

Drinking water, ecology, and gastroenteritis in New Zealand

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Abstract New Zealand has good quality drinking water derived from thousands of streams, rivers, lakes and aquifers fed by regular rainfalls ranging from 400 to 11 000 mm year⁻¹. These waters are treated variously to provide over 80% of 3.6 million inhabitants with satisfactory drinking water. By international standards, New Zealand nevertheless has high incidence rates of potentially waterborne diseases such as campylobacteriosis, cryptosporidiosis, and giardiasis. Traditional public health interventions aimed at reducing the incidence of these diseases generally focus on water treatment and personal and food hygiene. However, continuing epidemics of most enteric diseases in New Zealand indicate that this approach is often less than effective. A broader approach might lie in the study of whole ecosystems to understand the interactions between climate, vegetation, geology, pathogens, animals and humans. For example, pastoral farming removes deep-rooted vegetation from hill sides and river banks, increasing the volume and speed of runoff during heavy rains, and thereby reducing natural self-purification of water contaminated by stock excrement. Stock or humans drinking water downstream may now arguably be exposed to pathogens more frequently than they would have been with a single contamination event following an exceptional flood. Ecological analysis of this kind can result in novel recommendations for the type, time and place of public health interventions, with a consequent reduction in the frequency with which pathogens contaminate water. A direct source of both human and stock infection is thereby removed, as are various sources of secondary human infection (meat from infected stock and faecal contamination from infected stock and humans, for example).

INTRODUCTION

Ecology is the study of relationships between the various components of living systems, and it follows that the ecology of waterborne diarrhoeal disease is an analysis of the way in which certain human pathogens such as *Campylobacter*, *Cryptosporidium* and *Giardia*, interact with their environment to cause disease. Naturally, there are the properties of the organisms themselves, coded in their genetic makeup, that determine if they cause human disease or not—factors that influence, for example, host specificity and virulence. There are also properties of the host humans that determine whether such organisms will cause disease. It is well known, for example, that infection with *Cryptosporidium* can be asymptomatic in some people, yet fatal in others who are immuno-compromized. However, from the perspective of the water industry, of greater interest is the role played by the environment in facilitating the spread of these diarrhoeal diseases, particularly through the medium of drinking water.

SOURCES OF DRINKING WATER IN NEW ZEALAND

New Zealand is more fortunate than many countries in that there are generally ample supplies of water for people, agriculture, and industry, with minor exceptions due to urban excesses and some intermittently drought affected agricultural regions. Regional rainfall in New Zealand ranges from 400 to 11 000 mm year⁻¹, feeding thousands of streams, rivers, lakes and aquifers (Tomlinson, 1992). Some 15% of the population draw their water directly from this rainfall by collecting it off roofs in storage tanks, resulting in drinking water of highly variable microbial quality (Hope, unpublished data). To the remainder of the population, surface waters provide about 60% of the water consumed, with groundwater making up the balance (Ministry for the Environment, 1997). These surface waters are of high quality by international standards (particularly in the South Island), but are being increasingly contaminated by microbes from agricultural and urban runoff. Because microbial contamination is rarely a problem with groundwater (although leachates and pesticides can be), the discussion of the ecology of waterborne protozoal disease will focus largely on surface waters as potential sources of human infection.

WATERBORNE *Campylobacter*

Infection with *Campylobacter* can cause a spectrum of disease, most commonly an acute enteritis (campylobacteriosis) with diarrhoea, abdominal pain, fever, nausea and vomiting. The disease is generally self-limiting and over within 3–4 days, but more serious complications can occur. Diagnosis is confirmed by growing the organisms from faecal specimens on selective culture media, and *Campylobacter jejuni* is most commonly involved. Campylobacteriosis is thought to account for about 10% of all diarrhoea world wide (Benenson, 1995), and is the most commonly reported disease in many countries including New Zealand. Poultry, cattle, pets and other animals act as reservoirs for the organism, and the most significant risk factors for infection in New Zealand are the consumption of raw or undercooked chicken (Ikram *et al.*, 1994; Eberhart-Phillips *et al.*, 1997), and contaminated drinking water (Brieseman, 1987; Stehr-Green *et al.*, 1991; Bohmer, 1997). However, public health interventions focused solely on these risk factors may have limited effectiveness, and have done little to reduce morbidity from the disease.

