Erfaringer fra Skottland basert på mange års overvåking av vannkilder
eller
Giardia and *Cryptosporidium* in water; some work from UK and its potential relevance to Norway

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Introduction

From 1990 I was based at the Scottish Parasite Diagnostic Laboratory (SPDL), Stobhill NHS Trust, in Glasgow, Scotland. In UK, SPDL has been a prominent laboratory in the field of research concerned with protozoan parasites in water. Much of the research undertaken there has been done with the support of Division of Environmental Health, Department of Civil Engineering at the University of Strathclyde, also located in Glasgow.

Amongst the work I have been involved with at SPDL, the following topics have been of importance;

1) surveillance: ongoing surveillance on occurrence of *Cryptosporidium* and *Giardia* in water
2) epidemiology: the occurrence and epidemiology of severe cryptosporidiosis and giardiasis, resulting in hospitalisation
3) outbreaks: investigation of outbreaks of waterborne or water-associated cryptosporidiosis and giardiasis.

Furthermore, detection of *Cryptosporidium* oocysts and *Giardia* cysts in water supply leads to the following questions:

1. are the parasites viable (alive)?
2. what is an effective means of killing them?
3. where do they come from?

I have also been involved in research work which seeks to address these concerns. In particular I have been involved in the development of a viability assay for *Cryptosporidium* oocysts (Campbell et al, 1992; Robertson et al, 1993), studies on the survival of *Cryptosporidium* oocysts in the environment (Robertson et al, 1992), studies on methods of water disinfection and their efficacy at inactivating *Cryptosporidium* oocysts (Campbell et al, 1995; Campbell et al, 1997), and studies on the occurrence, removal and destruction of both these parasites in sewage (Robertson et al, 1995a, 1995b & submitted, Whitmore and Robertson, 1995).

Below, as well as giving a brief overview of the three topics listed above, I will also give some information on our attempts to research some aspects of the last of the three questions. The questions of viability and survival are such broad topics that there is insufficient time to address them here.

Severe giardiasis and cryptosporidiosis (requiring hospitalisation) in Scotland

By using hospital discharge data compiled on a Scottish data base, and, where applicable by consulting hospital records, information on the extent of severe infection with *Giardia* and *Cryptosporidium* over a five year period was obtained and analysed (Robertson, 1996). This gave interesting comparative data, which could also be contrasted with those obtained in a similar study conducted in US concerned with hospitalisation due to severe giardiasis (Lengerich et al, 1994). In the Scottish study an attempt was also made to estimate the annual cost of these infections, basing the figures on published figures. It should be emphasised that these costs do not include the important, and insidious, costs of lost work, missed education, social costs etc. Some of the data is summarised in table 1 below.

For each patient, data was usually unavailable on the likely source of infection; both cryptosporidiosis and giardiasis can be transmitted directly (person to person or animal to person) or indirectly via a transmission vehicle such as food or water.

Table 1: Severe giardiasis and cryptosporidiosis in Scotland, 1990-1994 (based on data from Robertson, 1996)

	Giardiasis	Cryptosporidiosis
Mean no.cases hospitalised/year	38	65
Median duration of hospitalisation	3 days	4 days
Median age of patients	30 years	5 years
Mean no.lab. reports/year	368	903
Percentage hospitalised	10	7
Estimated annual costs	£31,000	£53,000

Outbreaks of waterborne cryptosporidiosis and giardiasis

Acquisition and collation of data concerning past waterborne outbreaks of cryptosporidiosis and giardiasis is important in attempting to assess why they have occurred and what factors are of importance in working towards prevention of recurrence. In table 2, some details of waterborne outbreaks of cryptosporidiosis and giardiasis are described. This table is not comprehensive but gives an overview of some of the factors in some of the outbreaks. A more detailed and comprehensive review of waterborne outbreaks of cryptosporidiosis has recently been published (Craun et al, 1998). An important point to note is that during these outbreaks, frequently cysts or oocysts have not been detected in the water supply, and that when they have been detected, numbers have generally been low. This provides an interesting contrast with the numbers of *Cryptosporidium* oocysts and *Giardia* cysts detected in Sydney's water supply in Australia between late July and mid-September this year (1998). Whilst there was no apparent increase in the incidence of cryptosporidiosis and giardiasis in the population affected by this incident, numbers as high as 10,000 parasites per 100 L were reported. This clearly contrasting data with apparently gross contamination of water supply obviously raises a series of questions which a large number of researchers, particularly in Australia, will doubtless be considering in the months ahead. Possible reasons which have been put forward (Anonymous, 1998) include:

1) Boil water protection. The 'boil water' notices enabled most of the population to protect themselves from infection by these parasites. However, the time lag from sampling until test result is at least 6 hours, so the affected water would have already passed into the distribution system. Furthermore, surveys conducted over this period indicate that only between 64-74% of the affected population complied with the 'boil water' recommendation.

