $\beta$ -Poisson) used in quantitative microbial risk assessment (QMRA) (Haas *et al.* 1999; Teunis & Havelaar 2000) was made against the rates of illness reported in the UK randomised epidemiology studies (Kay *et al.* 1994; Fleisher *et al.* 1996). A range of enterococci:enteric virus ratios were investigated to adjust the slope of the model curves, although a ratio of about 500:1 was anticipated (Grabow *et al.* 1998). Fixed variables were ingestion volume (50 ml) and percent infected becoming ill (50%).

## RESULTS AND DISCUSSION

### Influence of environmental factors on enterococci counts

Stepwise regression analysis using enterococci as the dependent variable consistently showed rainfall reported on the day of sampling (rather than in the previous 24 h)

to be the strongest predictor. These results were consistent with faecal indicator counts versus rainfall results for all of the Sydney beaches previously published (NSW-EPA 2000). What was new however, were peaks in enterococci counts in the absence of rain events being generally explained by wind effects. The prevailing summer south-easterly wind off Bondi and South Cronulla beaches at  $>7.5 \text{ m}\cdot\text{s}^{-1}$  appeared to direct (rising) primary sewage plume waters onshore (released at 60–80 m depth off Bondi, whereas at cliff edge at Cronulla) (Pritchard 1997). Furthermore, warmer, less saline (separate) storm waters also appeared to be trapped longer during these periods of south-east winds.

Sunlight hours on the day of sampling contributed to a significant decrease in counts, while sunlight hours the day before sampling showed little correlation. High enterococci counts were also associated with a rising or high tide some 70% of the time. Hence, rainfall alone was sufficient during wet events, whereas wind direction/speed, sunlight and tide were considered important in

**Table 3** | Example sanitary assessment scheme for stormwater discharges\*

Sanitary conditions	Stormwater dry weather enterococci counts (median CFU·100 ml <sup>-1</sup> )			
	<100	101-300	301-500	501-700
Combined sewer overflow/septic seepage impacted	Follow up	Follow up	High	Very high
Influenced by human excreta (e.g. aged sewer mains)	Medium	Medium	High	Very high
Not influenced by human excreta	Low	Medium	Follow up	Follow up

\*Scores based on Farnham Report risk matrix (WHO 2001).

explaining increased faecal loading to bathing waters during dry periods.

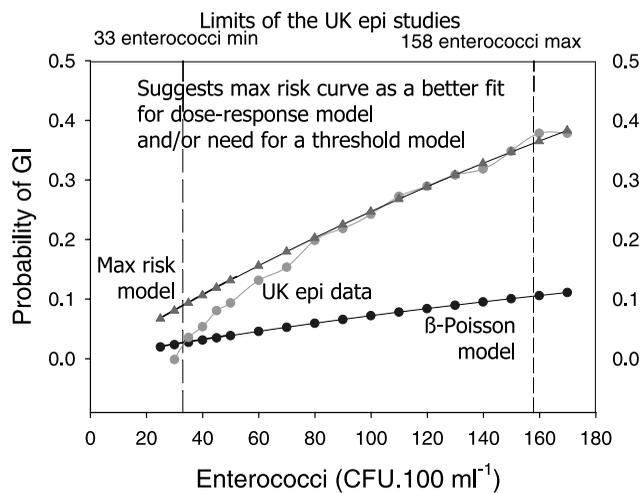
Of particular concern was the equal weighting applied in the Farnham Report to ocean outfalls and stormwater drains for the sanitary survey, given Sydney's attempt to run separate sewage and stormwater systems. In addition, enterococci may also arise from various sources, such as animals (so no human enteric viruses) and possibly coastal wetland/seaweed sources (Grant *et al.* 2001) (so no faecal association). Interestingly, for the three Sydney beaches, the previously poorest performing beach (South Cronulla) complied with local guidelines 100% following the upgrading of the local outfall from a cliff-edge primary to a tertiary-treatment facility. Hence, despite the presence of stormwater drains and normal onshore winds during the summer of 2001, minimal faecal pollution was detected at South Cronulla. As a result, further resolution to that described in the Farnham Report by way of an alternative ranking of stormwater drains is proposed for Sydney (Table 3), and a similar approach could be applied to riverine flow and bather shedding (Stewart *et al.* 2002; Soller *et al.* 2003).

