

Common themes contributing to recent drinking water disease outbreaks in affluent nations

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ABSTRACT

New Zealand experienced its largest waterborne disease outbreak in modern history in August 2016 with 5,500 cases and four fatalities. This recent outbreak is one of 24 drinking-waterborne disease outbreaks in affluent nations that have been reported in the scientific literature since the infamous Walkerton, Ontario, Canada fatal outbreak (2,300 cases, seven fatalities) in May 2000. These disasters were all eminently preventable given the economic and intellectual resources existing in the countries where they occurred. These outbreaks are analysed according to major recurring themes, including: complacency, naiveté and ignorance, failure to learn from experience and *chemophobia*. Lessons that can be learned to improve preventive approaches for ensuring safe drinking water are based on an extensive and authentic body of evidence in support of meaningful improvements. Philosopher George Santayana captured this need with his famous quote: *'Those who cannot remember the past are condemned to repeat it.'*

Key words | causal factors in failure, safe drinking water, waterborne disease

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INTRODUCTION

Surprisingly, despite having the economic and knowledge resources to eliminate them, drinking-waterborne disease outbreaks in developed countries keep occurring (Hrudehy & Hrudehy 2004, 2014). Public health risk can never be managed to zero, particularly when there is a substantial human element involved in causation. However, a review and analysis of the occurrence and causes of drinking-waterborne disease outbreaks in developed countries reveals a depressing contribution and role for ignorance and complacency, even among supposedly trained and knowledgeable practitioners. The observed ignorance and complacency is difficult to reconcile with the readily available evidence that should enable the concerned practitioners to avoid

such disasters. This review summarizes common causal themes from 24 drinking-waterborne disease outbreaks in affluent nations since the infamous fatal outbreak in Walkerton, Canada, in May 2000.

MATERIALS AND METHODS

In this paper, the discussion has been developed from an analysis of the circumstances and factors contributing to drinking-waterborne disease outbreaks in jurisdictions 2004, 2014 which had the resources, both economic and technical, to avoid such public health disasters. A comprehensive data base of published reports of drinking-waterborne disease outbreaks in developed countries was created and maintained. The data base was initiated by collecting English language publications in the peer-reviewed

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scientific literature from fields including epidemiology, public health, water quality and environmental engineering. The collected publications were supplemented by official investigation reports and documented public inquiries produced in whatever local language they were accessible (Hrudehy & Hrudehy 2014).

RESULTS AND DISCUSSION

The 24 outbreaks occurring since 2000 and their salient features are summarized in Table 1. Only salient details of each outbreak are provided. However, details in support of the themes that are discussed below are evident in the references cited for each outbreak in Table 1.

Major recurring themes contributing to failure

The scope of commentary on the highlighted outbreaks is intentionally concise, but a more expansive explanation and documentation of the themes summarized below can be accessed online at Hrudehy (2017). The publication (Hrudehy 2017) was evidence prepared for and used by the New Zealand Government Inquiry into Havelock North Drinking Water (Government of New Zealand 2017). The facts reported in the peer-reviewed literature for each outbreak are inherently limited unless they have also been subjected to an independent inquiry or an investigation, either of which has published an accessible report in any language. For the outbreaks listed in Table 1, only Havelock North in 2016 and North Battleford in 2001 had full independent inquiries while Alamosa in 2008, Nokia in 2007 (in Finnish), Östersund in 2010 (in Swedish), Saratoga Springs in 2010 and Skellefteå in 2011 (in Swedish) had published investigation reports. For cases without accessible resources, it was necessary to triangulate findings from multiple available sources to the greatest degree possible to determine what causal factors contributed to the outbreak. Each outbreak listed in Table 1 includes one or more literature citations that provide additional details about the circumstances associated with each outbreak.

