



**CHALMERS**  
UNIVERSITY OF TECHNOLOGY

## Safe drinking water and waterborne outbreaks

Downloaded from: <https://research.chalmers.se>, 2026-04-06 05:13 UTC

Citation for the original published paper (version of record):

Moreira, N., Bondelind, M. (2017). Safe drinking water and waterborne outbreaks. *Journal of Water and Health*, 15(1): 83-96. <http://dx.doi.org/10.2166/wh.2016.103>

N.B. When citing this work, cite the original published paper.

# 1 Safe drinking water and waterborne outbreaks

2 N. A. Moreira<sup>1,2</sup>, M. Bondelind<sup>2\*</sup>

3 <sup>1</sup> Cranfield Water Science Institute, Cranfield University, Bedfordshire, MK43 0AL, UK

4 <sup>2</sup> Department of Civil and Environmental Engineering, Chalmers, Sven Hultins gata 8, 412 96  
5 Göteborg, Sweden

6 \*Corresponding author, email: [mia.bondelind@chalmers.se](mailto:mia.bondelind@chalmers.se)

## 8 Abstract

9 The present work compiles a review on drinking waterborne outbreaks, with the perspective of  
10 production and distribution of microbiologically safe water, during 2000-2014. The outbreaks  
11 are categorised in raw water contamination, treatment deficiencies and distribution network  
12 failure. The main causes for contamination were: for groundwater, intrusion of animal faeces  
13 or wastewater due to heavy rain; in surface water, discharge of wastewater into the water source  
14 and increased turbidity and colour; at treatment plants, malfunctioning of the disinfection  
15 equipment; and for distribution systems, cross-connections, pipe breaks and wastewater  
16 intrusion into the network. Pathogens causing the largest number of affected consumers were  
17 *Cryptosporidium*, norovirus, *Giardia*, *Campylobacter*, and rotavirus. The largest number of  
18 different pathogens was found for the treatment works and the distribution network. The largest  
19 number of affected consumers with gastrointestinal illness was for contamination events from  
20 a surface water source, while the largest number of individual events occurred for the  
21 distribution network.

22 Keywords: distribution network, drinking water, pathogens, water treatment, water safety plan,  
23 waterborne outbreak.

## 24 Introduction

25 Drinking water safety plays a significant role in establishing the quality of human life in modern  
26 societies. In that perspective, problems with microbial pathogens within the production and  
27 distribution of drinking water can have an important impact on public health. The occurrence  
28 of a waterborne disease outbreak (WBO) may also have the effect of lowering trust, increase  
29 perceived risk and decrease acceptance for the drinking water (Bratanova et al. 2013).

30 Waterborne outbreaks are caused by drinking water contamination worldwide (Karanis et al.  
31 2007). One of the most challenging issues facing the drinking water treatment plants (WTP) are  
32 the uncertainties related to climate change and the effect it will have on the surface water  
33 quality. Increase of extreme hydrological events in addition to changes in air temperature may  
34 increase the risk of WBOs. The most vulnerable water bodies to future climate changes are  
35 likely to be shallow lakes, where the chemical processes will be altered by the impact of an  
36 increase in water temperature, increases in pH and larger alkalinity generation in the lakes  
37 themselves. Additionally, sewage discharge from combined sewage systems caused by heavy  
38 rainfall has been demonstrated to spread waterborne pathogens within the surface waters.  
39 Furthermore, increased temperatures may increase disinfection by-products formation rate in  
40 surface waters at natural temperatures, between 5 and 30 °C (Delpha et al. 2009). Consequently,  
41 environmental contamination, intensive livestock rearing, surface water and discharge of  
42 wastewater into drinking water sources are risk factors that need to be addressed (Chalmers  
43 2012).

44 In the production of safe and aesthetically suitable water for human consumption, the analysis  
45 and evaluation of risks to the complete drinking water system, from the catchment until it  
46 reaches the consumer, is considered of paramount importance by the World Health  
47 Organisation (WHO). To achieve that aim, a framework for safe drinking water was developed  
48 by the WHO throughout the application of guidelines designated as water safety plans (WSP)  
49 (WHO 2011). Through the WSP, hazards and hazardous events that can affect the safety of the  
50 production of drinking water from the catchment to consumer are identified. The risks  
51 associated with the events are assessed and control points and barriers are implemented if  
52 needed. The WSP should be reviewed regularly and continuously updated (Bartram et al. 2009).  
53 To quantify the barrier effect and the treatment required the Microbial Barrier Analysis model  
54 (MBA) can be used (Ødegaard & Østerhus 2014). First the raw water quality is evaluated and  
55 according to the quality the necessary treatment efficiency is determined. Thereafter the  
56 removal and inactivation efficiency of the barriers installed at the WTP are calculated. The  
57 difference between the required and the calculated barrier efficiency shows if supplementary  
58 surveillance or additional treatment is required.

59 In spite of the generalised use of risk ranking in water safety plans, the evaluation and  
60 comparison of water safety measures does not have a common and structured approach (Lindhe  
61 et al. 2013). As a result, the primary safety procedures against microbiological hazards are still  
62 a capable sanitation and drinking water infrastructures (Baldursson & Karanis 2011). Thus,  
63 reviewing WBOs associated with drinking water production can help to shed light on the most  
64 problematic issues faced by the water industry. The aim of the present work is to review causes  
65 for drinking water disease outbreaks to assess possible patterns and accountability issues for  
66 those events, in order to improve drinking water safety.

## 67 **Method**

68 This study of causes for drinking water disease outbreaks is based on information and literature  
69 collected from sources including Scopus, Eurosurveillance, PubMed, New Zealand's Institute  
70 of Environmental Science and Research (ESR), Canada Communicable Disease Report  
71 (CCDR) and Morbidity and Mortality Weekly Report from the USA CDC (Centers for Disease  
72 Control and Prevention). Keywords used in the search comprised: waterborne, water treatment,  
73 outbreak, *Cryptosporidium*, *Campylobacter*, *Giardia*, norovirus, rotavirus, and adenovirus. The  
74 number of identified outbreaks may be misrepresentative because of voluntary nature of  
75 reporting processes (Brunkard et al. 2011) or that the events may not have been mentioned in  
76 scientific publications. In total 66 reviewed articles were found to be eligible accordingly to the  
77 criteria: (i) data in the timeframe 2000-2014; (ii) drinking water outbreak confined  
78 geographically to Europe, North America and New Zealand; (iii) surveillance of potential  
79 factors of interest to the drinking water industry affecting the occurrence of parasite  
80 transmission hazards.

81 The time frame for this study is 2000-2014. Regulations are continuously being updated and  
82 implemented for improved safety of drinking water. Therefore, only recent events that may be  
83 of interest for the water industry today are included in this review. For example, the United  
84 Kingdom alone was responsible for 73.6% of the waterborne outbreaks in Europe until 2003  
85 (Karanis et al. 2007). The implementation of a new set of regulations in the year 2000,  
86 concerning drinking water production, that took place in the UK led to reductions in  
87 cryptosporidiosis that were considered statistically relevant (Lake et al. 2007).

88 In this review drinking water outbreaks confined geographically to Europe, North America and  
89 New Zealand have been reviewed. Here public national systems to register the occurrence of  
90 waterborne outbreaks are available. In developing countries, the information related with  
91 WBOs is less available or even absent and the countries have therefore not been included in

92 this review (Baldursson & Karanis 2011). Thus the available reports of incidents, according to  
 93 the stipulated eligibility criteria, resulted in the inclusion of 15 countries: Canada, Denmark,  
 94 Finland, France, Greece, Ireland, Italy, Netherlands, New Zealand, Norway, Spain, Sweden,  
 95 Switzerland, UK and USA. The creation of public national systems to register the frequency  
 96 and prevalence of waterborne outbreaks or protozoan infections may vary among the countries.  
 97 The surveillance of potential factors of interest to the drinking water industry affecting the  
 98 occurrence of parasite transmission hazards has to be known for the event to be included in this  
 99 review.