2) Species. It has been suggested that the species of parasite may not have been infective to humans. In particular it has been proposed that the initial source of contamination was from feral ruminants, feral pigs or marsupials excreting species or strains of parasite which cannot infect humans.

3)Viability and infectivity. It has been suggested that the parasites present in the water were either dead, or damaged to such an extent that they would not be capable of initiating infection. Apparently viability assessment was made on some of the parasites isolated in the water, but the data on this is presently unavailable.

4) Immunity. It has been suggested that the high levels of parasites in Sydney's water supply may not be unusual, and was only detected recently because of improved monitoring. If this was so, it has been argued, that much of Sydney's population may have already been exposed to these parasites over a prolonged period and have acquired immunity to them. However, this would not explain why a rise in incidence of these infections was not observed in those who would not have had the opportunity to develop such immunity, for example babies, or newcomers and visitors to Sydney.

5) Surveillance sensitivity. It has been suggested that infection with these parasites may have increased in Sydney, but the surveillance system is insufficiently sensitive to have detected this. Whilst it is usual for only a small proportion of individuals who develop diarrhoea for any reason to seek medical attention, and of those only a small proportion will submit specimens for analysis, and of those only a small proportion will be analysed for parasites, this does not seem a likely explanation here. Not only was there considerable, high profile publicity, prompting the public to seek medical investigation for any gastro-intestinal disorder, but also in a previous outbreak of cryptosporidiosis in Sydney, associated with a swimming pool, the surveillance system was sufficiently sensitive to detect an increase in illness rates.

Legislation

The two most recent waterborne outbreaks of cryptosporidiosis described in table 2, one in Devon, England and one in Milwaukee, USA have given fresh impetus to the formulation of legislation in both USA and UK for protection of water supplies against being vehicles for parasitic infection. In UK, the government Department of Environment, Transport and Regions (DETR) has prepared and published a consultation paper *«Preventing Cryptosporidium getting into Public Drinking Water Supplies»*. This document is apparently available for perusal on the WWW at: www.environment.detr.gov.uk/wqd/consult/crypto/. In USA, the Environmental Protection Agency (EPA) has formulated Information Collection Rules (ICR), Enhanced Surface Water Treatment Rules (ESWTR), and is in the process of completing Method 1622, a proscribed system for analysing water samples for *Cryptosporidium*.

The legislation proposed by UK and USA have some fundamental differences, as well as some similarities. Important aspects of the proposed legislation for both UK and USA are described in table 3. The UK legislation was purportedly triggered by a court ruling that the report of an outbreak investigation team was inadmissible as evidence in the prosecution of a water company following a *Cryptosporidium* outbreak (Anonymous, 1998). It is reported that instead of pursuing improvements in investigative procedures to enable such prosecutions to be feasible under existing laws, the UK government has opted to impose a set of stringent regulations on water supply companies, with the backup of the threat of prosecution and unlimited fines (Anonymous, 1998). It is also deduced that in this format, prosecution of companies could be commenced even when there is no evidence of illness associated with a breach of the prescribed standard (Anonymous, 1998).

Table 2: Some outbreaks of waterborne cryptosporidiosis and giardiasis

CRYPTOSPORIDIOSIS			
Location	**No. affected**	**Oocysts/cysts detected in water**	**Possible cause**
Texas, USA	79	None detected	Sewage contamination of well
Georgia, USA	13,000	0,63-2,2/L	Operational procedure faults
Ayrshire, Scotland	27	0,04-4,8/L	Post-treatment contamination
Swindon, England	516	0,002-77/L	Slurry contamination of raw water
Isle of Thanet, England	>47	None detected	Unknown
Milwaukee, USA	403,000	0,13/L in ice	Contamination of raw water
Devon, England	600	Oocysts detected	Contamination of raw water
GIARDIASIS			
Sälen, Sweden	>1400	Cysts not detected	Sewage contamination
Bristol, England	108	Cysts not detected	Post-treatment contamination
Massachusetts, USA	703	Cysts detected	Operational difficulties
Across USA, 1965-1986	Over 23000 individuals affected in more than 90 separate incidents		

