

A water contamination incident in Oslo, Norway during October 2007; a basis for discussion of boil-water notices and the potential for post-treatment contamination of drinking water supplies

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ABSTRACT

Over a 5 day period in October 2007 a boil-water notice was served on the majority of Oslo, capital city of Norway, as a result of a combination of bacteriological findings (coliforms, intestinal enterococci, and *E. coli*), and very low numbers of *Cryptosporidium* oocysts and *Giardia* cysts in 10 L water samples taken from the water distribution network. The water source had been regularly monitored for these parasites and generally found to be negative. Over 460,000 residents were affected by the boil-water notice, as were many thousands of businesses.

Despite an extensive outbreak of waterborne giardiasis in Bergen, Norway during 2004/2005, occurrence of parasites in Norwegian drinking water supplies has apparently continued to be considered to be of minimal relevance by Norwegian health authorities. Here we describe the background and occurrence of the episode in Oslo, including the species of *Cryptosporidium* detected, and use this event, in conjunction with incidents from other countries, as a basis to discuss the following issues: 1) under which circumstances should the occurrence of *Cryptosporidium* oocysts and *Giardia* cysts in water supplies trigger the issue of a boil-water notice, and 2) the possibilities and probabilities of post-treatment contamination events in the water distribution network.

Key words | boil-water notice, contamination event, *Cryptosporidium*, *Giardia*, monitoring, post-treatment contamination

BACKGROUND

Oslo is the capital city of Norway, and as of 1st January 2007, had approximately 560,000 citizens (Statistics Norway 2008). The water supply needs of Oslo are met by 4 water-treatment plants (Oset, Langlia, Skullerud and Alunsjøen), treating waters derived from four different surface water sources (Maridalsvannet, Langliavann (reserve supply due to high humus content), Elvåga and Alunsjøen respectively). Maridalsvannet and Langliavann are located in the forest to the north of Oslo (Nordmarka), whilst Elvåga lies in the forest to the east of Oslo (Østmarka) and Alunsjøen lies in a separate forested area (Lillomarka), adjacent to Nordmarka.

The majority of the water supply for Oslo (85–90%) is met by Maridalsvannet, with the water treated at Oset treatment plant. Although access to Maridalsvannet is restricted, there is considerable wildlife in the catchment (including moose, roe deer, and beavers), which have the potential to contaminate this water supply, and the area is widely used for recreation, with potential for contamination by humans, horses and dogs.

As of October 2007, the treatments in place at Oset treatment plant included aeration, microscreening (mesh size 5 micrometres) and chlorination. As these treatments

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are insufficient to inactivate or remove protozoa such as *Cryptosporidium*, if the raw water becomes contaminated with infectious oocysts, then there is obviously a considerable risk of the treated water also becoming similarly contaminated. A new treatment plant is under construction at Oset and is due to begin servicing consumers from early 2008. Treatments at the new plant will include flocculation and filtration, as well as UV-disinfection.

Between June 1998 and October 1999, a survey on the occurrence of *Cryptosporidium* oocysts and *Giardia* cysts in raw waters in Norway was conducted, in which over 400 samples from 147 different sites in Norway, including Maridalsvannet, Langliavann, and Alunsjøen, were analysed (Robertson & Gjerde 2001). Thirty-nine samples from Maridalsvannet were analysed as part of this survey, of which 2 were positive (one *Giardia* cyst in one 10 L sample and one *Cryptosporidium* oocyst in one 10 L sample).

Although the majority of water suppliers in Norway did not continue with analysis of water for these parasites, Oslo Kommune, Vann-og Avløpsetaten (Oslo City Council Department of Water and Sewerage, Oslo VAV) decided to continue monitoring for these parasites, with water from Oset treatment works (both treated and untreated), monitored most frequently of the four sources. Following a wide-spread waterborne outbreak of giardiasis in Bergen in autumn/winter 2004/2005 affecting between 1300 to 2500 individuals (Nygård *et al.* 2006; Robertson *et al.* 2006), the frequency of monitoring of Oslo's water supply for parasites was increased. In 2006, raw water entering Oset treatment works was analysed for *Cryptosporidium* oocysts and *Giardia* cysts on a monthly basis, and treated water was monitored for these parasites on 5 of these occasions. Additionally, the 3 major streams flowing into Maridalsvannet (Grytbekken, Dausjøelva and Skjærsjøelva) were also analysed for *Cryptosporidium* oocysts and *Giardia* cysts on a regular, but not monthly, basis with samples being taken on 8 occasions during 2006. Whilst neither parasite was detected in the treated water samples analysed, in the raw water samples entering the treatment works *Cryptosporidium* oocysts were detected on 3 occasions during 2006 (25% of samples positive), at a maximum concentration of 2 oocysts per 10 L and *Giardia* cysts were detected on 2 occasions during 2006 (17% of samples positive), at a maximum concentration of 2 cysts per 10 L.