Complacency, naiveté and ignorance

The overwhelming message that arises when reviewing the details of drinking-waterborne disease outbreaks in affluent countries is how eminently preventable they all were. With few exceptions, e.g., Northampton in 2008 (Hrudehy & Hrudehy 2014), those who were in the most direct position to know and understand what happened to allow an outbreak to occur generally have not openly elaborated the contributing causes of the failure. The contamination agents responsible for causing disease and death in drinking-waterborne disease outbreaks are as well documented as any public health threats could possibly be. The circumstances and causes of such outbreaks were identified beginning in the 1850s (Hrudehy & Hrudehy 2004) by pioneers Dr John Snow (cholera) and Dr William Budd (typhoid). Yet, almost 170 years later, we allow such conditions to occur throughout the developing world mainly because of pervasive poverty. More difficult to understand is how drinking-water disease outbreaks caused by microbial pathogens of faecal origin are allowed to keep happening in countries that have the economic and technical resources to prevent them. In many of the outbreak cases, those responsible for delivering safe drinking-water seem to have overlooked or misunderstood how prevalent faecal contamination of water sources is and in a few remarkable cases where sewage contamination has been confirmed, personnel reasonably expected to be knowledgeable have failed to recognize the public health risk, e.g., North Battleford in 2001 (Stirling *et al.* 2001; Hrudehy & Hrudehy 2004, 2014), Transtrand in 2002 (Carrique-Mas *et al.* 2003), Nokia in 2007 (Hrudehy & Hrudehy 2014), Adliswil in 2008 (Breitenmoser *et al.* 2011; Hrudehy & Hrudehy 2014), Lilla Edet in 2008 (Larsson *et al.* 2013), Östersund in 2010 (Hrudehy & Hrudehy 2014), and Skellefteå in 2011 (Bjelkmar *et al.* 2017). There is also a failure in some cases to recognize that livestock and wildlife can and do host human infective pathogens and discharge them in their faeces: Te Aute in 2001 (McElnay & Inkson 2001), Alamosa in 2008 (Hrudehy & Hrudehy 2014), Darfield in 2012 (Bartholomew *et al.* 2014), Baker City in 2013 (DeSilva *et al.* 2015) and North Havelock in 2016 (Government of New Zealand 2017). All faecal matter may contain human infectious pathogens

Table 1 | Published drinking-waterborne disease outbreaks since the fatal outbreak in Walkerton, Ontario, Canada in May 2000

Year	Location	Source water	Treatment	Major failures	Pathogens	Cases confirmed	Total cases estimated	Hospital admissions	Deaths	Comments and reference citations
2001	North Battleford, SK, Canada	surface, river	coagulation, filtration, chlorination	poor fine-particle removal performance; intake located 3.5 km downstream of sewage effluent discharge	<i>Cryptosporidium parvum</i> type 1 (human)	375	5,800–7,100	50	–	Raw water quality problems caused by the sewage discharge were overlooked for years. In March 2001, maintenance to an up-flow clarifier was followed by poor turbidity removal. Stirling et al. (2001) .
2001	Te Aute, College, Hawkes Bay, New Zealand	surface, mountain spring	pressure sand filter, cartridge filter, UV	cattle grazing in a swampy area where springs arose – caused manure to contaminate raw water, raw water 460–980 <i>E. coli</i> /100 mL; treated water 22–59 <i>E. coli</i> /100 mL	<i>Campylobacter jejuni</i>	only a few stool samples taken	95–185	not reported	–	Although UV treatment was provided, the source water was allowed to become seriously contaminated and the treatment process was not operated effectively, UV lamp burned out. McElnay & Inkson (2001) .
2002	Transtrand, Sweden	ground	no treatment	cracked sewer located ~10 m from one well supplying the responsible system	norovirus	4	~500	not reported	–	~1/3 of cases could have been avoided by effective implementation of a ‘boil water’ advisory. Community opposed chemical disinfection. Carrique-Mas et al. (2003) .
2002	Santa Maria de Palautordera, Spain	surface, river from a mountain region	not described other than chlorination	served by 3 water companies with 2 drawing from river source, one kept running with inadequate chlorination during high turbidity	<i>Shigella sonnei</i>	181	756	not reported	–	Rural community of about 6,300, heavy rainfall caused a high turbidity episode during which one river plant shut down while the other remained operating with inadequate treatment and inadequate chlorination resulting in 37 times higher illness attack rate vs plant that shut down. Arias et al. (2006) .
2004	Bergen, Norway	surface, lake		inadequate source protection, inadequate treatment	<i>Giardia</i>	1,300	4,000–6,000	not reported	–	Misjudged source contamination risk from <i>Giardia</i> because the pathogen (<i>Giardia</i>) was not endemic in this region. Nygård et al. (2006) .