Table 3: Comparison of UK and USA legislation for monitoring of water supply for *Cryptosporidium*

UK PROPOSED LEGISLATION	USA LEGISLATION
Continuous monitoring of final water	Initial monitoring of raw water
1000 L of final water for each analysis	10 L of raw water for each each analysis
Analysis to be conducted independent of water companies	Analysis to be conducted by approved laboratories
Method: filter, IMS, microscopy	Method filter, IMS, micrnscopy
Finished water to contain less than 1 oocyst per 10 litres	If more than 1 oocyst per litre detected, final water must be monitored

Occurrence of *Cryptosporidium* oocysts in UK waters

Given the number of waterborne outbreaks of cryptosporidiosis which have occurred in UK and the low concentrations of oocysts which have been detected in water during these outbreaks, there is considerable interest in gaining information about the numbers of *Cryptosporidium* oocysts in water in the absence of any outbreak. Acquisition of such background data is not only pertinent for increasing our knowledge about this parasite, but also for identification of risk factors. In tables 4 and 5, data from two separate studies are summarised; the first (The National Cryptosporidium Survey Group, 1992) based on water samples taken in England, and the second (Humphreys et al, 1995) based on water samples taken in Scotland.

In the first survey (table 4; The National Cryptosporidium Survey Group, 1992) a considerable difference was noted between water sources on the occurrence of *Cryptosporidium* oocysts. In all water sources, concentrations of oocysts were low. Groundwaters generally had lower concentrations of oocysts than river waters. Nevertheless, for all water types, oocyst concentrations were not always significantly lower than those detected during outbreaks of waterborne cryptosporidiosis.

In the second survey (table 5; Humphreys et al, 1995), both raw and final water were analysed. Whilst the

Table 4: *Cryptosporidium* oocysts in UK raw waters (based on data published in The National Cryptosporidium Survey Group, 1992)

SITES	NO. SAMPLES	% POSITIVE	CONCENTRATIONS (oocysts/litre)
River A	375	4.5	0.07 - 4.0
River B	691	52.2	0.04 - 3.0
River C	430	4.4	0.07 - 2.75
Groundwaters D			
Borehole D11	44	0	-
Borehole D12	42	0	-
Borehole D13	34	0	-
Groundwaters E			
Borehole E14	46	6.5	0.004 - 0.026
Borehole E15	48	4.1	0.007 - 0.922
Borehole E16	44	6.8	0.009 - 0.390

proportion of raw waters considered to contain *Cryptosporidium* oocysts was significantly higher than the proportion of final waters considered to contain oocysts, the percentage of positive final waters is not negligible. Furthermore, when the final water was found to be positive, oocyst concentration was within the range of concentrations detected in raw water. This study also attempted to assess the viability of oocysts detected in raw water. 27% of the samples on which viability assessment was conducted were considered to contain viable oocysts.

Occurrence of *Giardia* cysts in UK waters

As with *Cryptosporidium,* acquisition of data on the occurrence of *Giardia* cysts in water is of pertinence. In table 6 results from a study (Smith et al, 1993) on the occurrence of *Giardia* cysts in raw and final waters in Scotland are summarised. Comparison of these data with those described in tables 4 and 5 for *Cryptosporidium,* indicates that *Giardia* cysts are more widespread in both raw and final waters, although they too generally occur at low concentrations. Again, whilst significantly more raw waters than final waters were

Table 5: *Cryptosporidium* oocysts in Scottish raw and final waters (based on data published in Humphreys et al, 1995)

	RAW WATER	FINAL WATER
OCCURRENCE		
No. examined	403	15
No. positive	61	1
% positive	15	7
CONCENTRATION		
No. examined	61	1
Range (oocysts/litre)	0.0012-0.12	0.006
Mean value (oocysts/litre)	0.02	-
VIABILITY		
No assessed for viability	22	-
No containing viable oocysts	6	-
% containing viable oocysts	27	-

considered to be positive for *Giardia* cysts, concentrations of parasites detected in positive final and positive raw waters were similar.

During the course of this study (Smith et al, 1993), water was also analysed at 21 water treatment plants in Scotland with water samples taken both before and after treatment. Of the 21 treatment plants involved in the study, *Giardia* cysts were detected in the raw water in 9 (43%) of the plants, but in the final water *Giardia* cysts were detected in only 4 (19%) of the plants. In all instances when *Giardia* cysts detected in the final water, cysts were also detected in the raw water at that plant.