Additionally, amongst the 24 stream samples analysed during 2006, 6 (25%) were positive for *Cryptosporidium* oocysts and/or *Giardia* cysts, with a maximum concentration of 3 *Cryptosporidium* oocysts in a 10 L stream water sample.

During 2007, the same monthly sampling regime had continued and as of 28th September 2007, all raw water samples analysed from the Oset treatment works inlet during 2007 ($n=9$) and all the treated water samples ($n=4$) had been negative for *Cryptosporidium* oocysts and *Giardia* cysts.

All sample collection was conducted by personnel from Oslo VAV and the analysis of water samples was conducted at the Parasitology Laboratory of the Norwegian School of Veterinary Science (NVH), using the US EPA Method 1623 (Anonymous 2005), with membrane filtration of 10 L grab samples as the first step in the procedure. The recovery efficiency of this method at this laboratory is between 50–60% for the whole procedure (Robertson & Gjerde 2000).

THE INCIDENT

A time-line of events is summarised in Table 1 (Fauskerud 2008 personal communication; Dybing & Krogh 2007) and described in more detail below. On 5th October 2007, a pharmaceutical company which receives mains water supplied from Oset water treatment works, reported to Oslo VAV that between 18th September and 3rd October coliform bacteria had been detected in 9 tap water samples analysed by the company. In 6 of these samples the bacteria had been identified; 4 samples contained *Enterobacter amnigenus* and 2 samples *Serratia fonticola*.

In response to this report, on 8th October Oslo VAV took 3 water samples from different points in the water distribution network in the immediate area around the pharmaceutical company facilities. Whilst 2 samples were bacteriologically negative, one sample was positive, with 9 coliforms and 1 *E. coli* per 100 ml. A repeat sample from this site (10th October) demonstrated 4 coliforms, 4 *E. coli*, and 2 intestinal enterococci per 100 ml. Based on these results, on 12th October, 3 further water samples were taken for bacteriological analysis and 1 10 L sample for parasitological analysis and a boil-water notice was instituted for a restricted area (3 streets) in the immediate

Table 1 | Time-line of events in the water contamination incident in Oslo in October 2007*

Date	Event
18th Sept. to 3rd Oct.	Bacteriology: coliform bacteria detected in 9 tap water samples analysed at GE Healthcare; 4 samples contained <i>Enterobacter amnigenus</i> and 2 samples contained <i>Serratia fonticola</i> .
5th Oct.	Action taken: results above reported to Oslo City Council Department of Water and Sewerage (Oslo VAV).
8th Oct.	Bacteriology: three samples taken by Oslo VAV from different sites in water distribution network close to GE Healthcare; 2 samples negative, 1 sample positive (coliforms and <i>E. coli</i>).
10th Oct.	Bacteriology: repeat sample from site of positive sample also positive (coliforms, enterococci, and <i>E. coli</i>).
12th Oct.	Action taken: localised boil-water notice issued. Bacteriology: three further samples taken for bacteriological analysis. Parasitology: one 10 L sample taken by Oslo VAV for parasitological analysis at NVH. Analysis revealed that the sample was very dirty (high debris and algal content); 1 presumptive <i>Giardia</i> cyst detected.
13th and 14th Oct.	Bacteriology: further samples taken for bacteriological analysis from previous sampling sites and 10 new sites.
15th Oct.	Bacteriology: 5 samples from 13th and 14th demonstrated possible coliforms, but colonies small and atypical. Parasitology: four 10 L samples taken from distribution network for parasitological analysis.
16th Oct.	Bacteriology: analyses from 12th, 13th, and 14th October reported to be negative for coliform bacteria, intestinal enterococci and/or <i>E. coli</i> . Parasitology: analyses from 15th October revealed one negative sample, one <i>Giardia</i> -positive sample (1 cyst/10 L), and two <i>Cryptosporidium</i> -positive samples (1 oocyst/10 L and 2 oocysts/10 L). Action taken: Crisis meeting held from late evening on 16th October.
17th Oct.	Action taken: Oslo-wide boil-water notice issued. Extensive sampling regime for parasitological analyses of water from the different points in the distribution network commenced (see Table 2 for numbers of analyses and results).
21st Oct.	Action taken: Boil-water notice rescinded.
22nd Oct.	Action taken: Sampling regime gradually and systematically reduced.