In addition, the application of faecal sterols and *C. perfringens* to aid faecal source identification is recommended for spot checks (Ashbolt *et al.* 2000, 2002). It is important to note that in a 2-year survey (largely during dry periods) of stormwater drains in Sydney, enterococci numbers ranged from 60 to 3000 CFU·100 ml<sup>-1</sup>, while the overall mean proportion of 50-l samples containing cell-culture infective enteric viruses (adeno- entero- and reo-

viruses) was 11.1% with 95% confidence intervals (CI) of 7.01–17.4% (unpublished). Hence it would be reasonable to assume that despite the likely presence of domestic pet, animal and bird faeces in Sydney's separate storm water system, within the Sydney environs storm waters may well have some human sewage presence, presumably from leakage from the sewerage system.

### Relating indicators to infection risks

A comparison of the dose–response curves used in QMRA with rates of infection reported in the UK randomised control study revealed that the controversially steep curve associated with gastrointestinal infections in the latter (Kay *et al.* 2003) did not fit with the standard models, even with a highly infectious agent like rotavirus. However, a reasonable fit was obtained with the maximum risk curve ( $r=1$ , in the exponential model;  $P_{\text{infection}} = 1 - e^{-rD}$ ) (Teunis & Havelaar, 2000) (Figure 1), particularly for doses of greater than 60 enterococci·100 ml<sup>-1</sup>. Indeed, the maximum risk curve predicted greater illness than that measured for <60 enterococci·100 ml<sup>-1</sup>. This result supports the hypothesis that we may be underestimating gastrointestinal risk in sewage-impacted waters by a simple linear conversion of enterococci counts to pathogens present (as used in this study). In other words, despite a strong epidemiological association with enterococci counts that can be mathematically described (Wyer *et al.* 1999; Kay *et al.* 2003), the enterococci:pathogen ratio (or



**Figure 1** | Best virus dose-response model fits to UK epidemiological data for gastrointestinal illness (GI) (assuming enterococci:virus ratio 1:175, 50 ml ingestion and 50% of those infected become ill).

range of pathogens) may change in a quantitative sense, such as what one would expect from differential die-off of the two groups, and exemplified with counts between old to new faecal input. There may be value, therefore in using a more persistent faecal marker, such as *Clostridium perfringens* (Ashbolt *et al.* 1997) in future QMRA studies.

Conversely, a good fit was possible with the adenovirus exponential dose-response model (Crabtree *et al.* 1997) (assuming 1700 viruses·100 ml<sup>-1</sup> primary sewage) against AFRI, possibly reflecting that respiratory pathogens may persist more like enterococci in marine waters. Hence, these, and previous results (Ashbolt *et al.* 1997) suggest that crude QMRA models may provide sufficiently accurate estimates of bather risk to be of value and deserve more extensive evaluation. In the future, such models may even provide interim advice until epidemiological data can be collected for a bathing region shown to have different enterococci behaviour to those where the UK coastal epidemiological studies were undertaken.

The uncertainties in applying the results of the UK epidemiological data to regions like Sydney revolve around possible relative differences in the survival of enterococci and the major pathogens of concern (enteric viruses) in warm, clear waters subject to high sunlight intensities. Also, although *Giardia* cysts have been

detected in Sydney's coastal waters (data not published), cysts would be expected to rapidly become non-infectious in the warm waters (Johnson *et al.* 1995; Connolly *et al.* 1999).