The rate of campylobacteriosis in New Zealand in 1993 was twice the rate of notification in England, and more than three times the rate in Australia and Canada (New Zealand Communicable Disease Centre, 1993); it is now over 200 cases per 100 000 per year (ESR, 1997). The direct cost of campylobacteriosis to the New Zealand community is estimated to be NZ\$4.48 million per year, with true costs possibly in the order of NZ\$40 million per year when under-reporting is considered (Withington & Chambers, 1997). There are good grounds to believe that climatic and agricultural factors are important influences on the prevalence of the organism in the New Zealand environment. Outbreaks of campylobacteriosis that were linked to the water supply have followed heavy rain, and are likely to be related to nearby grazing animals (Brieseman, 1987; Stehr-Green *et al.*, 1991). In other countries, the

importance of extreme rainfall events for waterborne gastroenteritis has also been demonstrated (Bolton *et al.*, 1987; Patz *et al.*, 1996), and the suggestion has been made that horizontal transmission from the environment is the most likely route for infection of new chicken flocks (Jacobs-Reitsma *et al.*, 1995).

The traditional public health interventions aimed at reducing the incidence of campylobacteriosis focus on water treatment and personal and food hygiene. A more effective approach may be to reduce the frequency with which the organism contaminates food and water in the first place, thereby reducing the number of primary infections that can subsequently seed further infections in the community. Such primary prevention requires a detailed knowledge of the ecology of the disease, including consideration of the interactions between climate, vegetation, and reservoir animals. By adopting an ecological approach of this kind, recommendations for public health interventions that are not otherwise obvious may result. For example, when applied to the mosquito borne disease Ross River virus in Australia, this approach led to a fundamental change in the recommendations for vector control (Weinstein, 1997). We are currently modelling the combinations of environmental factors that coincide with high regional notification rates of campylobacteriosis. Using Geographic Information Systems (GIS), we are attempting to understand how agricultural practices and climate interact to result in waterborne campylobacteriosis, and hope to thereby reduce the seeding of *Campylobacter* in places where outbreaks could subsequently arise (e.g. daycare centres, abattoirs).

WATERBORNE *Cryptosporidium*

Cryptosporidiosis is a diarrhoeal disease caused by infection with the protozoan *Cryptosporidium parvum*. Infection is asymptomatic in some individuals, but may also cause profuse watery diarrhoea with other gastrointestinal symptoms. Children and the elderly may be particularly severely affected, and in those with concurrent HIV infection or otherwise compromised immune systems, the infection can be lethal. (There is no reliable curative treatment, partly because infection is intracellular.) Oocysts of the parasite can be identified in faecal smears by Enzyme Linked Immunosorbent Assay (ELISA) and in water samples following filtration. Novel techniques are also under development, including immunomagnetic separation (Ionas *et al.*, 1997). World wide in distribution and found in over a dozen other vertebrates, *Cryptosporidium parvum* has been responsible for a large number of faecal-oral, food-borne, and waterborne epidemics, none more famous than the Milwaukee outbreak when 403 000 individuals were symptomatically infected through a contaminated water supply, with 4000 hospitalizations and 104 deaths (MacKenzie *et al.*, 1994).

From an ecological perspective, the key features of this organism are first, its high resistance to chlorination and ability to pass through most filters in municipal water treatment plants, and second, the existence of an animal reservoir which can infect people both by direct contact and by faecally contaminating water supplies. Although *Cryptosporidium* has been implicated in a number of outbreaks of diarrhoeal disease in New Zealand, the first clearly documented epidemic occurred in 1998, most likely as a result of a faecal accident contaminating at least one public swimming pool (Baker *et*

al., 1998). A human reservoir for *Cryptosporidium* was almost certainly involved in this outbreak, but it remains unclear if the organism was originally introduced into the human population from an animal or drinking water source.