*Information in this table compiled from different sources, including data accrued in-house, personal communication from S. Fauskerud of Oslo VAV, and also from Dybing & Krogh (2007).

surroundings of the affected locality. One presumptive *Giardia* cyst (good morphology and fluorescence characteristics of the shell, but empty, and therefore no internal morphology) was detected in the 10 L water sample, which was noted during the analysis as being particularly dirty, with high content of debris and algae. On 13th and 14th October further samples were taken for bacteriological analysis, both from the previous sampling sites and from 10 new sites. Additionally, it was decided on 15th October to take 4 further samples for parasitological analysis.

On 16th October, neither coliform bacteria, nor *E. coli*, nor intestinal enterococci were reported to have been detected in the samples taken on 12th October (3 samples), 13th October (13 samples) and 14th October (13 samples), although initial tests had shown possible coliforms but colonies were small and atypical. However, amongst the 4

10L water samples taken for parasitological analysis, which were again noted as being particularly dirty, *Cryptosporidium* oocysts were detected in 2 samples (1 oocyst per 10 L and 2 oocysts per 10 L), *Giardia* was detected in 1 sample (1 cyst per 10L) and 1 sample was negative for both parasites.

Following the report of these results to Oslo VAV, a 'crisis meeting' was held involving members of the Oslo VAV crisis team, the Oslo Health Authority, the Food Safety Authority and the Public Health Institute and based both on the detection of *E. coli* and on the results of the parasitological analyses, it was decided to institute a boil-water notice for all areas of the city supplied with water from Oset treatment works. The authors of the present report were not consulted in reaching this decision. The boil-water notice was effectively in action from the morning of 17th October with communication to the city residents

and work-places by all available media, including internet, radio and television broadcast.

A wide-spread sampling regime was instituted from 17th October, in which 10 L water samples were collected from various sites, including raw and treated water at the treatment works and various sites throughout the water distribution system, giving a total of 21 samples. This sampling regime was repeated daily until 21st October when, on the basis of the results obtained, the boil-water notice was rescinded and the extensive sampling regime replaced by a 7-site daily sampling regime from the 22nd to 25th October. From then until the end of November, the 7 sites were sampled twice weekly and reduced to once per week in December. With the exception of 1 group of 21 samples, which were analysed at M-Lab in Stavanger, Norway, all samples were analysed at the Parasitology Laboratory at NVH. The results for October are summarised in Table 2. None of the positive samples were untreated water from Oset water treatment plant, but one positive sample on 17th October was from treated water from the plant. The other positive samples were from different points in the water distribution system in Oslo.

Additionally, two different boats which suspected that they might have loaded contaminated water in Oslo requested analysis of 10 L water samples for *Cryptosporidium* oocysts and *Giardia* cysts. The result from one boat (analysis conducted at NVH) was negative, whereas in

the sample from the other boat (analysis conducted at M-lab, Stavanger), 2 *Giardia* cysts with excellent morphology and fluorescence characteristics were identified.

All the slides from the samples identified as positive at NVH were stored and subsequently molecular studies were conducted on 4 of these containing *Cryptosporidium* oocysts (1 from 15th October containing 2 *Cryptosporidium* oocysts, 2 from 17th October each containing 1 *Cryptosporidium* oocyst and 1 from 20th October containing 2 *Cryptosporidium* oocysts). The cover-slip from each slide was carefully removed and retained, top-side down, whilst 25 µl aliquots of AL lysis buffer (Qiagen GmbH, Germany) were added to the slide wells which were carefully and gently scraped using a sterile scalpel blade. The buffer and scrapings were then pipetted into a microcentrifuge tube. This process was repeated 4 times, collecting the buffer and scrapings into the appropriate tube for each slide, and then the cover-slip was replaced onto the slide which was then re-screened. For each slide the oocysts could no longer be detected.

The contents of each tube were re-suspended in Tris-EDTA buffer and held at 100°C for 1 hour, before the DNA was isolated using QIAamp DNA mini kit (Qiagen GmbH), using an overnight lysis step at 56°C. PCR was conducted of the SSU rRNA gene using published primers (Xiao *et al.* 1999) and the following PCR conditions: 95°C 15 min, 50 cycles of, 94°C for 45 sec, 55°C for 45 sec, 72°C

Table 2 | Results of analysis of 10 L water samples for *Cryptosporidium* oocysts and *Giardia* cysts in Oslo in October 2007