(continued)

Table 1 | continued

Year	Location	Source water	Treatment	Major failures	Pathogens	Cases confirmed	Total cases estimated	Hospital admissions	Deaths	Comments and reference citations
2004	Lake Mývatn, Iceland	Ground, feeding lake	well is 1.2 m deep, 3–4 m from lake shore	septic tank installed 80 m upstream of a shallow well, sewage contamination of groundwater	norovirus	4 laboratory confirmed	>100	not reported	–	Reported outbreak in 2004 followed a previous outbreak in 2001 with 117 cases, misdiagnosed as food poisoning. Gunnarsdottir <i>et al.</i> (2013).
2004	South Bass Island, OH, USA	ground, private wells, surface, Lake Erie	wells, untreated, surface not reported	island served by hundreds of private wells in karst geology subject to sewage contamination; many cross-connections	<i>Campylobacter jejuni</i> , norovirus, <i>Giardia</i>	29 laboratory confirmed	1,450	not reported	–	Cases not clearly documented for private wells v. treated system, but numerous cross-connections to private wells were found that made treated system vulnerable. O'Reilly <i>et al.</i> (2007), Fong <i>et al.</i> (2007).
2007	Nokia, Finland	ground & lake bank infiltration	pH adjust, aeration, chlorination, sand filtration	cross-connection at sewage treatment plant without proper backflow prevention, slow response	<i>Campylobacter</i> spp., norovirus, <i>Giardia</i> , <i>Salmonella</i> spp., <i>Clostridium difficile</i> , rotavirus	not reported, but multiple pathogens confirmed	6,500	not reported	2	Nokia had a water safety plan but it failed to identify the cross-connection vulnerability. Water treatment staff thought consumer complaints were caused by change in water source, allowed consumers to receive drinking water contaminated with 400 m ³ of sewage effluent for 2 days. Hrudely & Hrudely (2014).
2007	Galway, Ireland	not described	1 plant coagulation, filtration, 1 w/o filtration	not described	<i>Cryptosporidium hominis</i> & <i>parvum</i>	242	unknown	not reported	–	'Boil water' notice in place for 158 days affecting 120,000 consumers. Estimated economic cost was >19,000,000€. Pelly <i>et al.</i> (2007), Chyzheuskaya <i>et al.</i> (2017).
2008	Adliswil, Switzerland	ground	no treatment	cross-connection at a sewage treatment plant without proper backflow prevention, rapid response	pathogens not identified	not reported	180	not reported	–	This failure was very similar to Nokia and it happened only a few months after Nokia. Wastewater officials did not expect serious consequences because the wastewater was 'treated'. Hrudely & Hrudely (2014).

2008	Lilla Edet, Sweden	river	chlorination coagulation direct filtration	chronically sewage-polluted river source did not have continuous effective treatment	norovirus	33 laboratory confirmed	2,400	not reported	–	Rural community of 4,900 with limited treatment capability, combined sewage contamination of source water following heavy rain. Larsson <i>et al.</i> (2013).
2008	Podgorica, Montenegro	ground, largest source from karst spring	chlorination	no contact time provided, no chlorine residual monitoring, leaky distribution system (~40% water loss) and distribution system pressure losses	viral gastroenteritis	1,699	10,000–15,000	not reported	–	Main water source is down-gradient from a small village relying on septic tank-drainage fields. No coliform detections before outbreak, but 3/8 positive after with no chlorine residual detected. Electrical failures at 2 pump stations created low pressure events in distribution system. Werber <i>et al.</i> (2009).
2008	Alamosa, CO, USA	'secure' ground water	no treatment	vermin contamination of poorly maintained above-ground water storage led to high quality supply being contaminated in distribution/storage	<i>Salmonella</i>	124 laboratory confirmed	1,300	20	1	Alamosa was operating under a State agency approved waiver to provide drinking water that was not chlorinated or disinfected in any way because the 'secure' groundwater supply from artesian bores showed no signals of coliform contamination. Hruday & Hruday (2014).
2008	Northampton England	surface reservoir	ozone pre-oxidation, coagulation, clarification, granular filtration, ozonation, GAC	a rabbit gained access to a GAC backwash tank: it drowned and was found in the chlorine contact chamber, contaminating the entire distribution system with oocysts affecting 258,000 consumers	<i>Cryptosporidium cuniculus</i>	22	422	not reported	–	This outbreak was detected because of extraordinary continuous monitoring of treated water for <i>Cryptosporidium</i> oocysts and the rapid precautionary measures taken by the water utility in calling an immediate 'boil water' advisory without waiting for confirmation of the cause of the problem. The total cost was estimated at £4.9 million. Hruday & Hruday (2014).
2009	Tune, Denmark	ground	no chlorination	undisinfected groundwater was contaminated by combined sewer overflow	<i>Campylobacter jejuni</i>	not reported	~770	not reported	–	Heavy rainfall led to surface flooding that was believed to have contaminated wells Gaardbo Kuhn <i>et al.</i> (2017).