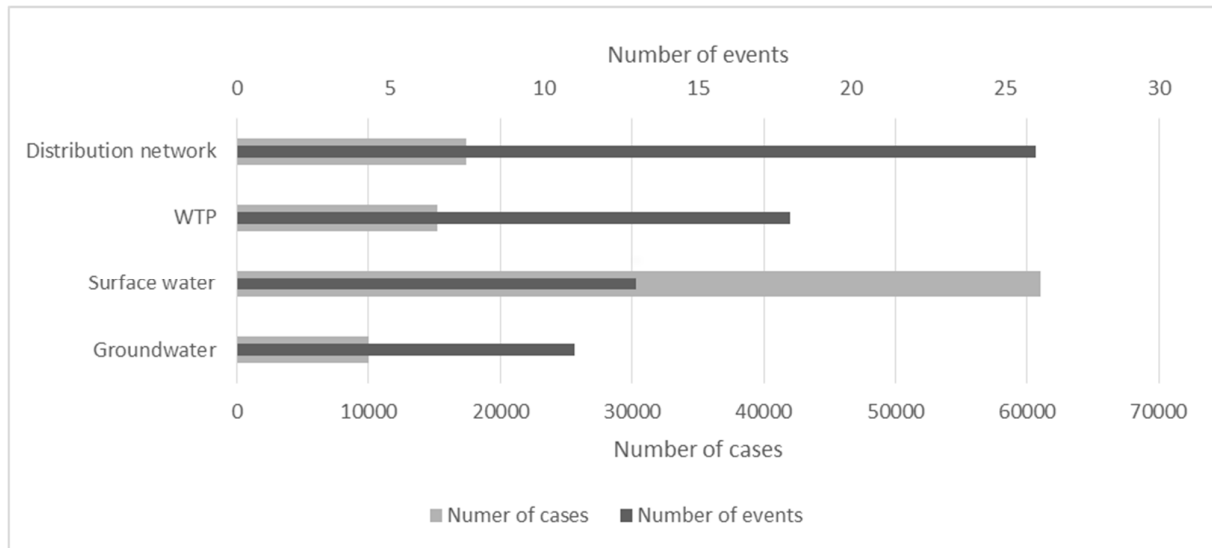
100 The results of this review are summarised in Tables 1-4 that present the year of the event;  
 101 country and specific location (when available); estimated number of infections; population  
 102 served by the water works or distribution system; causative agent; probable cause for the  
 103 outbreak to occur; and key reference. The medium value was used when the number of  
 104 estimated cases was presented in the form of an interval in the reviewed articles.

## 105 Results

106 Three areas of the WBOs origins in the drinking water systems are analysed in this paper: raw  
 107 water contamination; treatment deficiencies at the waterworks; and distribution systems failure.

### 108 WBOs caused by raw water contamination

109 The probable causes for outbreaks correlated with the contamination of raw water in the  
 110 catchment areas are shown in Tables 1-2 and Figure 1-3. The enteric disease outbreaks have  
 111 been divided into two categories, specifying the origin of the drinking water supply:  
 112 groundwater-related WBOs in Table 1, and surface water-related WBOs in Table 2.



113

114 **Figure 1. The number of events of WBOs and the number of cases of illnesses among the consumers.**

115 11 drinking water-related outbreaks were associated with groundwater contamination, which  
 116 instigated gastrointestinal illness amongst an estimated total of 10021 consumers (Table 1,  
 117 Figure 1). Even though the large majority (82%) of reported outbreaks originated by  
 118 groundwater contamination occurred before 2007, no time-related pattern can be inferred due  
 119 to the significant delay between incidents and dates of reporting.

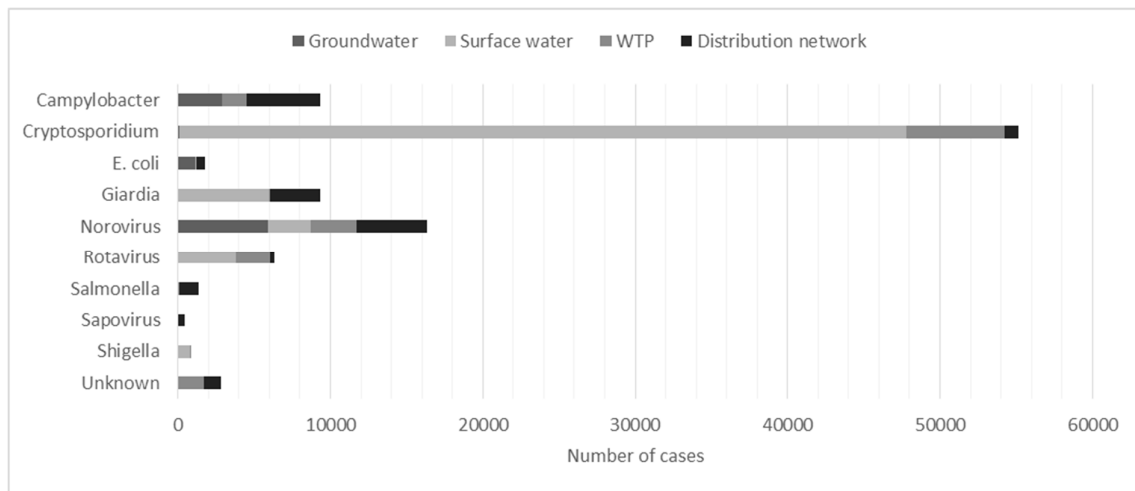
120 The aetiological agents for the events with groundwater contamination were norovirus in six  
 121 outbreaks, *Cryptosporidium* in two events, one event with *Campylobacter*, one with two  
 122 bacterial pathogens (*E. coli* and *Campylobacter*), and also one with both norovirus and

123 *Campylobacter*. Taking into account the information displayed in Table 1 and Figure 2-3,  
124 norovirus is the prevailing pathogen being present in seven of the WBOs, even though in one  
125 occasion as part of a multi-agent outbreak. *Campylobacter*, on the other hand, was present in  
126 three outbreaks, but only in one occasion it was the single detected aetiological agent.

127 Several causes of the WBOs for the events with groundwater contamination are presented,  
128 where heavy rain was linked to six outbreaks; contaminated runoff, decreased raw water  
129 quality, sewage contamination, and snowmelt were associated with one event each; finally,  
130 multiple contamination causes were responsible for one outbreak. Surficial run-off seems to be  
131 the suspected cause for the large majority (73%) of raw water contamination occurrences, since  
132 the events are mostly caused by infiltration of polluted water subsequent to heavy rainfall  
133 circumstances. In three outbreaks, animal faecal residues were the probable origin for the  
134 microbiological contamination.

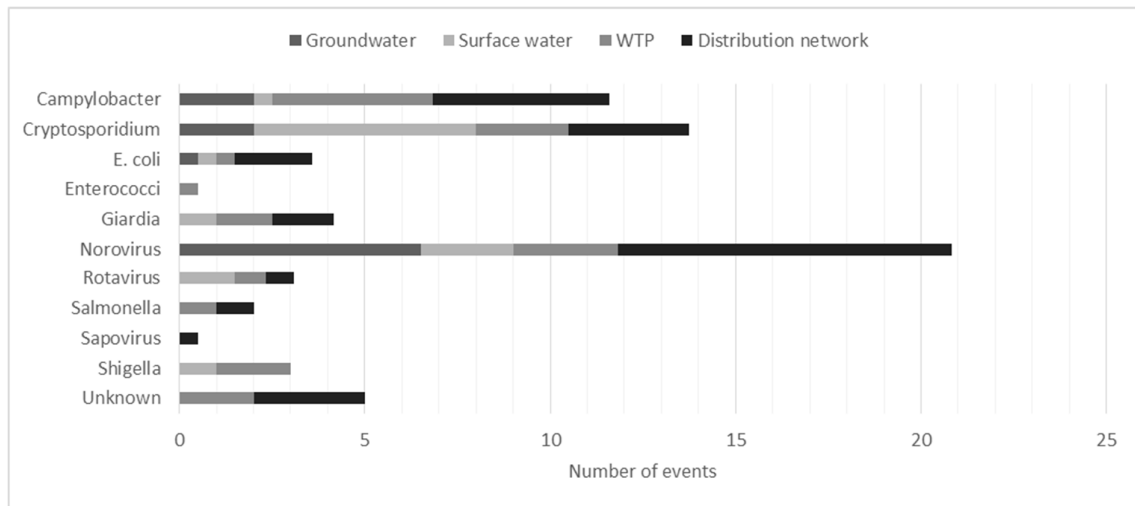
135 The outbreaks for the events with groundwater contamination show that five countries endured  
136 more than a 1000 cases of infectious gastrointestinal illness, in one single event: Canada,  
137 Finland, France, Greece and USA.