Sampling date	Number of samples	No (%) positive for <i>Cryptosporidium</i> oocysts	No (%) positive for <i>Giardia</i> cysts	Maximum no. of parasites detected (per 10 L sample)	PCR results
12 Oct	1	0	1 (100%)	1 cyst	
15 Oct	4	2 (50%)	1 (25%)	2 oocysts	<i>C. hominis</i>
17 Oct	21	7 (33%)	0	1 oocyst	PCR unsuccessful
18 Oct	21	1 (5%)	0	1 oocyst	
19 Oct*	21	0	0	–	
20 Oct	20	2 (10%)	1 (5%)	2 oocysts	<i>C. parvum</i>
21 Oct	20	1 (5%)	0	1 oocyst	
22 Oct	7	0	0	–	
23 Oct	7	0	0	–	
24 Oct	7	0	0	–	
25 Oct	7	0	0	–	
29 Oct	7	0	0	–	

*Analysed at M-Lab, Stavanger.

for 60 sec. A final elongation phase was at 72°C for 10 min. The primer concentration was 10 pmol, and for each sample the PCR was conducted in duplicate with either 3 µl or 4 µl of template. For each PCR, positive and negative controls were also included. Despite the PCR being conducted twice, visualisation of the PCR product by electrophoresis on 1% agarose gels and ethidium bromide staining did not demonstrate a positive result from either of the samples which had contained a single oocyst. However, from the two samples which had each contained 2 oocysts, a PCR product of the expected size (approximately 850 bp) was obtained, purified (High Pure PCR product purification kit; Roche Diagnostics GmbH), and sequenced on both strands at MWG Biotech, Germany. Chromatograms and sequences were examined using Vector NTI Invitrogen Software and sequence searches conducted using BLAST. Although only portions of the sequences for the 1st sample (from 15th October) were of sufficient quality to be of use, they demonstrated that at least one of the oocysts in this sample was *C. hominis*. Both forward and reverse sequences of the 2nd sample (from 20th October) were of good quality, with no double peaks, and demonstrated that at least one of the oocysts in this sample were *C. parvum*.

As at least one of the oocysts, from one of the initial samples in this incident before the boil-water notice had been implemented, was identified as being *C. hominis*, a species which generally only occurs in humans and not in the plethora of mammalian hosts associated with *C. parvum* infections, it is probable that the water supply had experienced a contamination event with faecal matter of human origin. This, together with the bacteriological findings, indicated that this was probably a post-treatment contamination event, which might have occurred in the water distribution system at an individual location. That the contamination was largely localised and was undetectable within a few days, suggests that the contamination event was likely to be a one-off incident, perhaps in association with a particular event such as maintenance work, rather than a severe or continuous fault within the distribution network. The oocysts in the later sample being demonstrated to be *C. parvum* might indicate contamination from either human sources (sewage leak) or from animals, possibly as an entirely separate event to the initial contamination incident.

Elevated numbers of *Cryptosporidium* infection or *Giardia* infection associated with this incident were not observed amongst the population of Oslo, although more than usual numbers requested analysis for these parasites.

DISCUSSION

Issuing and rescinding a boil-water notice

In the incident described here a boil-water notice of a relatively short duration (5 days) affected a considerable proportion of the population of Oslo, in the absence of any increase in the incidence of illness and with only relatively low numbers of parasites (mostly 1 per 10 L; maximum of 2 per 10 L) being detected in the water samples analysed. Even when accounting for the low recovery efficiency of the method, the numbers of parasites detected were not higher than 4 per 10 L. The implementation of boil-water notices in response to *Cryptosporidium*, in particular, but also *Giardia* contamination of water supplies is becoming more common in industrialised countries and may, in part, be influenced by pressures from today's hyperactive media channels which demand immediate reactions to events. Such boil-water notices may be in force for no more than a couple of days as in this case or for example in an incident in Glasgow, Scotland during August 2002 ([Scottish Parliament Information Centre 2002](#)) or may continue for periods of weeks, for example during the 1995 outbreak of cryptosporidiosis in Torbay, UK ([Harrison *et al.* 2002](#)), the Irish outbreak in May 2002 ([Gillooly 2003](#)), the Irish outbreak in spring 2005 ([Outbreak Control Team Health Service Executive–South Eastern Area 2005](#)), or even months, for example sporadically over approximately 2 months during the incident in Sydney, Australia between July and September 1998 ([McClellan 1998a](#)) and for 13 months in Thunder Bay, Canada from September 1997 following detection of 2 *Giardia* cysts in a treated water sample ([Wallis *et al.* 2001](#)). However, reservations have been expressed about the use of such notices and it has been proposed that the implementation of boil-water notices, associated with suspected contamination of public water supplies by *Cryptosporidium*, is seldom a good idea ([Irvine 2004](#)). The rationale behind this theory is multi-faceted and

is based upon several concepts, some of which might be considered controversial, whereas several are broadly accepted. These include:

- that adherence to a boil-water notice, both for individuals and for affected businesses, is disruptive, expensive and possibly dangerous (a theoretical increased risk of scalding injuries);
- that if the boil-water notice is applied because of an outbreak then the notice is applied too late for prevention;
- that if the boil-water notice is applied because of raised counts of oocysts in the water supply then it is possible that these oocysts are non-pathogenic to humans or non-viable, that there may be too few to cause infection, that the sampling system is so unrepresentative of the entire water system that raised counts may merely reflect clumping;
- that because of the difficulties listed in the previous bullet point, oocyst counts in water do not assist in predicting if an outbreak is likely to occur;
- that generally although the disease associated with infection is unpleasant, unless the individual is immunocompromised the disease is not life-threatening;
- that many in the target population do not adhere to the advice, thus implying that it is wasted effort;
- that the media create an unnecessary furore over such incidents;
- that boil-water notices result in loss of faith in the water supply by consumers, which may be prolonged, or even indefinite.

As if in anticipation of such debate, when the new quality water regulations were first introduced in the UK regarding water analysis for *Cryptosporidium*, a guidelines paper was published (Hunter 2000) discussing those circumstances in which the issuing of a boil-water notice might be advisable, and when the potential risks to health from not issuing a boil-water notice might outweigh the negative effects associated with the implementation of such a notice. The factors in favour of issuing a boil-water notice which are listed by Hunter (2000) include: a) a history of waterborne outbreaks associated with the same source; b) high oocyst counts in consecutive samples; c) other evidence of treatment failure; d) a relatively high turbidity

in treated water for that supply; e) a groundwater source; f) demonstration of oocyst viability.

In the Oslo incident none of these criteria were met, and the numbers of parasites detected were very low (although higher than those reported from various other incidents which have also resulted in boil-water notices, for example in the Carlow Town incident the oocyst concentrations ranged from 0.009 to 0.28 oocysts per 10L water; [Outbreak Control Team Health Service Executive–South Eastern Area 2005](#)). However, the factors which supported the issue of a boil-water notice in the Oslo incident included: a) detection of both *Giardia* cysts and *Cryptosporidium* oocysts from a water supply in which neither parasite had been detected in the treated water for the previous 11 samples, taken over the course of over 2 years; b) bacteriological results indicative of post-treatment contamination; c) although turbidity measurements were not particularly raised, quantities of particulate matter were high in some samples, indicating a local contamination event. These three factors together suggested the possibility of a post-treatment contamination event. Additionally, although it was not possible to assess the viability of the parasites detected during the incident, the *Cryptosporidium* oocysts were demonstrated as being of species infective to humans, and the oocysts in one of the earliest samples were also very probably derived from a human infection. Thus, whilst guidelines on issuing of boil-water notices are indubitably of value, it should also be emphasised that each incident must be judged individually, and it is not always possible to extrapolate from one situation to another, and it may, indeed, be erroneous to do so.

Thus, if high numbers of parasites are detected in a water source, it is obvious that an immediate response is necessary, but when numbers are lower, the issue may be less clear-cut. The use of absolute or threshold numbers for recommending whether or not a boil-water notice should be implemented has been previously discussed. Wallis *et al.* (1996) proposed that *Giardia* concentrations of less than 3 to 5 cysts per 100 L should not trigger a boil-water advisory, but repeated samples of above 5 cysts per 100 L should, whereas Haas & Rose (1995) proposed higher action thresholds for *Cryptosporidium* (10 to 30 oocysts per 100 L). As has been pointed out by Irvine (2004),

the recommendation in Northern Ireland that a boil-water notice might be considered if there is a sustained and rising count above 1 oocyst per 10 L final water (Anonymous 2001a), is probably based upon the UK Drinking Water Inspectorate regulatory level. However, as Irvine (2004) also states, converting oocyst counts to an estimate of risk of an outbreak is neither simple nor straightforward. In the Sydney incident, oocyst and cyst counts were sometimes as high as over several hundred per sample, or even up to several thousand per sample. However, problems in the analytical laboratory suggest that at least some of these data are over-estimates, and re-analysis of the samples in other laboratories yielded much lower figures (McClellan 1998b), and no associated rise in infections was reported. Frequently oocyst or cyst counts from a water supply associated with an outbreak are low, but often these counts are made several weeks after the period of infection has passed, and the relevant sampling period has been missed.