(continued)

Table 1 | continued

Year	Location	Source water	Treatment	Major failures	Pathogens	Cases confirmed	Total cases estimated	Hospital admissions	Deaths	Comments and reference citations
2010	Køge, Denmark	ground	no chlorination	no cause was identified although the outbreak occurred after heavy rainfall; this cause was discounted by engineering investigation	<i>Campylobacter jejuni</i>	61	>400	not reported	–	Town of 20,000 residents. 'It was decided not to treat the water supply system with chloride [sic], considering the health risks of rinsing with chloride [sic] for the population, the environmental impact, and the costs.' Gubbels <i>et al.</i> (2012).
2010	Östersund, Sweden	surface, lake	ozone pre-oxidation, sand filtration, chlorination	an apartment building sewer was cross-connected to a storm drain that discharged to a small creek <500 m up-current from the drinking water treatment plant intake; an infected family resided in the apartment building; the water treatment processes were not operated at an efficiency level capable of removing <i>Cryptosporidium</i> oocysts	<i>Cryptosporidium</i>	>29, final number not reported	27,000	57 reported, 270 est.	–	The largest reported outbreak of cryptosporidiosis in European history. The underlying cause was evident naiveté by water authorities with their belief in the pristine status of the raw water source. The lake source was subject to many inputs of human sewage and the water treatment plant and its operating processes were not adequate to deal with a serious challenge of <i>Cryptosporidium</i> oocysts such as occurred. A UV-disinfection system was installed as a result of this outbreak. Direct costs to the community were estimated at 6.2 million kroner and indirect costs at 220 million kroner. Hrudey & Hrudey (2014).
2010	Saratoga Springs, UT, USA	ground	not clear but likely no chlorination	cross-connection likely caused by plumbing connections in individual dwellings with irrigation	<i>Campylobacter</i>	17	>333	not reported	–	The source of the contamination was assumed to be faecal, but a definitive source was not identified. Utah County Health Department (2010).
2011	Skellefteå Sweden	river	sand filtration chlorination	source water contamination, inadequate treatment	<i>Cryptosporidium hominis</i>	not reported	18,500	not reported	–	<i>Cryptosporidium</i> -infected sewage contamination of river source water with inadequate treatment for that pathogen Bjelkmar <i>et al.</i> (2017).

2012	Kalundborg Denmark	not identified	not identified	a water line break causing reduced pressure was located below a leaking sewer line	norovirus	not reported	>150	not reported	–	Outbreaks regarded as rare in Denmark (despite published reports of 3 outbreaks between 2009 and 2012) with ‘low’ rates attributed to common use of groundwater; van Alphen <i>et al.</i> (2014).
2012	Ellasona, Greece	spring source	chlorination only	level of chlorination and monitoring of chlorine residual were not adequate	not identified, rotavirus implicated	394	3,600	not reported	–	Community of 7,233, with rural population of 1,337, livestock or human fecal contamination suspected but not confirmed. Mellou <i>et al.</i> (2014).
2012	Darfield, New Zealand	‘deep’ well & river via bank infiltration	chlorination was required for river supply	pump failure led to total supply from river bank infiltration, but chlorine tank was empty, alarm disabled & monitors not calibrated	<i>Campylobacter</i>	29 laboratory confirmed 138 probable	828–1,987	not reported	46 – sought medical attention	Rural town of 3,280, outbreak followed heavy rain while chlorination was not operative, as required, and source was vulnerable to livestock grazing up-gradient from the infiltration gallery. Bartholomew <i>et al.</i> (2014).
2013	Baker City, OR, USA	surface	chlorination only	system had no barrier for this pathogen and inspection of watershed revealed cattle near water intake	<i>Cryptosporidium</i>	23 laboratory confirmed	2,780	not reported	–	Community of 9,828 with a partially fenced surface watershed in livestock country, yet it had a filtration exemption. Heavy rain in June likely contributed to washing livestock manure into the water supply. DeSilva <i>et al.</i> (2015).
2016	Havelock North, New Zealand	ground	none, but short-term chlorination	after recurring <i>E. coli</i> detections, chlorination required for at least 72 hours, but was stopped as soon as possible; the shallow wells were subject to flooding and aquifer was contaminated by sheep grazing nearby	<i>Campylobacter</i>	252	5,500	45	4	Community of 14,000. An outbreak of campylobacteriosis in 1998 that was attributed to possible contamination of the same supply aquifer was not known by current operators of the system. The regulator and operators treated the supply as ‘secure’ under the national drinking-water standards, thereby allowing water supply without disinfection. Chlorination remains controversial in New Zealand. Government of New Zealand (2017).

and must be regarded as a public-health threat to any drinking-water supply.