138



139

140 **Figure 2. The total number of affected consumers for each pathogen. If several pathogens were present during one**  
141 **outbreak, the number of affected consumers have been divided with the number of present pathogens.**



142

143

144

**Figure 3** The number of cases of WBOs where each pathogen was present. If several pathogens were present, each occasion has been divided into fractions for each pathogen.

145

**Table 1** – List of outbreaks originated from raw water contamination (groundwater).

Year	Location, country	Est. cases	Pop. served	Causative agent	Probable causes for outbreak occurring	Reference
2000	Walkerton, Canada	2300	4800	<i>Campylobacter</i> and <i>E. coli</i>	Contamination from livestock faecal residue following heavy rainfall	(Hrudey et al. 2003)
2000	Clitheroe, UK	58	17252	<i>Cryptosporidium</i>	Contamination with animal faeces following abnormally heavy rain	(Howe et al. 2002)
2001	Southern Finland	1000	18000	<i>Campylobacter</i>	Floodwater from a dike contaminated by runoff (probably from animal sources)	(Hänninen et al. 2003)
2002	Isère, France	2000	5600	Norovirus	Heavy rains lead to overflow in the Sewage treatment works upstream and the flooding of raw water borehole	(Tillaut et al. 2004)
2002	Transtrand, Sweden	500	772	Norovirus	Crack in sewage pipe 10m from one of the supplying wells	(Carrique-Mas et al. 2003)

Year	Location, country	Est. cases	Pop. served	Causative agent	Probable causes for outbreak occurring	Reference
2004	Ohio, USA	1450	Unknown	<i>Campylobacter</i> and norovirus	Multiple contamination of aquifer from onsite septic systems, land application of sludge and infiltration of run-off	(O'Reilly et al. 2007)
2005	Xanthi, Greece	709	13956	Norovirus	Contamination of well following a heavy rain event	(Papadopoulos et al. 2006)
2006	Xanthi, Greece	1640	100882	Norovirus	Groundwater contamination following a heavy rain event	(Vantarakis et al. 2011)
2006	Portlaw, Ireland	8	Unknown	<i>Cryptosporidium</i>	Moderate risk of groundwater contamination previously identified; UV treatment unit was commissioned	(HPSC 2007)
2009	Evertsberg, Sweden	200	400	Norovirus	Well contaminated by snowmelt	(Riera-Montes et al. 2011)
2011	Agrigento, Italy	156	4965	Norovirus	Infiltration of contaminated surficial waters following heavy rain	(Giammanco et al. 2014)

146

147 13 waterborne outbreaks caused by contaminated surface water have been identified, Table 2  
148 and Figure 1. A time-related pattern could be suggested for the outbreaks originated by surface  
149 water contamination where a majority of the cases of illness (87%) occurred after 2007 but that  
150 may be due to selection bias.

151 The aetiological agents for the events with surface water contamination were the protozoan  
152 pathogen *Cryptosporidium* in six events while norovirus was present in two outbreaks. *Shigella*,  
153 *Giardia*, and norovirus were the causative pathogen in one outbreak each and multiple  
154 aetiologies were responsible in two outbreaks.

155 For surface water contamination events the causes of the WBOs were heavy rainfall, sewage  
156 contamination, animal or farming activities and increased organic matter. The majority of the  
157 infections in the identified events were related to wastewater contamination.

158 The highest number of estimated cases caused by surface water contamination were  
159 concentrated in only one country (Sweden) responsible for 49400 infected drinking water  
160 consumers, mainly due to two especially large outbreaks in 2010 and 2011. The second largest  
161 number of affected consumers was located in Norway.

162 Table 2 – List of outbreaks originated from raw water contamination (surface water).

Year	Location, country	Est. cases	Pop. served	Causative agent	Probable causes for outbreak occurring	Reference
2002	Midlands, Ireland	> 31	25000	<i>Cryptosporidium</i>	Contamination with farmyard slurry and manure following very heavy rains	(Jennings & Rhatigan 2002)
2002	St. Maria de Palautordera, Spain	756	6343	<i>Shigella</i>	Heavy rain led mud and organic material into the WTP	(Arias et al. 2006)
2004	Bergen, Norway	6000	48000	<i>Giardia</i>	Leaking sewage pipes with drainage to the raw water source	(Nygård et al. 2006) (Røstum et al. 2009)
2005	Gwynedd and Anglesey, UK	231	60000	<i>Cryptosporidium</i>	Natural (wildlife) contamination, septic tanks and sewage treatment works; streaming and stratification in raw water (lake); UV system subsequently installed	(Mason et al. 2010) (Chalmers et al. 2010)
2005	South East England, UK	140	Unknown	<i>Cryptosporidium</i>	Low water levels in the river may have reduced dilution from sewage discharge	(Nichols et al. 2006)
2005	Oregon, USA	60	Unknown	<i>Campylobacter</i> and <i>E. coli</i>	Inadequate treatment after heavy rainfall conditions	(Yoder et al. 2008)
2006	Cardrona, New Zealand	218	3800	Norovirus	Contamination from sewage overflow	(Hewitt et al. 2007)
2007	Galway, Ireland	304	Unknown	<i>Cryptosporidium</i>	Very wet winter contributed to contamination of lake probably due to run-off from land following slurry spreading	(Pelly et al. 2007) (HPSC 2008)
2008	Lilla Edet, Sweden	2400	7500	Norovirus	Contaminated raw water from point source pollution caused by wastewater	(Larsson et al. 2013)

Year	Location, country	Est. cases	Pop. served	Causative agent	Probable causes for outbreak occurring	Reference
2009	San Felice del Benaco, Italy	299	3360	Rotavirus and norovirus	Contamination of lake due to over-capacity of the sewage system and/or illegal wastage	(Scarcella et al. 2009)
2010	Östersund, Sweden	27000	51000	<i>Cryptosporidium</i>	Faecal contamination of raw water	(Widerström et al. 2014)
2011	Skellefteå, Sweden	20000	71580	<i>Cryptosporidium</i>	Contamination from wastewater	(Andersson et al. 2014)
2012	Elassona, Greece	3620	37264	Rotavirus	Heavy rain lead to increased coloured water	(Mellou et al. 2014)

163

#### 164 **WBOs caused by treatment failure**

165 Analysing the 18 reviewed incidents originated by treatment deficiencies in the drinking water  
166 production, which are displayed in Table 3, Figure 1-3, it can be observed that several causative  
167 agents are present and no obvious one is predominant. Nevertheless *Campylobacter* was the  
168 most frequent aetiology, present in almost one third of the outbreaks even though not  
169 exclusively in one of those events. Norovirus was present in two out of four outbreaks as part  
170 of a multiple pathogen occurrence. *Cryptosporidium* was responsible for three outbreaks but in  
171 one of those as part of a mixed-agent outbreak. Both rotavirus WBOs and one of the *Giardia*  
172 outbreaks were part of events with multiple aetiologies. *Shigella*, *Salmonella*, Enterococci and  
173 *E. coli* were also present in occurrences leading to the contamination of the drinking water.

174 The technical reasons that ultimately led to the outbreaks can be divided into two main groups.  
175 The first group is 11 outbreaks caused by disinfection-related problems and in the second group  
176 four WBOs were related with difficulties with increased turbidity in the inflow of raw water.  
177 The treatment deficiencies were sometimes loosely associated with maintenance work or strain  
178 within the treatment process train in coping with increased demand. An event in Sweden  
179 demonstrates that chemicals used in the production of water can be contaminated. In this event  
180 salt used in the water softening process was contaminated with Enterococci and *E. coli*.

181 The location of seven of the reported illnesses caused by waterborne outbreaks originated from  
182 treatment deficiencies in North America, where Canada had one outbreak and USA six  
183 occurrences with significant impact. Within Europe a total number of eight outbreaks occurred  
184 which corresponds to 43% of estimated cases. In Italy and France the outbreaks were larger and  
185 caused more than 2500 cases of gastrointestinal illnesses. Finally, in New Zealand the three  
186 reported WBOs only affected a smaller number of consumers.