Assessing whether low numbers of oocysts or cysts isolated from a water supply are viable or infectious, as suggested in Hunter (2000) remains problematic, but determining whether the species or genotype is likely to be infective to humans can often be accomplished. In the incident in Glasgow in 2002, which resulted in a 5 day boil-water notice (Scottish Parliament Information Centre 2002), the *Cryptosporidium* oocysts were apparently of a strain non-harmful to humans (Irvine 2004), and in the outbreak in and around Carlow Town, which resulted in a boil-water notice of over 5 weeks (Outbreak Control Team Health Service Executive–South Eastern Area 2005), the *Cryptosporidium* oocysts in the patients were *C. hominis*, whereas only *C. parvum*, *C. muris* and *C. andersoni* were detected in the water. In the Oslo incident, the two species of *Cryptosporidium* detected are infectious to humans. However, in both the Glasgow and Oslo incidents, neither of which had associated cases, identification of the species was conducted retrospectively, and it should be realised that this remains relatively time-consuming and may not immediately, or necessarily at all, provide a definitive answer. It should also be realised that the results from molecular analyses may not represent all the parasites present in a particular water source. Therefore, except perhaps in instances of very gross contamination, water utilities are

unlikely to be able to base their decisions on whether or not to issue a boil-water notice on the results of molecular studies. Nevertheless, such information is still useful retrospectively in order to assist in identifying, or eliminating, potential sources of contamination.

In our opinion, in general, and where oocyst or cyst counts are not so high that gross contamination appears to have occurred, it is important that a boil-water notice is based upon all the available data, including historical data, and other microbiological, biophysical, or environmental data (e.g. turbidity data, precipitation data) which may be indicative of a contamination event, or increased probability of such an event. It is important to realise that representative sampling of water for parasites is almost impossible to achieve, given the tremendous volume of water used on a daily basis, in comparison with the relatively small volume of water (between 10 and 1,000 L) analysed for these parasites. Nevertheless, repeat sampling of a source may indicate whether elevated counts are indicative of a one-off event or continuous contamination.

The proposal of providing information to the public regarding anomalies in the water supply, but not a definitive guideline on whether or not water should be boiled, allowing individuals to decide for themselves, is likely to be problematic. It is generally normal for government agencies and authorities to issue both information and advice simultaneously (Anonymous 2001b), albeit the advice is sometimes that consumers must make their own decisions based on personal circumstances. However, even if the information provided is complete and accurate, in the absence of clear and definitive guidelines it is likely that a large section of the public will be unable to interpret the information for themselves, and the authorities will be overwhelmed by questions and requests to assist with the interpretation. It is not unreasonable to expect that the public will react negatively to the limitations of the relevant agencies to address or answer such questions, and the uncertainty and jammed telephone lines may cause more consumer dissatisfaction than the implementation of a short-term, precautionary boil-water advisory, even if the notice is subsequently assessed as having been unnecessary. When parasite levels are higher than expected, but, even in consideration with other relevant data, it is uncertain whether or not they may pose a risk, an alternative

approach could be to issue a 'step-wise' boil-water recommendation which in the first instance is applicable only to those consumer groups who are at particular risk of infection or may be particularly seriously affected by infection; such groups could include the immunocompromised, the elderly and very young, and those who believe that they have a particularly high intake of tap water. If such an approach is used, it is important that follow-up information (removing the boil-water recommendation from all groups, extending it to the whole population, or prolonging it for the same group) is provided both regularly and clearly, and with sound scientific reasoning for the follow-up information, probably based on the results of further analyses.

Whilst Irvine (2004) believes that the issuing of a boil-water notice may result in a prolonged, or even permanent, loss of faith in the public water supply by the consumers, she does not address the potential for this occurring if a boil-water notice is not issued and infections subsequently result from ingestion of infective parasites with water, particularly if the water provider has had reason to believe that a contamination event might have occurred. It would be interesting to compare consumer opinions on public water supply in Bergen (where a widespread waterborne outbreak of giardiasis occurred, and a 6 week boil-water notice was subsequently issued; Robertson *et al.* 2006), with those in Oslo (where a precautionary 5 day boil-water notice was issued, and no associated parasitic infections were detected). In our opinion, an outbreak of waterborne infection, whether occurring in conjunction with a boil-water notice or not, is more likely to result in diminished consumer confidence in the public water supply than the issue of a boil-water notice in the absence of infection. Indeed, it may be true, and/or the public may believe it to be true, that the boil-water notice actually prevents infection occurring, as is its intention. Whilst this may not raise public confidence in the water supply *per se*, it may enhance the awareness of the public that the water supplier is striving to produce a safe and reliable product and service at a relatively low price. A very recently published report (Terragni *et al.* 2008) of a survey conducted by the Norwegian National Institute for Consumer Research (SIFO) in the wake of the Oslo incident demonstrates that of 868 Oslo residents asked, 97% were in total or

partial agreement with the authorities informing the public about the detection of parasites in the drinking water, and only 5% considered that a boil-water notice was completely unnecessary.