Today, we have progressed well past our knowledge of a few decades ago when science had not yet characterized previously unrecognized threats to safe drinking water, like *Cryptosporidium* oocysts. New pathogens will inevitably be discovered in the future, but the reality is that all microbial pathogens are microscopic particles that must pass through drinking-water systems in a viable state such that they can reproduce in a susceptible host and cause illness. These realities mean that water treatment that achieves effective fine-particle removal and disinfection that inactivates any pathogens not removed will prevent drinking-water disease outbreaks regardless of the genetic make-up of the pathogen.

The cases reviewed involve disturbingly simple failures such as not preventing livestock access or human sewage discharges from contaminating source waters. These are threats to drinking-water safety that are entirely well known and thoroughly characterized. Complacency, naiveté and ignorance seem to offer the only rational explanation as to why such events keep happening throughout the developed world.

Perhaps most frustrating is the myth that raw water supplies can be 'pristine' when it is clear that contamination by faecal material from humans, pets, livestock or wildlife can pose a public-health threat. In some cases of drinking-water disease outbreaks, e.g., Bergen in 2004 (Nygård *et al.* 2006), Östersund in 2010 (Hrudéy & Hrudéy 2014), and Havelock North in 2016 (Government of New Zealand 2017), officials apparently believed that their raw water source was pristine even though the source was obviously subject to human sewage discharge, livestock or wildlife faecal material (Hrudéy & Hrudéy 2014). The myth that a raw water source is pristine is particularly dangerous when it is used to justify avoiding adoption of any treatment technology that can be reliably applied to ensure safe drinking water. Of course, protecting source water from contamination is valuable in its own right, but the practical limitations must be recognized for source-water protection measures (such as fences and signs, among others) to achieve total prevention of any faecal contamination (human or animal) of a drinking-water source, e.g., Te Aute in 2001 (McElnay & Inkson 2001), Darfield in 2012

(Bartholomew *et al.* 2014), Baker City in 2013 (DeSilva *et al.* 2015), and Havelock North in 2016 (Government of New Zealand 2017).

Failure to learn from experience

Considering the recurring failures that are evident in the 24 outbreaks cited in this paper and summarized in Table 1, water purveyors are not universally learning from experience with failure. The lessons that need to be learned are not that complex, so we can only conclude there is a systematic failure to communicate these rather basic lessons to all those individuals who are responsible for providing safe drinking water for the public. We cannot imagine that such individuals would knowingly wish to make their consuming public ill. A more likely explanation is that such individuals have not been adequately trained to recognize and to avoid conditions that will allow such eminently preventable drinking-waterborne outbreaks from happening. To that end, we all have a responsibility to communicate public-health threats widely to all those who are engaged in the provision of drinking water. Philosopher George Santayana captured the need to learn from experience with his famous quote: 'Those who cannot remember the past are condemned to repeat it.'

Many of the cases reviewed included a mention of an outbreak occurring after a heavy rain event, e.g., Santa Maria in 2002 (Arias *et al.* 2006), Lilla Edet in 2008 (Larsson *et al.* 2013), Tune in 2009 (Gaardbo Kuhn *et al.* 2017), and Køge in 2010 (Gubbels *et al.* 2012). Occurrence of disease outbreaks after heavy rainfall is certainly common enough that extreme weather demands attention and such events should always warrant increased vigilance among those who are responsible for delivering safe drinking water, to the same extent that resulting floods are recognized as posing threats of direct physical harm.

Chemophobia

Any time dedicated to reviewing research on drinking-water quality and resulting standards for drinking water will reveal a preponderance of text discussing chemical contaminants versus microbial pathogens. A novice to the field could be forgiven for concluding that chemical contaminants pose a

greater threat to human health than microbial pathogens. That conclusion simply cannot be sustained by decades of public-health experience. The toll of death and disease caused by drinking-water-transmitted microbial pathogens remains huge across the developing world. Contaminated drinking water is estimated to cause more than 500,000 diarrheal deaths each year (WHO 2018). The pathogen-caused drinking-water outbreaks summarized in Table 1 represent only a limited sample of outbreaks. A similar search will reveal a very short list of chemical contaminants with reasonably certain evidence that they caused human disease or adverse health effects via drinking-water exposure. Arsenic, natural fluoride and lead are at the top of a very short list of chemicals that credibly qualify as showing reasonable certainty of causing human illness via drinking-water exposure. The identified chemicals cause only site-specific, localized problems. Microbial pathogens are pervasive; they are found wherever you find humans, live-stock, pets or wildlife, i.e., everywhere you find humans.