188 Table 3 – List of outbreaks originated from treatment deficiencies at the WTPs.

Year	Location, country	Est. cases	Pop. served	Causative agent	Probable causes for outbreak occurring	Reference
2000	Gourdon, France	2600	7088	<i>Campylobacter</i> , rotavirus and norovirus	Failure in the chlorination system (and possible contamination of groundwater from agricultural run-off)	(Gallay et al. 2006)
2000	Colorado, USA	27	Unknown	<i>Giardia</i>	Multiple failures in the pumping mechanism and filtration system; inadequate time for chlorination due to increased demand	(Lee et al. 2002)
2001	Saskatchewan, Canada	6450	18000	<i>Cryptosporidium</i>	Treatment deficiencies after maintenance work because of increased turbidity	(Stirling et al. 2001)
2001	Hawkes Bay, New Zealand	186	295	<i>Campylobacter</i>	Malfunction in the UV system and delayed installation of replacement components	(Thornley et al. 2002)
2001	Torres de Segre, Spain	344	1880	<i>Campylobacter</i>	Failure in chlorination system	(Godoy et al. 2002)
2001	Switzerland	650	Unknown	Norovirus	Treatment failure following deficiencies in chlorine and/or ozone application	(Fretz et al. 2005)
2001	Pennsylvania, USA	19	Unknown	Unknown	Unspecified treatment deficiency; no chlorine residual in the drinking water	(Blackburn et al. 2004)
2001	Wyoming, USA	83	Unknown	Norovirus	Failure of pellet chlorinator and septic tank contamination	(Blackburn et al. 2004)

Year	Location, country	Est. cases	Pop. served	Causative agent	Probable causes for outbreak occurring	Reference
2004	Ireland	14	25000	<i>Cryptosporidium</i>	High demand and turbidity issues lead to unfiltered water mixed with filtered one	(O'Toole et al. 2004)
2004	New Zealand	23	Unknown	<i>Shigella</i>	Treatment failure and inadequate raw water source	(ESR 2005)
2004	Montana, USA	70	Unknown	<i>Salmonella</i>	UV disinfection unit found to be out of service	(Liang et al. 2006)
2005	Carlow, Ireland	31	25000	<i>Cryptosporidium</i> and <i>Giardia</i>	Aging plant with turbidity problems in highly agricultural basin; sewage treatment plants upstream; rainfall peak	(Roch et al. 2005)
2006	Apulia, Italy	2860	Unknown	Rotavirus and norovirus	Technical problems with chlorination	(Martinelli et al. 2007)
2006	Valencia d'Aneu, Spain	≥68	180	<i>Shigella</i>	Chlorinator froze and stopped working; possible illegal discharge of wastewater near raw water source	(Godoy et al. 2011)
2006	Indiana, USA	32	Unknown	<i>Campylobacter</i>	Inadequate chlorination of the water supply; cross-contamination also possible when testing a new water main	(Yoder et al. 2008)
2007	Florida, USA	1663	Unknown	Unknown	Operation and maintenance deficiencies in water treatment	(Brunkard et al. 2011)

Year	Location, country	Est. cases	Pop. served	Causative agent	Probable causes for outbreak occurring	Reference
2010	Åhus, Sweden	Unknown	Unknown	Enterococci and <i>E. Coli</i>	Salt used in the water softening process was contaminated; rapid intervention of the municipality may have prevented an outbreak	(Norberg 2010)
2012	Darfield, New Zealand	138	3280	<i>Campylobacter</i>	Pump failure lead to exclusive use of river raw water; heavy rains resulted in increased turbidity, no multi-barrier approach	(Bartholomew et al. 2014)

189

190 **WBOs caused by distribution systems failure**

191 The 26 incidents that were reviewed for this chapter, Table 4 and Figure 1-3, were the  
192 consequence of network malfunction. Multiple aetiologies were present in seven outbreaks, and  
193 in many of them bacterial, viral and protozoan pathogens were simultaneously identified. Three  
194 WBOs had unidentified aetiologies. In the remaining outbreaks one single aetiological agent  
195 was detected: norovirus was responsible for seven outbreaks, *Cryptosporidium* and  
196 *Campylobacter* were causative of three outbreaks each, *E. coli*, *Giardia* and *Salmonella* were  
197 the single agent in one outbreak each.

198 The available information regarding the causes of distribution systems failures show that cross-  
199 connections are the main cause for outbreaks in the distribution system. Other identified causes  
200 were maintenance or repair works in the water mains, intrusion of sewage due to leakage,  
201 distribution system reservoir contamination and regrowth in the distribution network due to low  
202 demand. The cause that affected the highest number of consumers was intrusion of water into  
203 the distribution network.

204 More than half of the estimated cases of illnesses caused by waterborne outbreaks originating  
205 from distribution systems failure were located in Finland and together with USA almost three  
206 quarters of the affected consumers are accounted for. In USA five outbreaks occurred while in  
207 Finland only two outbreaks were identified. Among the remaining countries UK and Denmark  
208 have four respectively three identified outbreaks while the remaining countries have fewer  
209 identified outbreaks.

210

211 Table 4 – List of outbreaks originated from distribution systems failure.

Year	Location, country	Est. cases	Pop. served	Causative agent	Probable causes for outbreak occurring	Reference
2000	Strasbourg, France	53	60000	Unknown	Main repair in the network	(Deshayes & Schmitt 2001)
2000	Bari, Italy	344	1000	Norovirus	Break in pipeline public supply connecting to resort tank	(Boccia et al. 2002)
2000	Belfast, UK	117	Unknown	<i>Cryptosporidium</i>	Seepage of raw sewage from a septic tank into the water distribution system	(Glberman et al. 2002)
2000	South Wales, UK	281	Unknown	<i>Campylobacter</i>	Seepage of surface water contaminated by agricultural waste following heavy rainfall into drinking water reservoir	(Richardson et al. 2007)
2000	Ohio, USA	29	Unknown	<i>E. coli</i>	Possible back-siphonage from animal barn	(Lee et al. 2002)
2001	Darcy le Fort, France	563	1100	<i>Cryptosporidium</i> , rotavirus, <i>Campylobacter</i> and <i>E. coli</i>	Sewage contamination occurred in the distribution network upstream to the city	(Dalle et al. 2003)
2001	Lleida, Spain	96	293	Norovirus	Contamination of reservoir due to lack of maintenance and structural deficiencies	(Godoy et al. 2006)
2001	Utrecht, The Netherlands	37	1866	Norovirus	Drinking water system connected to grey water system in maintenance work; cross-connection not removed	(Fernandes et al. 2007)
2001	Belfast, UK	230	Unknown	<i>Cryptosporidium</i>	Wastewater into the drinking water supply due to a blocked drain	(Glberman et al. 2002)
2002	Vicenza, Italy	670	3006	Unknown	Broken sewage pipe allowed untreated water from the river to enter the city aqueduct	(Tramarin et al. 2002)

Year	Location, country	Est. cases	Pop. served	Causative agent	Probable causes for outbreak occurring	Reference
2002	Switzerland	125	Unknown	Norovirus	Faeces related contamination from a sewage leakage	(Fretz et al. 2005)
2004	Ohio, USA	1450	Unknown	<i>Campylobacter</i> , norovirus and <i>Giardia</i>	Unspecified distribution system deficiency related with untreated groundwater	(Liang et al. 2006)
2007	Køge, Denmark	140	5802	<i>Campylobacter</i> , <i>E. coli</i> and norovirus	Technical and human error at sewage treatment work allowed partially filtered wastewater to enter the drinking water system	(Vestergaard et al. 2007)
2007	Nokia, Finland	8453	30016	Norovirus, <i>Campylobacter</i> and <i>Giardia</i>	Drinking water network contaminated by treated sewage effluent	(Laine et al. 2010)
2007	Västerås, Sweden	400	Unknown	Unknown	Leaked sewage into drinking water network during maintenance work on a pipeline	(Nilsson 2008)
2008	Zurich, Switzerland	126	2000	<i>Campylobacter</i> and norovirus	Input of highly pressurised washwater from sewage plant into the drinking water system	(Breitenmoser et al. 2011)
2008	Northampton, UK	> 422	250000	<i>Cryptosporidium</i>	Dead rabbit found in a tank containing drinking water at the treatment works	(Smith et al. 2010) (Chalmers 2012)
2008	Colorado, USA	1300	Unknown	<i>Salmonella</i>	Likely animal contamination of a storage tank	(Brunkard et al. 2011)
2009	Utah, USA	8	Unknown	<i>Giardia</i>	Cross-connection between potable and non-potable water sources resulting in backflow	(Hilborn et al. 2013)