Whilst the decision to issue a boil-water notice might be relatively simple, especially if particular criteria are fulfilled, the decision on when to rescind such a notice may not be so easily made. Hunter (2000) makes the point that at the outset of issuing advice to boil water, there should be a clear understanding regarding the criteria which should be fulfilled in order for it to be removed. Similarly, the practicalities for agreeing such criteria are discussed by Harrison *et al.* (2002) in the context of the cryptosporidiosis outbreak in Devon, UK during 1995. In the Irish outbreak, specific criteria were agreed to be fulfilled regarding rescinding of the boil-water notice, including *Cryptosporidium* oocyst levels in the distribution network to be no higher than 0.05 oocysts per 10 litres for 7 consecutive days, and daily sampling for at least a month afterwards, despite the oocysts detected in the water supply being of different species to that which was associated with the infections (Outbreak Control Team Health Service Executive – South Eastern Area 2005).

If faults are detected in the water supply system or treatment works, which have resulted in a contamination event, it may be relatively easy to agree that the boil-water notice should be rescinded once the faults have been rectified and sufficient time has elapsed that any remaining infectious agents from the contamination event have been flushed through the system. However, as in the Oslo incident, when no such faults are detected, and particularly in the absence of infection in the community served, it may be more difficult to decide upon those criteria which should be fulfilled in order for a boil-water notice to be rescinded. In such situations a 'step-wise' boil-water advisory in which the boil-water notice can be scaled up or down, may be more useful. In the Oslo incident a significant reduction in the number of *Cryptosporidium*/*Giardia* positive samples in the distribution system, bacterial analyses being negative, and numbers of parasites detected never exceeding 2 per 10 L throughout the incident, were considered sufficiently indicative of the water being potable, to enable the boil-water notice to be rescinded, although an intensified sampling regime was maintained in the subsequent weeks.

The potential for post-treatment contamination of water

There is nothing new in considering the potential for water supplies being contaminated post-treatment, that is, after the water has left the water treatment works and has entered the distribution network. However, the incident in Oslo provides a suitable impetus to consider this potential anew, in the light of the data accrued over several years. It is particularly relevant as water treatment plants across both Europe and North America proceed to introduce expensive ultraviolet or membrane-filtration treatments into their works and thereby believe that they have overcome the problem of chlorine-resistant microorganisms such as *Giardia*, and more especially, *Cryptosporidium* being transmitted by the waterborne route. Although water supplies in UK must be amongst the most tested in the world for *Cryptosporidium*, the samples are generally procured immediately post-treatment and thus give no indication regarding the possibilities of post-treatment contamination. In tabulated overviews of documented waterborne giardiasis (1954–2001) and cryptosporidiosis (1983–2002) outbreaks worldwide, at least 11 outbreaks of giardiasis and at least 8 outbreaks of cryptosporidiosis were noted as being most probably due to post-treatment contamination (Karanis *et al.* 2007). These included the following more well-defined, post-treatment contamination outbreaks:

- (1) An outbreak of giardiasis at a private campground in Arizona, USA in 1980 in which a direct cross-connection was made between potable water pipes and pipes carrying sewage effluent for irrigation, and resulted in an estimated 2000 cases (unpublished manuscript, referenced by Karanis *et al.* 2007).
- (2) An outbreak of giardiasis in Bristol, UK in 1985 in which the water system was contaminated, possibly during engineering work on the water main, and resulted in over 100 cases (Jephcott *et al.* 1986).
- (3) An outbreak of giardiasis in Mjövik, Sweden in 1982 with 56 cases in which it was postulated that the water distribution had been damaged by tree roots and the sewer construction had been faulty (Neringer *et al.* 1987).
- (4) An outbreak of cryptosporidiosis in Ayrshire, UK in 1988 affecting many hundreds of individuals, in which a break-pressure tank was contaminated by irregular seepage of oocyst-containing water (possibly from cattle slurry spraying) (Smith *et al.* 1989).
- (5) An outbreak of giardiasis in a correctional facility in Tennessee, USA in 1994 involving over 300 cases in which there was a cross-connection between potable and wastewater lines, and a fall in pressure in the potable water system probably caused wastewater to flow back into the potable water line (Kramer *et al.* 1996).
- (6) An outbreak of giardiasis in Washington, USA in 1995 involving 87 cases in which an illegal cross-connection had been made between a domestic water supply and an irrigation system at a plant nursery (Lee *et al.* 2002).
- (7) An outbreak of cryptosporidiosis in Kanagawa, Japan in 1994 with 461 cases recorded, in which municipal drinking water was contaminated with sewage through connecting pipes (Kuroki *et al.* 1996).
- (8) An outbreak of cryptosporidiosis in Belfast, Ireland in 2000, with over 100 cases in which human sewage from a septic tank leaked into the drinking water distribution system (Glaberman *et al.* 2002).