An enormous amount of attention has been directed to disinfection by-products (Hrudey & Fawell 2015). Because microbial pathogens pose such well-documented, certain public-health risks to drinking water, disinfection has long been recognized as essential for ensuring safe drinking water. All disinfectants produce disinfection by-products to some degree, but chlorination, as the most common and cost-effective means of drinking-water disinfection, has received the most research attention. Despite an enormous number of research investigations, only a possible causal link with urinary bladder cancer has retained some credibility, but definitely far from certainty in epidemiologic evidence (Hrudey *et al.* 2015). The public-health risk from disinfection by-products is negligible where chlorination is regulated, yet a fear of chlorination over its possible health effects has allowed inadequate disinfection that has unfortunately been a contributing factor in many drinking-waterborne disease outbreaks. Opposition to chlorine disinfection was clearly a major factor in many of the listed outbreaks in Table 1 including: Walkerton in 2000 (Hrudey & Hrudey 2014), Transtrand in 2002 (Carrique-Mas *et al.* 2003), Alamosa in 2008 (Hrudey & Hrudey 2014), Tune in 2009 (Gaardbo Kuhn 2017), Køge in 2010 (Gubbels *et al.* 2012), Kalunderborg in 2012 (van Alphen *et al.* 2014), Darfield in 2012 (Bartholomew *et al.* 2014),

and Havelock North in 2016 (Government of New Zealand 2017).

Prevention of drinking-water outbreaks

Despite the discouraging evidence of the 24 outbreaks reported between 2001 and 2016 (three outbreaks causing fatalities), this period has also seen important advances in approaches to preventing outbreaks and other contamination failures. The World Health Organization (WHO) and the Australian National Health and Medical Research Council (NHMRC) worked in parallel from 2000 to 2004 to develop the water-safety plan approach for drinking-water quality management. This risk management approach, which identifies threats to drinking-water safety and focuses on effective operations, has been enshrined in their respective drinking-water guidelines (WHO 2017; NHMRC 2018). Conceptually, the water safety plan approach is much superior to a narrow focus strictly on numerical water-quality criteria for preventing the factors contributing to the outbreak failures documented in Table 1. However, it is noteworthy that two of the utilities experiencing outbreaks, Nokia in 2007 (Hrudey & Hrudey 2014) and Havelock North in 2016 (Government of New Zealand 2017), had water-safety plans. Evidently, having a water-safety plan that is not carefully prepared and scrupulously followed will not prevent an outbreak.

CONCLUSIONS

Despite unprecedented knowledge about public health, drinking-water quality and safety, at least 24 outbreaks of waterborne disease in affluent nations have occurred in the period from 2001 to 2016. The contributing causes are not obscure and the outbreaks are inherently preventable. The identified causes suggest a need for an expanded commitment to informing operational personnel, managers and regulators about the authentic negative experience in such outbreaks.

Adoption of a water-safety plan approach offers an opportunity to prevent waterborne disease outbreaks. However, the fact that two of the water utilities that experienced outbreaks had water-safety plans indicates that the quality of

and commitment to implementing a water-safety plan are essential to achieving any preventive benefit.

The ongoing occurrence of such observed, preventable waterborne disease outbreaks should lead water managers to take all reasonable steps under their influence to ensure that such failures are not allowed to occur within the systems for which they are responsible. Philosopher George Santayana captured this need to learn from experience with his famous quote: *‘Those who cannot remember the past are condemned to repeat it.’*