Limited data are available on the relative persistence of enteric viruses and enterococci in bathing waters (Gantzer *et al.* 1998; Ricca & Cooney 1999; Aulicino *et al.* 2001; Noble & Fuhrman 2001). One cannot simply assume that coliphages are appropriate models for enteric virus behaviour, even though F-RNA coliphages and enterococci may behave in a similar way to environmental inactivation (Davies-Colley *et al.* 2000). For example, F-DNA coliphages are thought to only be inactivated by solar UV-B (300–320 nm) and unaffected by other factors, whereas enterococci and F-RNA coliphages appear to be inactivated by a wide range of wavelengths (300–550 nm) by (DO-dependent) photo-oxidation (Davies-Colley *et al.* 2000). It has been suggested that somatic coliphages may be the preferred index microbe for enteric viruses in marine waters, but F-RNA coliphages for freshwaters (Chung & Sobsey, 1993; Sinton *et al.* 2002). However, without data on the loss of infectivity of currently non-culturable enteric viruses, such as the human caliciviruses (*Norovirus*), it is safer to base a model on the most persistent phage group, or even the very persistent (Davies *et al.* 1995) spores of *C. perfringens*.

### Management options

Given the extensive 6-day sampling for microbiology and on-line rainfall and wind direction/speed information available for Sydney's beaches, a user-friendly format for bather risk management could be based on key environmental predictors of faecal pollution. Such that daily rainfall, wind direction and tide can in part replace regular and costly microbiological testing, and provide estimates of faecal pollution in real time and allow immediate control measures, such as (internet/radio/beach) signage or temporary beach closures.

As illustrated for storm waters (Table 3), further refinement of the Farnham Report sanitary conditions (WHO 2001) was necessary to more accurately reflect likely sanitary conditions at selected Sydney beaches.

Undertaking such changes to the qualitative risk matrices for sanitary surveys simply forces agencies to get back in touch with what factors really impact on bather risk for their region. Hence, improved sanitary inspections would be a sound replacement for time/money saved through the reduced microbiological monitoring recommended by WHO (2001).

## CONCLUSIONS

At Sydney's city bathing beaches, environmental factors appear to be good predictors for enterococci counts. Daily rainfall was the only parameter required when >10–20 mm fell in 24 h (or >5 mm over 4–5 days), the range covering the different beach catchments studied and reported by NSW-EPA (2000). Sunlight hours on the day of sampling contributed to a significant decrease in counts, and high enterococci counts were also associated with a rising or high tide some 70% of the non-rain event time. Hence, rainfall alone is sufficient during wet events, whereas wind direction/speed, sunlight and tide were considered important in explaining increased faecal loading to Sydney's bathing waters during dry periods.

QMRA models (maximum risk, exponential model for gastroenteritis and adenovirus exponential model for respiratory illness) were fitted to the UK epidemiological data, and show potential for use. In the absence of sound epidemiological data at beaches with enterococci behaviour likely to differ from the UK epidemiological study sites, QMRA may therefore provide supporting information for beach management. However, greater detail (than in the WHO Farnham Report) in ranking faecal source inputs, such as illustrated for Sydney's storm water is recommended as a higher priority for beach management.

With or without reduced microbiological compliance testing in Sydney, resources should be directed to understanding the source(s) of faecal contamination, comparing enterococci/enteric virus survival under Sydney's environmental conditions (clear warm water) and spot checks for recalibration of environmental factors with enterococci (or other indicators) at beaches.