These selected cases demonstrate that post-treatment contamination, resulting in outbreaks of cryptosporidiosis and giardiasis occur in a variety of situations and circumstances around the globe, and may impact on a significant number of the population.

Also notable from the information collated in Karanis *et al.* (2007), is the relatively high proportion of waterborne outbreaks of both cryptosporidiosis and giardiasis in which it was not possible to pin-point the cause of the contamination. In several of these outbreaks, treatment deficiencies at the associated water works were not identified and/or parasites were not detected in the raw water source; in one, an outbreak of cryptosporidiosis in Nevada USA between 1993 and 1994, in which there were over 100 estimated cases and at least 20 deaths due to cryptosporidiosis amongst HIV-infected people, the treatment works was described as a modern facility providing water of excellent quality (Solo-Gabrielle & Neumeister 1996). Post-treatment contamination was suggested as a possible cause in this case and must also be considered in the various other outbreaks where no other obvious cause could be determined.

Therefore, despite water treatment works installing the most state-of-the-art technologies in order to inactivate or remove *Cryptosporidium* oocysts and *Giardia* cysts, if there are inadequacies within the water distribution system, which may include aging or improperly maintained infrastructure, such as pipelines or seals, or inadequate securing of the water supply during maintenance work, then the potential for contamination of drinking water supply with these parasites still exists. A cohort study conducted in Norway demonstrated that breaks or maintenance in the water distribution system increased the risk of gastrointestinal illness amongst consumers (Nygård *et al.* 2007).

In general, analysis of post-treatment contamination outbreaks with parasites indicated that these have often resulted from cross-connection between potable water pipes and sewerage pipes, although agricultural sources of contamination have also occurred. Such cross-connection may be directly due to human error or perfidy, or due to environmental factors causing leakages in adjacent pipes, but loss of pressure may also be of importance. In the Oslo incident, no evidence of failure in the distribution network was detected; the factors which were investigated by Oslo VAV included construction work in the area, work on the distribution network itself, and loss of water pressure due to fire department activity.

CONCLUSIONS

A post-treatment water contamination incident in Oslo during October 2007 is described, in which low numbers of *Giardia* cysts and *Cryptosporidium* oocysts were detected in the distribution network supplied from a source in which these parasites are rarely found. These findings, along with microbiological evidence of contamination, were sufficient to result in a temporary and short-term boil-water notice being issued for the majority of Oslo residents. On the basis of this event, and others, we discuss the criteria for issuing, and rescinding, boil-water notices, and suggest that a 'step-wise' boil-water notice, directed only at those consumers at particular risk, might be appropriate in some instances when numbers of parasites detected are very low. We propose that, unless it is obvious that a gross contamination event has occurred, warranting immediate action, it is

essential that all the relevant information is considered when deciding whether or not to issue a boil-water notice; this not only includes data on oocyst or cyst counts, but archived data, other microbiological data, and biophysical and environmental data. It should also be realised by water providers that information on viability or genetic data may not be immediately or perhaps, ever, available and often the decision will need to be taken without such information.

That the Oslo incident was probably a post-treatment contamination event has been used to discuss the possibility of such events occurring. This seems to us to be increasingly important; as more water treatment works invest heavily in treatments to inactivate or remove parasites, it should also be emphasised that these will be of little worth if the network is not properly maintained or secured during maintenance work or if pressure breaks occur, which may result in post-treatment contamination events. In general, water samples which are analysed for *Cryptosporidium* and/or *Giardia* are either raw or treated water collected at the treatment works, and very rarely collected from the water distribution network. In the Oslo incident, the contamination event would probably not have been initially noticed, but for the fact that it occurred close to a pharmaceutical company which conducted its own microbiological analyses of the tap water. Whether a waterborne outbreak of infection might have occurred if these analyses had not been conducted, the source of which would probably not have been identified, is impossible to determine.

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