The rate of cryptosporidiosis in New Zealand is 9.8 cases per 100 000 (ESR, 1998), on a par with England on 8.3, but below Scotland's 17 per 100 000 (Public Health Laboratory Service, 1998). Anecdotally, such high rates appear to occur in countries with a high proportion of the country devoted to agricultural use like Scotland and New Zealand—the latter of which has over 50% of land devoted to agriculture and very high stocking densities by world standards (Ministry for the Environment, 1997). There is no reason to suspect that hygiene in, for example, daycare centres or swimming pools is lower in New Zealand than any other country, and the question must therefore be asked: does our ubiquitous farm animal reservoir play a significant role in the transmission of cryptosporidiosis in this country?

School farm visits are a recognized risk factors for outbreaks of cryptosporidiosis (Shield *et al.*, 1990), presumably because of the direct contact between children and farm animals. In Scotland such visits have now been banned, and a national case control study of risk factors for cryptosporidiosis in New Zealand is underway to determine exactly what proportion of the disease burden could be saved by implementing such measures. In that study, we are paying particular attention to the potential importance of the few cases that may be responsible for bringing *Cryptosporidium* from the animal reservoir into an outbreak scenario. For example, as our interim data stand following the massive outbreak in swimming pools, one might conclude that a large percentage of cases results from exposure to the organism in recreational waters. However, rather than spending hundreds of thousands of dollars on upgrading pool filter systems (as has occurred), it may be possible to prevent the person who had the faecal accident from becoming infected with *Cryptosporidium* in the first place. If this original (index) case acquired the infection either by direct contact with farm animals or by drinking water contaminated by farm or other animals, the frequency of such outbreaks would obviously be reduced by minimizing contact with farm animals and by keeping them out of water catchment areas. A possible explanation for New Zealand's high rates of cryptosporidiosis lies in the frequent violations of such basic public health precautions.

We are currently attempting to correlate regional *Cryptosporidium* rates with the quality of the water catchment in the same area, and with the degree of treatment to which that water has been subject. If our suspicion that stock seed infections through the water supply is well founded, we expect to see lower rates of cryptosporidiosis in areas supplied by catchments with natural vegetation cover. With New Zealand's many diverse water sources, the country forms a natural experiment for the analysis of the relationship between ecosystem (catchment) health and human health.

WATERBORNE *Giardia*

Giardiasis is another protozoal diarrhoea, caused by *Giardia lamblia*. Infection may be asymptomatic or associated with mild to severe diarrhoea, usually with abdominal cramps and greasy stools. Infection is rarely fatal, because the parasite adheres to the

intestinal mucosa where it can be readily attacked with oral antiprotozoal agents. This fact is often used to differentiate the infection empirically from cryptosporidiosis, which does not respond to antiprotozoal agents. The organism is worldwide in distribution and identified in both faecal and environmental samples by special staining to detect cysts (or trophozoites) on microscopy. In most countries and including New Zealand, it has been implicated in outbreaks due to direct faecal-oral transmission (e.g. daycare centres) as well as faecal contamination of food and water.

Based on laboratory data, the rate of giardiasis in New Zealand is high by international standards (84.7 cases per 100 000 compared with England's 13.5 and Scotland's 2.4; New Zealand Communicable Disease Centre, 1993). The reasons for these high rates may be similar to those discussed for cryptosporidiosis, but the nature of the reservoir for *Giardia* is less clear. The organism may have an animal reservoir similar to that for *Cryptosporidium*, and possibly including possums, or a human reservoir may be the predominant one with strain differences determining host specificities. In either case, the presence of the organism in the freshwaters of New Zealand's National Parks again signals a relationship between ecosystem health and human health. Although New Zealand's environment is one of the cleanest in the world and a great source of attraction to environmentally conscious tourists, there are signs in many of our National Parks warning visitors to boil their drinking water because of *Giardia*. In other parks, the tourists themselves are possibly contaminating the very ecosystem they have come to admire.