REFERENCES

- Arias, C., Sala, M. R., Domínguez, A., Bartolomé, R., Benavente, A., Veciana, P., Pedrol, A. & Hoyo, G. 2006 Waterborne epidemic outbreak of *Shigella sonnei* gastroenteritis in Santa Maria de Palautordera, Catalonia, Spain. *Epidemiol. Infect.* **134** (3), 598–604.
- Bartholomew, N., Brunton, C., Mitchell, P., Williamson, J. & Gilpin, B. 2014 A waterborne outbreak of campylobacteriosis in the South Island of New Zealand due to a failure to implement a multi-barrier approach. *J. Water Health* **12** (3), 555–563.
- Bjelkmar, P., Hansen, A., Schönning, C., Bergström, J., Löfdahl, M., Lebbad, M., Wallensten, A., Allestam, G., Stenmark, S. & Lindh, J. 2017 Early outbreak detection by linking health advice line calls to water distribution areas retrospectively demonstrated in a large waterborne outbreak of cryptosporidiosis in Sweden. *BMC Public Health* **17**, 328.
- Breitenmoser, A., Fretz, R., Schmid, J., Besl, A. & Etter, R. 2011 Outbreak of acute gastroenteritis due to a washwater-contaminated water supply, Switzerland, 2008. *J. Water & Health* **9** (3), 569–576.
- Carrique-Mas, J., Andersson, Y., Petersén, B., Hedlund, K.-O., Sjögren, N. & Giesecke, J. 2003 A Norwalk-like virus waterborne community outbreak in a Swedish village during peak holiday season. *Epidemiol. Infect.* **131**, 737–744.
- Chyzheuskaya, A., Cormican, M., Srivinas, R., O'Donovan, D., Prendergast, M., O'Donoghue, C. & Morris, D. 2017 Economic assessment of waterborne outbreak of cryptosporidiosis. *Emerg. Infect. Dis.* **23** (10), 1650–1656.
- DeSilva, M. B., Schafer, S., Kendall Scott, M., Robinson, B., Hills, A., Buser, G. L., Salis, K., Gargano, J., Yoder, J., Hill, V., Xiao, L., Roellig, D. & Hedberg, K. 2015 Communitywide cryptosporidiosis outbreak associated with a surface water-supplied municipal water system – Baker City, Oregon, 2013. *Epidemiol. Infect.* **144**, 274–284.
- Fong, T. T., Mansfield, L. S., Wilson, D. L., Schwab, D. J., Molloy, S. L. & Rose, J. B. 2007 Massive microbiological groundwater contamination associated with a waterborne outbreak in Lake Erie, South Bass Island, Ohio. *Environ. Health Persp.* **115** (6), 856–864.
- Gaardbo Kuhn, K., Falkenhorst, G., Emborg, H.-D., Ceper, T., Torpdahl, M., Krogfelt, K. A., Ethelberg, S. & Mølbak, K. 2017 Epidemiological and serological investigation of a waterborne *Campylobacter jejuni* outbreak in a Danish town. *Epidemiol. Infect.* **145**, 701–709.
- Government of New Zealand 2017 *Government Inquiry into Havelock North Drinking Water*. May 2017. Auckland, New Zealand. www.dia.govt.nz/Government-Inquiry-into-Havelock-North-Drinking-Water (accessed December 6, 2018).
- Gubbels, S. M., Kuhn, K. G., Larsson, J. T., Adelhardt, M., Engberg, J., Ingildsen, P., Wilchen Hollesen, L., Muchitsch, S., Mølbak, K. & Ethelberg, S. 2012 A waterborne outbreak with a single clone of *Campylobacter jejuni* in the Danish town of Køge in May 2010. *Scand. J. Infect. Dis.* **44**, 586–594.
- Gunnarsdottir, M. J., Gardarsson, S. M. & Andradottir, H. O. 2013 Microbial contamination in groundwater supply in a cold climate and coarse soil: case study of norovirus outbreak at Lake Mývatn, Iceland. *Hydrol. Res.* **44** (6), 1114–1128.
- Hrudey, S. E. 2017 *Converting Hindsight into Foresight*. Evidence Prepared for Water New Zealand for submission to the Government Inquiry into Havelock North Drinking-Water. In Stage 2 submissions. <https://www.dia.govt.nz/Government-Inquiry-into-Havelock-North-Drinking-Water> (accessed December 6, 2018).
- Hrudey, S. E. & Fawell, J. 2015 40 years on – what do we know about drinking water disinfection by-products (DBPs) and human health? *Water Sci. Technol. – Water Supply* **15** (4), 667–674.
- Hrudey, S. E. & Hrudey, E. J. 2004 *Safe Drinking Water – Lessons from Recent Outbreaks in Affluent Nations*. IWA Publishing, London, UK.
- Hrudey, S. E. & Hrudey, E. J. 2014 *Ensuring Safe Drinking Water – Learning from Frontline Experience with Contamination*. American Water Works Association, Denver, CO, USA.
- Hrudey, S. E., Backer, L. C., Humpage, A. R., Krasner, S. W., Singer, P. C., Stanford, B. D., Michaud, D. S. & Moore, L. E. 2015 Evaluating evidence for association of human bladder cancer with drinking water chlorination disinfection by-products. *J. Toxicol. Environ. Health – Part B* **18** (5), 213–241.
- Larsson, C., Andersson, Y., Allestam, G., Lindqvist, A., Nenonen, N. & Bergstedt, O. 2013 Epidemiology and estimated costs of a large waterborne outbreak of norovirus infection in Sweden. *Epidemiol. Infect.* **142**, 592–600.
- McElroy, C. & Inkson, I. 2001 *Outbreak of Campylobacteriosis Traced to a School Water Supply*. Hawke's Bay District Health Board, Hawke's Bay, New Zealand.
- Mellou, K., Katsioulis, A., Potamiti-Komi, M., Pournaras, S., Kyritsi, M., Katsiaflaka, A., Kallimani, A., Kokkinos, P., Petinaki, E., Sideroglou, T., Georgakopoulou, T., Vantarakis, A. & Hadjichristodoulou, C. 2014 A large waterborne gastroenteritis outbreak in central Greece, March 2012: challenges for the investigation and management. *Epidemiol. Infect.* **142**, 40–50.