Year	Location, country	Est. cases	Pop. served	Causative agent	Probable causes for outbreak occurring	Reference
2010	Køge, Denmark	409	20000	<i>Campylobacter</i>	Contamination of central water supply system by unknown mechanism	(Gubbels et al. 2012)
2010	Öland, Sweden	200	Unknown	Norovirus	Untreated water from well in the drinking water network	(Hallin 2012)
2010	Utah, USA	628	Unknown	<i>Campylobacter</i>	Cross-connection between potable and non-potable water sources resulting in backflow	(Hilborn et al. 2013)
2012	Kilkis, Greece	79	1538	Norovirus	Heavy snowfall and runoff, low temperatures and 15 days without use of school's public water supply increased microbial load	(Mellou et al. 2013)
2012	Kalundborg, Denmark	187	Unknown	Norovirus	Contamination from sewage pipe due to fall in pressure, throughout water supply system repairs	(van Alphen et al. 2014)
2012	Vuorela, Finland	800	2931	Sapovirus and <i>E. coli</i>	Main pipe accidentally broken during road construction; flushing after breakage repair proved insufficient and storage reservoir was contaminated	(Jalava et al. 2014)
2013	Guipuzko, Spain	238	650	Norovirus and rotavirus	Cross-connection between drinking water supplies and industrial water taken from a river	(Altzibar et al. 2015)

212

## 213 Discussion

214 In this paper the causes of WBOs have been investigated. The main causes for contamination  
215 of groundwater sources identified in this paper were the intrusion of animal faeces or  
216 wastewater due to heavy rains Even if the large majority of the reported events occurred before  
217 2007, a time-related pattern cannot be inferred and further measures to reduce the contamination

218 risks to the raw water and the catchment areas should be thoroughly implemented, with the  
219 establishment of protection areas and identification of potential contamination sources, for  
220 instance. The outbreaks originated by surface water contamination did on the other hand occur  
221 after 2007 for the majority of the cases of illness, but this does not sanction any assumption  
222 regarding the protection of raw water sources. The main causes for contamination of surface  
223 waters, identified in this study, are the discharge of wastewater into the water source and  
224 increased turbidity and colour of the water. These events may occur during heavy rains but also  
225 at low water levels. This indicates that further measures to reduce the contamination risks to  
226 the raw water and the catchment areas still needs to be implemented for surface water sources.  
227 Measures that could be applied are the establishment of protection areas, the identification of  
228 potential contamination sources and increased monitoring of raw water quality parameters.

229 *Cryptosporidium*, norovirus, *Giardia*, *Campylobacter* and rotavirus were the main pathogens  
230 causing the highest amount of affected consumers, Figure 2, however, the choice of keywords  
231 in the literature search may have introduced a bias which downplayed the role of other causative  
232 agents. The identified pathogens have in common a moderately to long persistence in water  
233 supplies and are moderately to highly infective (Åström 2011). Both *Cryptosporidium* and  
234 *Giardia* are highly resistant to chlorine disinfection, and turbidity control (e.g., chemical  
235 coagulation followed by filtration) is essential for adequate treatment of the water. The highest  
236 number of different pathogens has been identified for the WTP and the distribution network.  
237 Although the number of identified events was larger for the distribution system in comparison  
238 to the number of surface water outbreaks, the number of consumers with gastrointestinal illness  
239 was highest for contamination events related with a surface water source, around six times  
240 higher than for groundwater contamination, Figure 1. However, to prevent the outbreaks in  
241 these occasions the WTPs would have had to adequately treat the contaminated water and, thus,  
242 the failure has not only occurred in the source water but also at the WTPs.

243 The main failure at WTPs causing a WBO has been identified to be the malfunctioning of the  
244 UV treatment step or the chlorination equipment. Thereafter comes increased turbidity,  
245 maintenance work, high or low demand of water and malfunctioning equipment (e.g. pumps).  
246 For many of the events several failures have occurred simultaneously. To reduce the risk of a  
247 WBO, a risk assessment tool for the disinfection step has been developed in Norway. The tool  
248 can be used to identify risks within the disinfection processes chlorination, UV and ozonation,  
249 and thus enabling the prevention of WBOs (Ødegaard et al. 2006).

250 The distribution network had the highest number of individual events of WBOs. However, the  
251 number of affected consumers was low for each event, and therefore the total number of  
252 affected consumers is not very high. The causes identified in this study for WBOs at the  
253 distribution network were cross-connections, pipe breaks and wastewater intrusion into the  
254 network. Also, cases of contamination of distribution system reservoirs are reported. One event  
255 in Greece highlights the magnitude of the challenge posed by norovirus because of its  
256 persistence in water. Previous work has demonstrated a persistence that can be higher than 15  
257 days (Seitz et al. 2011), and that it is resistant at low levels of chlorine disinfection  
258 (Kambhampati et al. 2015).

259 In this study causes and pathogens of WBOs have been critically evaluated. Limitations in this  
260 study are that outbreaks have only been evaluated if the cause of the event was indicated in the  
261 reference and if the event was present in the chosen databases. In a recent review the responsible  
262 authorities and the water industry were directly contacted about recent WBOs in the Nordic  
263 countries (Guzman Herrador et al. 2015). In total, a number of 175 outbreaks were identified in  
264 total which exceeds the number of outbreaks identified in our study. However, the number of  
265 cases of illnesses is of the same order of magnitude for Sweden, Finland and Denmark, if  
266 adjusted for the year 1998-1999 (Miettinen et al. 2001). Consequently, this indicates that the

267 identified causes for outbreaks in this review may not cover minor events that have only affected  
268 a small number of consumers.

269 This work has not addressed the differences between small and large water treatment plants.  
270 The tendency is that medium and large waterworks receive more attention than small ones in  
271 these systematic approaches (Coulibaldy & Rodriguez 2004). In a study published in 2011 that  
272 analysed small water treatment plants in Finland, it was indicated that nonconformity in the  
273 production of microbiological safe drinking water is more probable in small rather than large  
274 waterworks that were distributing water to a minimum of a 1000 consumers (Zacheus &  
275 Miettinen 2011). Previous reviews have highlighted that the number of small waterborne  
276 outbreaks that are not reported or that are merely poorly documented is not negligible (Hrudey  
277 & Hrudey 2007). In countries like Finland where the number of affected consumers is below  
278 0.01% (the USA EPA guideline), it is considered that the production of safe drinking water in  
279 all types of settings and/or limitations is not guaranteed and more measures need to be  
280 implemented (Zacheus & Miettinen 2011).

281 The main objective for the water treatment systems is to deliver drinking water to consumers  
282 that is both aesthetically suitable and safe (Zhang et al. 2012). With continuously changing raw  
283 water quality, variations in water demand and operational challenges at the WTP, risk  
284 assessment of the water treatment systems have become increasingly important. This has also  
285 been stressed by the World Health Organisation. Many tools are available for risk assessment  
286 of the water treatment systems. However, identifying possible risk scenarios proves  
287 challenging. We expect that this critical evaluation of the causes of WBOs will help the water  
288 industry in their work with WSP to identify risks that may lead to waterborne outbreaks. This  
289 paper clearly demonstrates the need for further research to reduce the risks of WBOs and the  
290 need for well-founded guidelines for identification of risks in the production of drinking water.  
291 Additionally, it is suggested that experiences on WBOs are shared within and between water  
292 companies and researchers to improve risk analysis tools and risk reduction measures in order  
293 to provide a safe drinking water.

## 294 **Conclusions**

295 The importance of identifying and addressing the potential risks in the drinking water systems  
296 is of the foremost significance to prevent outbreaks and assure the deliverance of safe water to  
297 consumers. The main causes of contamination identified in this review are:

- 298 • *Groundwater sources*: intrusion of animal faeces or wastewater due to heavy rains;
- 299 • *Surface water sources*: discharge of wastewater into the water source and increased  
300 turbidity and colour of the water;
- 301 • *WTP*: malfunctioning of the disinfection, increased turbidity, maintenance work, high  
302 or low demand of water and malfunctioning equipment (e.g. pumps);
- 303 • *Distribution network*: cross-connections, pipe breaks and wastewater intrusion into the  
304 pipe network. Also, cases of contamination of reservoirs are reported.