AN ECOLOGICAL APPROACH TO FUTURE STUDIES

We have described a possible scenario to help explain the high rates of campylobacteriosis, cryptosporidiosis, and giardiasis in New Zealand: pathogens of animal or human origin contaminate our freshwaters frequently, and infect both animal and human consumers down stream. These consumers can transmit the disease to large numbers of secondary cases by faecal-oral spread in, for example, food preparation, daycare, and even swimming pools. People drinking water from catchments unaffected by agriculture and tourism are therefore considered less likely to become infected and therefore less likely to seed further infections in their area.

The very complexity of this scenario precludes a traditional epidemiological approach to establishing its validity or otherwise. A suitable alternative approach can be borrowed from the science that specializes in the study of relationships between the components of living ecosystems—ecology. The question then becomes one of establishing the key environmental determinants of distribution and abundance of *Campylobacter*, *Cryptosporidium* and *Giardia* in an ecosystem which includes humans. Using this approach we are building spatial models to identify the possible combinations of environmental determinants that may increase the incidence of disease. Mapping these combinations can provide clues to "hot spots" in New Zealand, wherein more detailed hypothesis-testing studies can then be carried out.

A further advantage of such an ecological analysis is that it can help identify data deficiencies for monitoring both ecosystem health and human health. For example, we know that up to a quarter of New Zealand's freshwaters contain *Cryptosporidium* and

Giardia (Brown *et al.* 1998), but these data are not at a sufficient level of resolution to carry out correlations between the incidence of organisms in the environment and the regional rates of human infection. Our scenario also requires some knowledge of the levels of protozoa in sources of stock drinking water, because stock could later seed infections elsewhere. The New Zealand Ministry for the Environment's current freshwater microbial study may provide some of the data required, and highlights the importance of multidisciplinary and multi-institutional collaboration in the analysis of whole ecosystems.

For argument's sake, assume that our analysis were to demonstrate an increase in cases and secondary sources of human infection (meat from infected stock, faecal contamination from infected stock and humans), in areas where pastoral farming and climate combine to lead to a high incidence of human pathogens in freshwater supplies. A public health intervention aimed at reducing the incidence of disease may then be to re-forest the catchment area. Without an ecological analysis, it is possible instead that the recommendation would have been made to upgrade the filtration and disinfection procedures at water treatment plants—a far more costly and less efficient exercise.

A final point relates our current knowledge of the ecology of waterborne diarrhoeal pathogens in New Zealand to our future management of our diarrhoeal disease burden. We have highlighted that public health interventions based on an ecological analysis are not always the most obvious. Therefore, if we do not establish the scientific rationale for such interventions in the present state of our ecosystem, we will have little hope of containing these diseases in the future: the ecology of waterborne diarrhoeal disease in New Zealand will be rendered infinitely more complex by the addition of influences leading to "emerging pathogens" (Russell *et al.*, 1998) and global climate change (Hales *et al.*, 1997). If we do not establish scientifically sound and ecologically based management strategies for waterborne disease in New Zealand in the present, we will have little hope of doing so in the future, to the ultimate detriment not only of human health, but of agricultural production, tourism, and our unique ecosystems generally.