In two of the plants in which cysts were detected both before and after treatment, the treatment in place was microstraining which would be unlikely to remove *Giardia* cysts; microstraining is designed for removal of objects with a diameter greater than 35 µm. In the other 2 plants in which *Giardia* cysts were detected both before and after treatment, coagulation flocculation, slow sand filtration, and rapid gravity filtration were in place.

Cryptosporidium and *Giardia* in sewage

Both agricultural contamination (e.g. slurry spraying) and sewage contamination have been associated with

Table 6: *Giardia* cysts in Scottish raw and final waters (based on data published in Smith et al, 1993)

	RAW WATER	FINAL WATER
OCCURRENCE		
No. examined	53	106
No. positive	26	20
1% positive	49	19
CONCENTRATION		
No. examined	26	20
Range (cysts/litre)	0.01- 1.05	0.01-1.67
Median value (cysts/litre)	0.03	0.02

waterborne outbreaks of cryptosporidiosis and giardiasis. There is also the potential for grazing domestic animals and wild animals to contaminate water courses. As some sewage treatment works discharge into water courses which are, downstream, abstracted for potable supply or used for agricultural or recreational purposes, it would be pertinent to gather information on the occurrence of these parasites in sewage and assess the removal efficiencies of conventional sewage treatment regimes.

In one study (Robertson et al, 1995a; Robertson et al, 1995b; Robertson et al, submitted) 6 treatment works in Scotland were investigated to assess the concentrations of *Giardia* cysts and *Cryptosporidium* oocysts entering and leaving these plants and thus estimate the removal efficiency of these plants for these parasites.

The concentrations of parasites in the sewage influent at the 6 treatment plants are summarised from Robertson et al, (1995b) in table 7 below. Interestingly, far higher concentrations of *Giardia* cysts than *Cryptosporidium* oocysts were detected in the sewage influent. However, of the 6 communities served by these sewage treatment plants, many more cases of cryptosporidiosis were diagnosed and reported than cases of giardiasis. In the community served by sewage treatment plant C, where over 40,000 *Giardia* cysts per litre were detected and over 100 *Cryptosporidium* oocysts per litre, no cases of either of these infections were reported to be diagnosed, either during the 3 year period of the study, or in the preceding 5 years. Whilst the potential for animal infections must be included, such data indicate that both these infections, but in particular *Giardia* infection, are probably underdiagnosed in UK.

Table 7: *Cryptosporidium* oocysts and *Giardia* cysts in sewage influent (based on data published in Robertson et al, 1995b)

Sewage Treatment Works	*Cryptosporidium* oocysts/L Range (n)	*Giardia* cysts/L Range (n)
STW A	Not detected - 52 (6)	235-1790 (6)
STW B	5 - I 5 (6)	135-3040 (6)
STW C	5 - 110 (6)	1345-43907 (6)
STW D	8 - 150 (6)	102-3240 (6)
STW E	Not detected - 70 (6)	135-1160 (6)
STW F	Not detected - 85 (6)	520-2885 (6)

As the concentrations of *Giardia* cysts are relatively high compared to *Cryptosporidium* oocysts, calculation of removal efficiency of sewage treatment is simpler for this parasite. In table 8, derived from data reported by Robertson et al, (1995a), concentrations of *Giardia* cysts at paired samples of influent and effluent are described together with the calculated removal efficiency. These data indicate that although removal efficiencies of *Giardia* cysts by conventional sewage treatment is relatively high, ranging from 57%-97%, because of the high numbers of *Giardia* cysts occurring in the sewage influent, high concentrations of *Giardi*a cysts may still be discharged in sewage effluent.

Relevance of UK information to Norway

Whilst UK and USA currently are the most prominent nations concerned with the presence of *Cryptosporidium* oocysts and *Giardia* cysts in water, other countries have been watching closely and many have commenced their own monitoring programmes. In some countries, tentative moves have been made to consider approaches to legislation, and this is likely to gather momentum within the next few years. In Canada, which between 1993 and 1996 has experienced four outbreaks of waterborne cryptosporidiosis involving over 350 confirmed cases of infection and over 30,000 possible cases (Craun *et al*, 1998), the proposed guidelines at present suggest parasites should be at concentrations of less than 1 in 100 L. However monitoring is currently not compulsory.