305 The main pathogens causing the highest amount of affected consumers are *Cryptosporidium*,  
306 norovirus, *Giardia*, *Campylobacter* and rotavirus, but it is possible that survey bias had an  
307 impact on these results. The highest number of different pathogens has been identified for the  
308 WTP and the distribution network. The highest number of affected consumers with  
309 gastrointestinal illness was for contamination events with a surface water source, while the  
310 highest number of events of WBOs occurred for the distribution network.

311 **References**

- 312 Altzibar, J. M., Zigorraga, C., Rodriguez, R., Leturia N., Garmendia, A. et al. 2015 Outbreak  
313 of acute gastroenteritis caused by contamination of drinking water in a factory, the Basque  
314 Country. *Journal of Water and Health* **13** (1), 168–173.
- 315 Andersson, T., Bjelkmar, P., Hulth, A., Lindh, J., Stenmark, S. & Widerström, M. 2014  
316 Syndromic surveillance for local outbreak detection and awareness: evaluating outbreak signals  
317 of acute gastroenteritis in telephone triage, web-based queries and over-the-counter pharmacy  
318 sales. *Epidemiology and Infection* **142**, 303-313.
- 319 Arias, C., Sala, M. R., Dominguez, A., Bartolomé, R., Benavente, A., et al. 2006 Waterborne  
320 epidemic outbreak of *Shigella sonnei* gastroenteritis in Santa Maria de Palautordera, Catalonia,  
321 Spain. *Epidemiology and Infection* **134**(3), 598-604.
- 322 Baldursson, S. & Karanis, P. 2011 Waterborne transmission of protozoan parasites: Review of  
323 worldwide breaks - An update 2004-2010. *Water Research* **45**, 6603-6614.
- 324 Bartholomew, N., Brunton, C., Mitchell, P., Williamson, J. & Gilpin, B. 2014 A waterborne  
325 outbreak of campylobacteriosis in the South Island of New Zealand due to a failure to  
326 implement a multi-barrier approach. *Journal of Water and Health* **12**(3), 555-563.
- 327 Bartram, J., Corrales, L., Davison, A. et al. 2009 Water safety plan manual: step-by-step risk  
328 management for drinking water suppliers. Geneva: WHO.
- 329 Blackburn, B.G., Craun, G., Yoder, J., Hill, V. & Calderon, R. 2004 Surveillance for  
330 Waterborne-Disease Outbreaks Associated with Drinking Water – United States, 2001-2002.  
331 Atlanta: Centers for Disease Control and Prevention.
- 332 Boccia, D., Eugenio Tozzi, A., Cotter, B., Rizzo, C., Russo, et al. 2002 Waterborne Outbreak  
333 of Norwalk-Like Virus Gastroenteritis at a Tourist Resort, Italy. *Emerging Infectious Diseases*  
334 **8**(6), 563-568.
- 335 Bratanova, B., Morrison G., Fife-Schaw C., Chenoweth J. & Mangold M. 2013 Restoring  
336 drinking water acceptance following a waterborne disease outbreak: The role of trust, risk  
337 perception, and communication. *Journal of Applied Social Psychology* **43**, 1761–1770.
- 338 Breitenmoser, A., Fretz, R., Schmid, J., Besl, A. & Etter, R. 2011 Outbreak of acute  
339 gastroenteritis due to a washwater-contaminated water supply, Switzerland, 2008. *Journal of*  
340 *Water and Health* **9**(3), 569-576.
- 341 Brunkard, J. M., Ailes, E., Roberts, V., Hill, V. & Hilborn, E. 2011 Surveillance for Waterborne  
342 Disease Outbreaks Associated with Drinking Water – United States, 2007-2008. Morbidity and  
343 Mortality Weekly Report, Atlanta: Centers for Disease Control and Prevention, pp 38-75.
- 344 Carrique-Mas, J., Andersson, Y., Petersén, B., Hedlund, K.-O., Sjögren, N., & Giesecke, J.  
345 2003 A Norwalk-like virus waterborne community outbreak in a Swedish village during peak  
346 holiday season. *Epidemiology and Infection* **131**, 737-744.
- 347 Chalmers, R.M. 2012 Waterborne outbreaks of cryptosporidiosis. *Ann Ist Super Sanità* **48** (4),  
348 429-446.
- 349 Chalmers, R.M., Robinson, G., Elwin, K., Hadfield, S., Thomas, E., Watkins, J., Casemore, D.  
350 & Kay, D. 2010 Detection of *Cryptosporidium* species and sources of contamination with  
351 *Cryptosporidium hominis* during a waterborne outbreak in northwest Wales. *Journal of Water*  
352 *and Health* **8**(2), 311-325.
- 353 Coulibaldy, H.D. & Rodriguez, M. 2004 Development of performance indicators for small  
354 Quebec drinking water utilities. *Journal of Environmental Management* **74**: 243-255.

- 355 Dalle, F., Roz, P., Dautin, G., Di-Palma, M., Kohli, E., Sire-Bidault, C., et al. 2003 Molecular  
356 Characterization of Isolates of Waterborne *Cryptosporidium* spp. Collected during an Outbreak  
357 of Gastroenteritis in South Burgundy, France. *Journal of Clinical Microbiology* **41**(6), 2690-  
358 2693.
- 359 Delpha, I., Jung, A.-V., Baures, E., Clement, M. & Thomas, O. 2009 Impacts of climate change  
360 on surface water quality in relation to drinking water production. *Environmental International*  
361 **35**, 1225-1233.
- 362 Deshayes, F. & Schmitt, M. 2001 Pollution du réseau d'eau potable à Strasbourg et survenue  
363 concomitante de gastroentérites. BEH (2), 5-7. [http://www.invs.sante.fr/beh/2001](http://www.invs.sante.fr/beh/2001/02/beh_02_2001.pdf)  
364 [/02/beh\\_02\\_2001.pdf](http://www.invs.sante.fr/beh/2001/02/beh_02_2001.pdf).
- 365 ESR 2005. Annual Summary of Outbreaks in New Zealand 2004 Institute of Environmental  
366 Science and Research. [https://surv.esr.cri.nz/PDF\\_surveillance/AnnualRpt/](https://surv.esr.cri.nz/PDF_surveillance/AnnualRpt/AnnualOutbreak/2004/2004OutbreakRpt.pdf)  
367 [AnnualOutbreak/2004/2004OutbreakRpt.pdf](https://surv.esr.cri.nz/PDF_surveillance/AnnualRpt/AnnualOutbreak/2004/2004OutbreakRpt.pdf).
- 368 Fernandes, T., Schout, C., Husman, A., Eilander, A., Vennema, H. & Van Duynhoven, Y. 2007  
369 Gastroenteritis associated with accidental contamination of drinking water with partially treated  
370 water. *Epidemiology and Infection*. **135**, 818-826.
- 371 Fretz, R., Svoboda, P., Lüthi, T.M., Tanner, M. & Baumgartner, A. 2005 Outbreaks of  
372 gastroenteritis due to infections with Norovirus in Switzerland, 2001-2003. *Epidemiology and*  
373 *Infection* **133**(3), 429-437.
- 374 Gallay, A., De Valk, H., Cournot, M., Ladeuil, B., Hemery, C., et al. 2006 A large multi-  
375 pathogen waterborne community outbreak linked to faecal contamination of a groundwater  
376 system, France, 2000. *Clinical Microbiology and Infection* **12**, 561-570.
- 377 Giammanco, G., Di Bartolo, I., Purpari, G., Costantino, C., Rotolo, V. et al. 2014 Investigation  
378 and control of a Norovirus outbreak of probable waterborne transmission through a municipal  
379 groundwater system. *Journal of Water and Health* **12**(3), 452-464.
- 380 Glaberman, S., Moore, J., Lowery, C., Chalmers, R., Sulaiman, I., Elwin, K. et al. 2002 Three  
381 Drinking-Water-Associated Cryptosporidiosis Outbreaks, Northern Ireland. *Emerging*  
382 *Infectious Diseases* **8**(6), 631-633.
- 383 Godoy, P., Nuín, C., Alesdà, M., Llovet, T., Mazan, R. & Domínguez, Á. 2006 Brote de  
384 gastroenteritis por Norovirus causado por el consumo de agua de suministro público. *Rev Clin*  
385 *Esp.* **206**(9), 435-7.
- 386 Godoy, P., Artigues, A., Nuín, C., Aramburu, J., Pérez, M., Domínguez, A. & Salleras, L. 2002  
387 Brote comunitario de gastroenteritis por *Campylobacter jejuni* originado por el consumo de  
388 agua del suministro público. *Medicina Clinica* **119**(18), 696-698.
- 389 Godoy, P., Bartolomé, R., Torres, J., Espinet, L., Escobar, A., Nuin, C. & Domínguez, A. 2011  
390 Brote de gastroenteritis por el consumo de agua de suministro público causado por *Shigella*  
391 *sonnei*. *Gac Sanit.* **25**(5), 363-367.
- 392 Gubbels, S.M., Kuhn, K. G., Larsson, J. T., Adelhardt, M., Engberg, J. et al. 2012 A waterborne  
393 outbreak with a single clone of *Campylobacter jejuni* in the Danish town of Køge in May 2010  
394 *Scandinavian Journal of Infectious Diseases* **44**, 586-594.
- 395 Guzman Herrador, B.R., Carlander, A., Ethelberg, S., De Blasio, B.F., Kuusi, M., Lund, V. et  
396 al. 2015 Waterborne outbreaks in the Nordic countries, 1998 to 2012. *Eurosurveillance* **20**(24),  
397 1-10.