REFERENCES

- Baker, M., Russell, N., Rosevere, C., O'Hallahan, J., Palmer, S. & Bichen, A. (1998) Outbreak of cryptosporidiosis linked to Hutt Valley swimming pool. *NZ Public Health Report* 5, 41–45.
- Benenson, A. S. (1995) *Control of Communicable Diseases Manual* (sixteenth edn). American Public Health Association, Washington DC, USA.
- Bohmer, P. (1997) Outbreak of campylobacteriosis at a school camp linked to water supply. *NZ Public Health Report* 4, 8.
- Bolton, F. J., Coates, D., Hutchinson, D. N. & Godfree, A. F. (1987) A study of thermophilic *Campylobacters* in a river system. *J. Appl. Bacteriol.* 62, 167–176.
- Brieseman, M. A. (1987) Town water supply as the cause of an outbreak of *Campylobacter* infection. *NZ Medical J.* 100, 212–213.
- Brown, T. J., Ionas, G., Learmouth, J. J., Keys, E. A. & McLenachan, P. A. (1998) The distribution of *Giardia* and *Cryptosporidium* in New Zealand waters: a nation wide survey. *Water and Waste NZ* 101, 60–63.
- Eberhart-Phillips, J., Walker, N. & Garrett, N. (1997) Campylobacteriosis in New Zealand: results of a case control study. *J. Epidemiol. and Community Health* 51, 686–691.
- ESR (Environmental Science and Research) (1997) National surveillance data. *NZ Public Health Report* 4, 86.
- ESR (Environmental Science and Research) (1998) National surveillance data. *NZ Public Health Report* 5, 2.
- Hales, S., Weinstein, P. & Woodward, A. (1997) Public health impacts of global climatic change. *Reviews on Environmental Health* 12, 191–199.

- Ikram, R., Chambers, S., Mitchell, P., Brieseman, M. A. & Ikram, O. H. (1994) A case control study to determine risk factors for *Campylobacter* in Christchurch in the summer of 1992–93. *NZ Medical J.* **107**, 430–432.
- Ioanas, G., Learmonth, S. D. & Keys, E. A. (1997) What is *Cryptosporidium*? Is it found in New Zealand waters? Can we improve current methods of detection? In: *Proc. 39th NZ Water and Waste Association Conf.* (Rotorua, August 1997), 115–120.
- Jacobs-Reitsma, W. F., Van de Giessen, A., Bolder, N. M. & Mulder, R. W. A. W. (1995) Epidemiology of *Campylobacter* spp. at two Dutch broiler farms. *Epidemiol. and Infection* **114**, 413–421.
- Ministry for the Environment (1997) *The State of New Zealand's Environment 1997*. Ministry for the Environment, Wellington, New Zealand.
- MacKenzie, W. R., Hoxie, N. J. & Proctor, M. E. (1994) A massive outbreak in Milwaukee of *Cryptosporidium* infection transmitted through public water supply. *New England J. Medicine* **331**, 161–167.
- New Zealand Communicable Disease Centre (1993) Surveillance Summary. *Communicable Disease New Zealand*. Supp. 1. NZCDC, Wellington, New Zealand.
- Patz, J. A., Epstein, P. R., Burke, T. A. & Balbus, J. M. (1996) Global climate change and emerging infectious diseases. *J. Am. Medical Assoc.* **275**, 3.
- Public Health Laboratory Service (1998) Public Health Laboratory Service Communicable Disease Surveillance Centre, *Cryptosporidium Capsule* **3**, 6.
- Russell, N., Weinstein, P. & Woodward, A. (1998) Cryptosporidiosis: an emerging microbial threat in the Pacific. *Pacific Health Dialog* **5**, 137–141.
- Shield, J., Baumer, J. H. & Dawson, J. A. (1990) Cryptosporidiosis: an educational experience. *J. Infection* **21**, 297–301.
- Stehr-Green, J. K., Nicholls, C., McEwan, S., Payne, A. & Mitchell, P. (1991) Waterborne outbreak of *Campylobacter jejuni* in Christchurch: the importance of a combined epidemiologic and microbiologic investigation. *NZ Medical J.* **104**, 356–358.
- Tomlinson, A. I. (1992) Precipitation and the atmosphere. In: *Waters of New Zealand* (ed. by M. P. Mosley), 63–74. Caxton Press, Christchurch, New Zealand.
- Weinstein, P. (1997) An ecological approach to public health intervention: Ross River virus in Australia. *Environmental Health Perspectives* **105**, 364–366.
- Withington, S. & Chambers, S. (1997) The cost of campylobacteriosis in New Zealand in 1995. *NZ Medical J.* **110**, 222–224.