## REFERENCES

- Ashbolt, N. J., Reidy, C. & Haas, C. N. 1997 Microbial health risk at Sydney's coastal bathing beaches. *Presented at the 17th Australian Water and Wastewater Association Meeting*, Melbourne, 16–21 March. AWWA, pp. 104–111.
- Ashbolt, N. J., Bartram, J., Calderon, R., Cotruvo, J., Dufour, A., Fleisher, J., Frick, W., Gearheart, R., Hearne, N., Jenkins, A., Jones, H., Day, D., McGee, C., Parker, L., Pond, K., Rees, G., Rosenblatt, D., Salas, H., Schaub, S. & van Maele, B. 2000 Approaches to microbiological monitoring. In *Monitoring Bathing Waters: A Practical Guide to the Design and Implementation of Assessments and Monitoring Programmes* (eds J. Bartram & G. Rees), pp. 167–218. E & F. N. Spon, London.
- Ashbolt, N., Roser, D., Leeming, R., Stevens, M., Laver, P., Magyar, C., Wade, A., Grooby, W. & Steffensen, D. 2002 Dry weather quality of protected versus developed surface water catchments—pathogen data and management. *Presented at the IWA 3rd World Water Congress*, Melbourne, Australia.
- Aulicino, F. A., Orsini, P., Carere, M. & Mastrantonio, A. 2001 Bacteriological and virological quality of seawater bathing areas along the Tyrrhenian coast. *Int. J. Environ. Hlth Res.* **11**, 5–11.
- Cabelli, V. J., Dufour, A. P., McCabe, L. J. & Levin, M. A. 1983 A marine recreational water quality criterion consistent with indicator concepts and risk analysis. *J. Wat. Pollut. Contr. Fed.* **55**, 1304–1314.
- Chung, H. & Sobsey, M. D. 1993 Comparative survival of indicator viruses and enteric viruses in seawater and sediments. *Wat. Sci. Technol.* **27**(3–4), 425–428.
- Connolly, J. P., Blumberg, A. F. & Quadri, J. D. 1999 Modeling fate of pathogenic organisms in coastal waters of Oahu, Hawaii. *J. Environ. Eng.* **125**, 398–406.
- Crabtree, K. D., Gerba, C. P., Rose, J. B. & Haas, C. N. 1997 Waterborne adenovirus—A risk assessment. *Wat. Sci. Technol.* **35**(11–12), 1–6.
- Davies, C. M., Long, J. A. H., Donald, M. & Ashbolt, N. J. 1995 Survival of fecal microorganisms in marine and freshwater sediments. *Appl. Environ. Microbiol.* **61**, 1888–1896.
- Davies-Colley, R. J., Donnison, A. M. & Sped, D. J. 2000 Towards a mechanistic understanding of pond disinfection. *Wat. Sci. Technol.* **42**(10–11), 149–158.
- Fleisher, J. M., Kay, D., Wyer, M. D., Salmon, R. L. & Jones, F. 1996 Non-enteric illnesses associated with bather exposure to marine waters contaminated with domestic sewage: the results of a series of four intervention follow-up studies. *Am. J. Pub. Hlth* **86**, 1228–1234.
- Gantzer, C., Dubois, E., Crance, J. M., Billaudel, S., Kopecka, H., Schwartzbrod, L., Pommepuy, M. & Le Guyader, F. 1998 Influence of environmental factors on the survival of enteric viruses in seawater [French]. *Oceanol. Acta* **21**, 983–992.
- Grabow, W. O. K., Vrey, A., Uys, M. & de Villiers, J. C. 1998 *Evaluation of the Application of Bacteriophages as Indicators*