In Australia, where between July 1998 until September 1998, over 3 million residents of Sydney were affected by three 'boil water notices' due to both *Cryptosporidium* and *Giardia* being

Table 8: ***Giardia*** **cysts in sewage influent and effluent and estimated removal efficiency of sewage treatment processes in place (based on data published in Robertson et al, 1995a)**

STW & treatment	n	Influent (mean no. cysts/L)	Effluent (mean no. cysts/L)	Mean removal efficiency
A (PS)	7	1403	445	67 %
B (PS, TF)	13	1063	333	57 %
C (PS, AS)	10	991	24	97 %
D (PS, AS)	8	1124	69	89 %
E (AS)	9	1281	43	86 %
F (PS, TF, 3°)	9	1238	248	69 %

Key:
PS: Primary settlement
TF: Trickling filters
AS: Activated sludge
3°: Tertiary treatment

detected in large concentrations in the water supply (Anonymous, 1998), there are currently no recommendations for monitoring of water for these parasites, although this is presently under review.

In Norway, anecdotal evidence indicates that the possibility of waterborne cryptosporidiosis and giardiasis has not, to date, been considered a serious concern. Indeed, it seems that in the medical profession, infection with either parasite is not usually considered in the routine diagnostic procedures for patients presenting with gastrointestinal symptoms. It would appear that, generally, requests for analysis of samples for *Giardia* or *Cryptosporidium* are only made if the patient has a recent history of foreign travel or is immunocompromised.

Nevertheless, neighbouring Sweden has experienced at least two outbreaks of waterborne giardiasis and at least one of waterborne cryptosporidiosis. Furthermore, in a survey undertaken there (Hansen & Stenström, 1998) 26% of raw waters sampled were found to contain *Giardia* cysts and 32% were found to contain *Cryptosporidium* oocysts, with mean concentrations of the parasites relatively high compared to data from UK studies (0.8 *Giardia* cysts per litre and 1.5 *Cryptosporidium* oocysts per litre).

In Norway itself, preliminary data from a survey being conducted by Norges veterinærhøgskole indicate that both *Giardia* and *Cryptosporidium* can be detected in Norwegian raw waters at low concentrations (see Bjørn Gjerde's article in this issue of Vann).

As the interest in both these parasites, and their potential for being transmitted by the waterborne route, infecting huge sections of communities, gathers momentum world-wide, with increased monitoring and increased legislation, it would be pertinent for Norway to discard the remnants of any previous complacency and take an active involvement. Strategies for determining the most sensible approach for Norway to this potential problem can be based upon those used in UK and USA. The following are suggestions for possible approaches:

1) Establishing the occurrence of cryptosporidiosis and giardiasis in the Norwegian population. This might include:

a) education of medical personnel to encourage samples from patients reporting with gastrointestinal infections to be screened for these infections.
b) setting up a reporting system so that relevant information on all patients diagnosed with these infections is compiled in a data base.
c) passive surveillance; analyses of a national data-base or local databases as described above to determine the extent of these infections and their epidemiology in the Norwegian population.
d) active surveillance; active screening of selected groups, for example kindergarten attendees, patients with suppressed immune systems etc.
e) analysis of sewage influent to establish possible levels of these infections in communities served by particular sewage treatment plants.

2) Establishing the occurrence of cryptosporidiosis and giardiasis in the animal population of Norway, which have the potential to contaminate water courses. This might include:

a) surveillance of domestic or semidomestic animals, particularly those which graze near water sources (e.g. cattle, sheep, reindeer)
b) surveillance of wild animals (in USA the American species of beaver has been associated with *Giardia* infection)

3) Continued surveillance of raw and final water. Most logically this would involve extension from a small pilot project to a larger, more organised approach in which water utilities are trained in the sampling and analysis of their own raw and final water, and the data generated monitored via a central data base.

4) Establishment of sources of contamination. In water bodies where either of these parasites are detected, it might be wise to attempt to establish the origins of the contamination (e.g. sewage effluent discharge, agricultural practices such as pasturing or slurry spraying, wild animal contamination) in order to develop protective catchment control measures.

4) Consideration of the possibility of infection with these parasites in any water-associated outbreak of disease in which no other aetiologic agent is identified.

Naturally such approaches do not come free, and ultimately it will be for the people of Norway to decide whether the benefits of active involvement and analysis of their own situation, outweigh the costs.