- NHMRC 2018 *Australian Drinking Water Guidelines 6: 2011. Version 3.5 Updated August 2018*. <https://nhmrc.gov.au/about-us/publications/australian-drinking-water-guidelines#block-views-block-file-attachments-content-block-1> (accessed December 6, 2018).
- Nygård, K., Schimmer, B., Søbstad, Ø., Walde, A., Tveit, I., Langeland, N., Hausken, T. & Aavitsland, P. 2006 **A large community outbreak of waterborne giardiasis-delayed detection in a non-endemic urban area**. *BMC Public Health* **6**, 141.
- O'Reilly, C. E., Bowen, A. B., Perez, N. E., Sarisky, J. P., Shepherd, C. A., Miller, M. D., Hubbard, B. C., Herring, M., Buchanan, S. D., Fitzgerald, C. C., Hill, V., Arrowood, M. J., Xiao, L. X., Hoekstra, R. M., Mintz, E. D., Lynch, M. F. & Outbreak Working Group 2007 **A waterborne outbreak of gastroenteritis with multiple etiologies among resort island visitors and residents: Ohio, 2004**. *Clin. Infect. Dis.* **44**, 506–512.
- Pelly, H., Cormican, M., O'Donovan, D., Chalmers, R., Hanahoe, B., Cloughley, R., McKeown, P. & Corbett-Feeney, G. 2007 **A large outbreak of cryptosporidiosis in western Ireland linked to public water supply: a preliminary report**. *Euro Surveill.* **12** (18), 3187.
- Stirling, R., Aramini, J., Ellis, A., Lim, G., Meyers, R., Fleury, M. & Werker, D. 2001 **Waterborne cryptosporidiosis outbreak, North Battleford, Saskatchewan, Spring 2001**. *Can. Commun. Dis. Rep.* **27** (22), 185–192.
- Utah County Health Department 2010 **Campylobacter Investigation**. www.utahcountyonline.org/dept/Health/campylobacter/ (accessed December 6, 2018).
- van Alphen, L. B., Dorléans, F., Schultz, A. C., Fonager, J., Ethelberg, S., Dalgaard, C., Adelhardt, M., Engberg, J. H., Fischer, T. K. & Lassen, S. G. 2014 **The application of new molecular methods in the investigation of a waterborne outbreak of norovirus in Denmark, 2012**. *PLOS One* **9** (9), e105053.
- Werber, D., Laušević, D., Mugoša, B., Vratnica, Z., Ivanović-Nikolić, L., Žižić, L., Alexandre-Bird, A., Fiore, L., Ruggeri, F. M., di Bartolo, I., Battistone, A., Gassilloud, B., Perelle, S., Nitzan Kaluski, D., Kivi, M., Andraghetti, R. & Pollock, K. G. J. 2009 **Massive outbreak of viral gastroenteritis associated with consumption of municipal drinking water in a European capital city**. *Epidemiol. Infect.* **137**, 1713–1720.
- WHO 2017 *Guidelines for Drinking-Water Quality*, 4th edn. incorporating the 1st addendum. WHO, Geneva, Switzerland. https://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en/ (accessed December 6, 2018).
- WHO 2018 **Drinking Water. Key Facts**. 7 February 2018. <https://www.who.int/news-room/fact-sheets/detail/drinking-water>.

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