- of Water Quality. WRC Report No 540/1/98. Water Research Commission, Pretoria.
- Grant, S. B., Sanders, B. F., Boehm, A. B., Redman, J. A., Kim, J. H., Mrse, R. D., Chu, A. K., Gouldin, M., McGee, C. D., Gardiner, N. A., Jones, B. H., Svejkosky, I., Leipzig, G. V. & Brown, A. 2001 Generation of enterococci bacteria in a coastal saltwater marsh and its impact on surf zone water quality. *Environ. Sci. Technol.* **35**(12), 2407–2416.
- Haas, C. N., Rose, J. B. & Gerba, C. P. 1999 *Quantitative Microbial Risk Assessment*. John Wiley & Sons, Inc., New York.
- Johnson, D. C., Reynolds, K. A., Gerba, C. P., Pepper, I. L. & Rose, J. B. 1995 Detection of *Giardia* and *Cryptosporidium* in marine waters. *Wat. Sci. Technol.* **31**(5–6), 439–442.
- Kay, D., Fleisher, J. M., Salmon, R. L., Jones, F., Wyer, M. D., Godfree, A. F., Zelenauch-Jacquotte, Z. & Shore, R. 1994 Predicting likelihood of gastroenteritis from sea bathing: results from randomised exposure. *Lancet* **344**, 905–909.
- Kay, D., Bartram, J., Prüss, A., Ashbolt, N., Dufour, A., Wyer, M., Fleisher, J., Fewtrell, L. & Rogers, A. 2003 Derivation of numerical values for the World Health Organization guidelines for recreational waters. *Wat. Res.* (submitted).
- Noble, R. T. & Fuhrman, J. A. 2001 Enteroviruses detected by reverse transcriptase polymerase chain reaction from the coastal waters of Santa Monica Bay, California: low correlation to bacterial indicator levels. *Hydrobiol.* **460**, 175–184.
- NSW-EPA 2000 *BeachWatch Report 1998–1999*. New South Wales Environmental Protection Agency, Sydney.
- Pritchard, T. 1997 Environmental performance of Sydney's deepwater outfalls. *Water—J. Am. Wat. Wrks Assoc.* **24**, 29–34.
- Prüss, A. 1998 Review of epidemiological studies on health effects from exposure to recreational water. *Int. J. Epidemiol.* **27**, 1–9.
- Ricca, D. M. & Cooney, J. J. 1999 Coliphages and indicator bacteria in Boston Harbor, Massachusetts. *Environ. Toxicol.* **14**, 404–408.
- Sinton, L. W., Hall, C. H., Lynch, P. A. & Davies-Colley, R. J. 2002 Sunlight inactivation of fecal indicator bacteria and bacteriophages from waste stabilization pond effluent in fresh and saline waters. *Appl. Environ. Microbiol.* **68**, 1122–1131.
- Soller, J., Olivieri, A., Eisenberg, J., Spear, R. & Tchobanoglous, G. 2003 Discussion: “Predicted public health consequences of body-contact recreation on a potable water reservoir”. *J. Am. Wat. Works Assoc.* **95**, 109–111.
- Stewart, M. H., Yates, M. V., Anderson, M. A., Gerba, C. P., Rose, J. B., De Leon, R. & Wolfe, R. L. 2002 Predicted public health consequences of body-contact recreation in a potable water reservoir. *J. Am. Wat. Works Assoc.* **94**, 84–97.
- Stuart, J. M., Orr, H. J., Warburton, F. G., Jeyakanth, S., Pugh, C., Morris, I., Sarangi, J. & Nichols, G. 2003 Risk factors for sporadic giardiasis: a case-control study in southwestern England. *Emerg. Infect. Dis.* **9**, 229–233.
- Teunis, P. F. M. & Havelaar, A. 2000 The beta Poisson dose-response model is not a single hit model. *Risk Anal.* **20**, 511–518.
- WHO 1999 *Health-based Monitoring of Recreational Waters: The Feasibility of a New Approach (The “Annapolis Protocol”)*. World Health Organization, Geneva.
- WHO 2001 *Bathing Water Quality and Human Health: Faecal Pollution Outcome of an Expert Consultation, Farnham, UK, April 2001*. Co-sponsored by Department of the Environment, Transport and the Regions, United Kingdom. World Health Organization, Geneva.
- Wyer, M. D., Kay, D., Fleisher, J. M., Salmon, R. L., Jones, F., Godfree, A. F., Jackson, G. & Rogers, A. 1999 An experimental health-related classification for marine waters. *Wat. Res.* **33**, 715–722.
- Wyn-Jones, A. P., Pallin, R., Deboussis, C., Shore, J. & Sellwood, J. 2000 The detection of small round-structured viruses in water and environmental materials. *J. Virol. Meth.* **87**, 99–107.