- 398 Hallin, E. 2012 Norovirus i vatten – en litteraturstudie. Stockholm: Svenskt Vatten Utveckling.  
399 (Norovirus in water – a literature review)
- 400 Hewitt, J., Bell, D., Simmons, G., Rivera-Aban, M., Wolf, S., & Greening, G. 2007  
401 Gastroenteritis Outbreak Caused by Waterborne Norovirus at a New Zealand Ski Resort.  
402 *Applied and Environmental Microbiology* **73**(24), 7853-7857.
- 403 Hilborn, E.D., Wade, T., Hicks, L., Garrison, L., & Gargano, J. 2013 Surveillance for  
404 Waterborne Disease Outbreaks Associated with Drinking Water and Other Nonrecreational  
405 Water – United States, 2009-2010. Atlanta: Centers for Disease Control and Prevention.
- 406 Howe, A.D., Forster, S., Morton, S., Marshall, R., Osborn, K., Wright, P., & Hunter, P. 2002  
407 Cryptosporidium Oocysts in a Water Supply Associated with a Cryptosporidiosis Outbreak.  
408 *Emerging Infectious Diseases* **8**(6), 619-624.
- 409 HPSC 2007. Annual Report 2006. Dublin: Health Protection Surveillance Centre.
- 410 HPSC 2008. Annual Report 2007. Dublin: Health Protection Surveillance Centre.
- 411 Hruday, S.E., Payment, P., Huck, P.M., Gillham, R.W., & Hruday, E.J. 2003 A fatal waterborne  
412 disease epidemic in Walkerton, Ontario: comparison with other waterborne outbreaks in the  
413 developed world. *Water Science and Technology* **47**(3), 7-14.
- 414 Hruday, S. E., & Hruday, E. 2007 Published Case Studies of Waterborne Disease Outbreaks -  
415 Evidence of a Recurrent Threat. *Water Environment Research* **79**(3), 233-245.
- 416 Hänninen, M., Haajanan, H., Pummi, T., Wermundsen, K., Katila, M.-L., Sarkkinen, H.,  
417 Miettinen, I. & Rautelin, H. 2003 Detection and Typing of *Campylobacter jejuni* and  
418 *Campylobacter coli* and Analysis of Indicator Organisms in Three Waterborne Outbreaks in  
419 Finland. *Applied and Environmental Microbiology* **69**(3), 1391-1396.
- 420 Jalava, K., Rintala, H., Ollgren, J., Maunula, L., Gomez-Alvarez, V. et al. 2014 Novel  
421 Microbiological and Spatial Statistical Methods to Improve Strength of Epidemiological  
422 Evidence in a Community-Wide Waterborne Outbreak. *PLoS ONE* **9**(8), 104713.
- 423 Jennings, P. & Rhatigan, A. 2002 Cryptosporidiosis outbreak in Ireland linked to public water  
424 supply. *Eurosurveillance* **6** (22). [http://www.eurosurveillance.org/ViewArticle.aspx?  
425 ArticleId=2089](http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=2089).
- 426 Kambhampati, A., Koopmans, M. & Lopman, B.A. 2015 Burden of norovirus in healthcare  
427 facilities and strategies for outbreak control. *Journal of Hospital Infection*, 89, pp.296-301.
- 428 Karanis, P., Kourenti, C. & Smith, H. 2007 Waterborne transmission of protozoan parasites: A  
429 worldwide review of outbreaks and lessons learnt. *Journal of Water and Health* **5**(1).
- 430 Laine, J., Huovinen, E., Virtanen, M. J., Snellman, M., Lumio, J. et al 2010 An extensive  
431 gastroenteritis outbreak after drinking-water contamination by sewage effluent, Finland.  
432 *Epidemiology and Infection* **139**(7), 1105-1113.
- 433 Lake, I.R., Nichols, G., Bentham, G., Harrison, F., Hunter, P., & Sari Kovats, R. 2007  
434 Cryptosporidiosis decline after regulation, England and Wales, 1989-2005. *Emerging  
435 Infectious Diseases* **13**(4), 623-625.
- 436 Larsson, C., Andersson, Y., Allestam, G., Lindqvist, A., Nenonen, N., & Bergstedt, O. 2013  
437 Epidemiology and estimated costs of a large waterborne outbreak of norovirus infection in  
438 Sweden. *Epidemiol. Infect.* **142**, 592-600.

- 439 Lee, S.H., Levy, D., Craun, G., Beach, M. & Calderon, R. 2002 Surveillance for Waterborne-  
440 Disease Outbreaks – United States, 1999-2000. Atlanta: Centers for Disease Control and  
441 Prevention.
- 442 Liang, J.L., Dziuban, E.J., Craun, G., Hill, V. & Moore, M.R. 2006 Surveillance for Waterborne  
443 Disease and Outbreaks Associated with Drinking Water and Water not Intended for Drinking  
444 – United States, 2003-2004. Atlanta: Centers for Disease Control and Prevention.
- 445 Lindhe, A., Rósen, L., Norberg, T., Røstum, J. & Petersson, T. 2013 Uncertainty modelling in  
446 multi-criteria analysis of water safety measures. *Environment Systems and Decisions* (33), 195-  
447 208.
- 448 Martinelli, D., Prato, R., Chironna, M., Sallustio A., Caputi G. et al. 2007 Large outbreak of  
449 viral gastroenteritis caused by contaminated drinking water in Apulia, Italy, May-October 2006.  
450 *Eurosurveillance* **12**(16)
- 451 Mason, B. W., Chalmers, R. M., Carnicer-Pont, D., & Casemore, D. P. 2010 A *Cryptosporidium*  
452 *hominis* outbreak in North-West Wales associated with low oocyst counts in treated drinking  
453 water. *Journal of Water and Health* **8**(2): 299-310.
- 454 Mellou, K., Katsioulis, A., Potamiti-Komi, M., Pournaras, S., Kyritsi, M. et al. 2014 A large  
455 waterborne gastroenteritis outbreak in central Greece, March 2012: challenges for the  
456 investigation and management. *Epidemiol. Infect.* **142**, 40-50.
- 457 Mellou, K., Sideroglou, T., Potamiti-Komi, M., Kokkinos, P., Ziros, P., Georgakopoulou, T.,  
458 & Vantarakis, A. 2013 Epidemiological investigation of two parallel gastroenteritis outbreaks  
459 In school settings. *BMC Public Health* **13**(241), 1-7.
- 460 Miettinen, I.T., Zacheus, O., Von Bonsdorff, C.H., & Vartiainen, T. 2001 Waterborne  
461 epidemics in Finland in 1998-1999. *Water Science and Technology* **43**, 67-71.
- 462 Nichols, G., Chalmers, R., Lake, I., Sopwith, W., Regan, M., Hunter, P. et al. 2006  
463 *Cryptosporidiosis*: a report on the surveillance and epidemiology of *Cryptosporidium* infection  
464 in England and Wales. Drinking Water Directorate Contract Number DWI 70/2/201, 129.
- 465 Nilsson, L. 2008 Cirkulation: Många sårbara punkter i dricksvattenkedjan. 13 February.  
466 Accessed October 13, 2014. [http://www.cirkulation.com/2008/02/manga-sarbara-punkter-i-](http://www.cirkulation.com/2008/02/manga-sarbara-punkter-i-dricksvattenkedjan/)  
467 [dricksvattenkedjan/](http://www.cirkulation.com/2008/02/manga-sarbara-punkter-i-dricksvattenkedjan/).
- 468 Norberg, P. 2010 Orsaksutredning bakteriekontamination av Åhus dricksvatten 2010  
469 Kristianstads Kommun, Kristianstad: C4 Teknik.
- 470 Nygård, K., Schimmer, B., Søbstad, Ø., Walde, A., & Tveit, I. 2006 A large community  
471 outbreak of waterborne giardiasis- delayed detection in a non-endemic urban area. *BMC Public*  
472 *Health* **6** (141).
- 473 O'Toole, C. E, Jennings, P., Meagher, G., & Kelly, I. 2004 *Cryptosporidium* Outbreak in a  
474 Continuously Tested Public Water Supply. *Epi-Insight* (National Disease Surveillance Centre)  
475 5(10), 1.
- 476 O'Reilly, C. E., Bowen, A., Perez, N., Sarisky, J., Shepherd, C. et al. 2007 A Waterborne  
477 Outbreak of Gastroenteritis with Multiple Etiologies among Resort Island Visitors and  
478 Residents: Ohio, 2004. *Clinical Infectious Diseases* **44**(4), 506-512.
- 479 Papadopoulos, V., Vlachos, O., Isidoridou, E., Kasmeridis, C., Pappa, Z., Goutzouvelidis, A.  
480 & Filippou, F. 2006 A Gastroenteritis Outbreak due to Norovirus Infection in Xanthi, Northern  
481 Greece: Management and Public Health Consequences. *J. Gastrointest. Liver Dis.* **15**(1), 27-  
482 30.