References

Anonymous (1998). Protozoa in Sydney. *Health Stream Program 1 (Public Health Risk Assessment; Cooperative Research Centre for Water Quality and Treatment) Newsletter* **Issue 11** 1-13.

Campbell, A.T., Robertson, L.J., Smith, H.V. (1992). Viability of *Cryptosporidium parvum* oocysts: correlation of *in vitro* excystation with inclusion or exclusion of fluorogenic vital dyes. *Applied and Environmental Microbiology* **58** 3488-3493.

Campbell, A.T., Robertson, L.J., Snowball, M.R., Smith, H.V. (1995). Inactivation of oocysts of *Cryptosporidium parvum* by ultraviolet irradiation. *Water Research* **29** 2583-2586

.

Campbell, A.T., Robertson, L.J., Anderson, R., Smith, H.V., Parker, J.F.W. (1997). Viability of *Cryptosporidium* oocysts: assessment following disinfection with ozone. In: *1997 International Symposium on Waterborne Cryptosporidium. Proceedings.* (ed.s Fricker, C.R., Clancy, J.L., Rochelle, P.A.). American Water Works Association, Denver, Colorado. pp 97-102.

Craun, G.F., Hubbs, S.A., Frost, F., Calderon, R.L., Via, S.H. (1998). Waterborne outbreaks of cryptosporidiosis. Journal American Water Works Association 90 81-91.

Hansen, A., Stenström, T.A. (1998). Kartleggning av Giardia och Cryptosporidium i svenska ytvattentäkter. Smittskyddinstitutet och Livsmedelsverket.

Humphreys, S.W., McCreadie, S., Smith, H.V. (1995). The occurrence and viability of *Cryptosporidium* sp. oocysts in an upland raw water source in Central Scotland. In: *Protozoan Parasites and Water* (ed.s Betts, W.B., Casemore, D., Fricker, C., Smith, H. and Watkins, J.). The Royal Society of Chemistry. 87-90.

Lengerich, E.J., Addiss, D.G., Juranek, D.D. (1994). Severe giardiasis in the United States. *Clinical Infectious Disease* **18** 760-763.

Robertson, L.J. Campbell, A.T., Smith, H.V. (1992). Survival of *Cryptosporidium parvum* oocysts under various environmental pressures. *Applied and Environmental Microbiology* 58 3494-3500.

Robertson, L.J., Campbell, A.T., Smith, H.V. (1993). *In vitro* excystation of *Cryptosporidium parvum.* Parasitology 106 13-19.

Robertson, L.J., Paton, C.A., Campbell, A.T., Smith, H.V., Smith, P.G. (1995a). Removal and destruction of *Giardia* cysts by sewage treatment processes. In: *Protozoan Parasites and Water* (ed.s Betts, W.B., Casemore, D., Fricker, C., Smith, H. and Watkins, J.). The Royal Society of Chemistry. 235-237.

Robertson, L.J., Smith, H.V., Paton, C.A. (1995b). Occurrence of *Giardia* cysts and *Cryptosporidium* oocysts in sewage influent in six sewage treatment plants in Scotland and prevalence of cryptosporidiosis and giardiasis diagnosed in communities served by those plants. In: *Protozoan Parasites and Water* (ed.s Betts, W.B., Casemore, D., Fricker, C., Smith, H. and Watkins, J.). The Royal Society of Chemistry. 47-49.

Robertson, L.J. (1996). Severe giardiasis and cryptosporidiosis in Scotland, UK. *Epidemiology and Infection* **117** 551-561.

Robertson, L.J., Paton, C.A., Campbell, A.T., Smith, P.G., Jackson, M.H., Gilmour, R.A., Black, S.E., Stevenson, D.A., H.V. Smith. *Giardia* cysts and *Cryptosporidium* oocysts at sewage treatment works in Scotland, UK. Submitted to *Water Research.*

Smith, H.V., Robertson, L.J., Gilmour, R.A., Morris, G.P., Girdwood, R.W.A., Smith, P.G. (1993). The occurrence and viability of Giardia cysts in Scottish raw and final waters. *Journal of the Institute of Water and Environmental Management* **7** 632-635.

The National Cryptosporidium Survey Group (1992). A survey of *Cryptosporidium* oocysts in surface and groundwaters in the UK. *Journal of the Institute of Water and Environmental Management* **6** 697-703.

Whitmore, T.N., Robertson, L.J. (1995). The effect of sewage sludge treatment processes on oocysts of *Cryptosporidium parvum. Journal of Applied Bacteriology* **78** 34-38.