483 Pelly, H., Cormican, M., O'Donovan, D., Chalmers, R. M., Hanahoe, B., Cloughley, R.,  
484 McKeown, P., & Corbett-Feeney, G. 2007 A large outbreak of cryptosporidiosis in western  
485 Ireland linked to public water supply: a preliminary report. *Eurosurveillance* **12** (18).  
486 [www.eurosurveillance.org/ViewArticle.aspx?ArticleId=3187](http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=3187).

487 Richardson, G., Thomas, D., Smith, R. M. & Nehaul, L. 2007 A community outbreak of  
488 *Campylobacter jejuni* infection from a chlorinated public water supply. *Epidemiology and*  
489 *Infection* **135**(7), 1151-1158.

490 Riera-Montes, M., Brus Sjölander, K., Allestam, G., Hallin, E., Hedlund, K.-O. & Löfdahl, M.  
491 2011 Waterborne norovirus outbreak in a municipal drinking-water supply in Sweden.  
492 *Epidemiology and Infection* **139**(12), 1928-1935.

493 Roch, B.A. O'Byrne, A.M., Leane, G. et al. 2005 Cryptosporidiosis Outbreak in Carlow Town  
494 and Environs 2005. Health Service Executive – South Eastern Area.

495 Røstum, J., Aasen, A., & Eikebrokk, B. 2009 Risk and Vulnerability Assessment (“Ros-  
496 Analysis”) of the Bergen Water Supply System – A Source to Tap Approach. In Risk  
497 Management of Water Supply and Sanitation Systems, edited by Petr Hlavinec, Cvetanka  
498 Popovska, Jiri Marsalek et al., 73-83. Springer Netherlands.

499 Scarcella, C., Carasi, S., Cadoria, F., Macchi, L., Pavan, A., Salamana, M. et al. 2009 An  
500 outbreak of viral gastroenteritis linked to municipal water supply, Lombardy, Italy, June 2009.  
501 *Eurosurveillance* **14**(29), 1-3.

502 Seitz, S. R., Leon, J. S., Schwab, K. J. et al. 2011 Norovirus Infectivity in Humans and  
503 Persistence in Water. *Applied and Environmental Microbiology*, **77**(19), pp.6884–88.

504 Smith, S., Elliot, A.J., Mallaghan, C., Modha, D., Hippisley-Cox, J., Large, S., Regan, M. &  
505 Smith G. E. 2010 Value of syndromic surveillance in monitoring a focal waterborne outbreak  
506 due to an unusual *Cryptosporidium* genotype in Northamptonshire, United Kingdom, June -  
507 July 2008 *Eurosurveillance* **15**(33), 1-9.

508 Stirling, R., Aramini, J., Ellis, A., Lim, G., Meyers, R., Fleury, M. & Werker, D. 2001  
509 Waterborne cryptosporidiosis outbreak, North Battleford, Saskatchewan, Spring 2001. Canada  
510 Communicable Disease Report **27**(22), 185-192.

511 Thornley, C., McDowell, R., Lopez, L. & Baker, M. 2002. Annual Summary of Outbreaks in  
512 New Zealand 2001 ESR. [https://surv.esr.cri.nz/PDF\\_surveillance/AnnualRpt/  
513 AnnualOutbreak/2001/2001OutbreakRpt.pdf](https://surv.esr.cri.nz/PDF_surveillance/AnnualRpt/AnnualOutbreak/2001/2001OutbreakRpt.pdf).

514 Tillaut, H., Encrenaz, N., Checlair, E., Alexandre-Bird, A., Santo, E. & Beaudeau, P. 2004  
515 Epidémie de gastro-entérite, Isère, novembre 2002. BEH **12**(3-4), 47-48.  
516 [http://opac.invs.sante.fr/doc\\_num.php?explnum\\_id=5801](http://opac.invs.sante.fr/doc_num.php?explnum_id=5801).

517 Tramarin, A., Fabris, P., Bishai, D., Selle, V. & De Lalla, F. 2002 Waterborne infections in the  
518 era of bioterrorism. *The Lancet* **360**(9346), 1699.

519 van Alphen, Lieke B., Dorléans, F., Schultz, A., Fonager, J., Ethelberg, S. et al. 2014 The  
520 Application of New Molecular Methods in the Investigation of a Waterborne Outbreak of  
521 Norovirus in Denmark, 2012. *PLoS ONE* **9**(9), e105053.

522 Vantarakis, A., Mellou, K., Spala, G., Kokkinos, P., & Alamanos, Y. 2011 A Gastroenteritis  
523 Outbreak Caused by Noroviruses in Greece. *International Journal of Environmental Research*  
524 *and Public Health* **8**, 3468-3478.

525 Vestergaard, L., Olsen, K., Stensvold, C, Böttiger, B., Adelhardt, M., Lisby, M., Mørk, L. &  
526 Mølbak, K. 2007 Outbreak of severe gastroenteritis with multiple aetiologies caused by  
527 contaminated drinking water in Denmark, January 2007. *Eurosurveillance* **12**(13).

528 WHO 2011 Guidelines for drinking-water quality, 4th ed. Geneva: World Health Organisation.

529 Widerström, M., Schönning, C., Lilja, M., Lebbad, M., Ljung, T., Allestam, G. et al. 2014 Large  
530 Outbreak of *Cryptosporidium hominis* Infection Transmitted through the Public Water Supply,  
531 Sweden. *Emerging Infectious Diseases* **20**(4), 581-589.

532 Yoder, J., Hlavsa, M., Craun, G., Hill, V., Roberts, V., Yu, P. et al. 2008 Surveillance for  
533 Waterborne Disease and Outbreaks Associated with Drinking Water and Water not Intended  
534 for Drinking – United States, 2005-2006. *Morbidity and Mortality Weekly Report* **57**(SS-9),  
535 39-69.

536 Zacheus, O. & Miettinen, I. 2011 Increased information on waterborne outbreaks through  
537 efficient notification system enforces actions towards safe drinking water. *Journal of Water and*  
538 *Health* **9**(4) 763-772.

539 Zhang, K, Achari, G., Sadiq, R., Langford, C. & Dore, M. 2012 An integrated performance  
540 assessment framework for water treatment plants. *Water Research* **46**, 1673-1683.

541 Åström, J. 2011 Microbial risks in surface water sources, PhD thesis. Gothenburg: Chalmers  
542 University of Technology.

543 Ødegaard, H., Fiksdal, L. & Østerhus, S. 2006 Optimal desinfeksjonspraksis for drikkevann  
544 fase 1, Report 147. Norsk vann og avløp BA (NORVAR BA).

545 Ødegaard, H. & Østerhus, S., 2014 Microbial barrier analysis (MBA) – a guideline. (202).  
546 Norsk Vann.