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Communitywide cryptosporidiosis outbreak associated with a surface water-supplied municipal water system – Baker City, Oregon, 2013

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SUMMARY

Cryptosporidium, a parasite known to cause large drinking and recreational water outbreaks, is tolerant of chlorine concentrations used for drinking water treatment. Human laboratory-based surveillance for enteric pathogens detected a cryptosporidiosis outbreak in Baker City, Oregon during July 2013 associated with municipal drinking water. Objectives of the investigation were to confirm the outbreak source and assess outbreak extent. The watershed was inspected and city water was tested for contamination. To determine the community attack rate, a standardized questionnaire was administered to randomly sampled households. Weighted attack rates and confidence intervals (CIs) were calculated. Water samples tested positive for *Cryptosporidium* species; a *Cryptosporidium parvum* subtype common in cattle was detected in human stool specimens. Cattle were observed grazing along watershed borders; cattle faeces were observed within watershed barriers. The city water treatment facility chlorinated, but did not filter, water. The community attack rate was 28·3% (95% CI 22·1–33·6), sickening an estimated 2780 persons. Watershed contamination by cattle probably caused this outbreak; water treatments effective against *Cryptosporidium* were not in place. This outbreak highlights vulnerability of drinking water systems to pathogen contamination and underscores the need for communities to invest in system improvements to maintain multiple barriers to drinking water contamination.

Key words: Community outbreaks, *Cryptosporidium*, water (safe).

INTRODUCTION

Cryptosporidiosis is a gastrointestinal illness caused by the parasite *Cryptosporidium* [1]. Outbreaks of human cryptosporidiosis have been associated with exposure to both recreational water and drinking water systems [2–5]. The first reported

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cryptosporidiosis outbreak related to a public water system occurred during 1987 [6]. During 1993, the largest known *Cryptosporidium* community drinking water outbreak occurred in Milwaukee, Wisconsin, sickening an estimated 403 000 persons with 58 confirmed cryptosporidiosis-associated deaths [7, 8].

In the general population, typical symptoms of cryptosporidiosis include diarrhoea (which can last 1–2 weeks) and abdominal cramps, although one study reported 39% of infections were asymptomatic [9]. *Cryptosporidium* infections are more common and more severe in immunocompromised persons [1, 10]. Two species, *Cryptosporidium hominis*, for which humans serve as predominant host, and *Cryptosporidium parvum*, which is commonly associated with cattle, cause the majority of human cryptosporidiosis [11]. Ingestion of oocysts expelled in faeces cause human infection [12–15].

Because *Cryptosporidium* tolerates the levels of chlorine typically used in water treatment, *Cryptosporidium*-specific treatment is typically accomplished through removal by filtration or inactivation by ultraviolet (UV) disinfection. After Milwaukee's outbreak, in 1993, the U.S. Environmental Protection Agency (EPA) issued enhanced regulations to control microbial contamination of surface drinking water sources, concentrating efforts on contamination by *Cryptosporidium* [16]. These regulations require surface water-supplied community drinking water systems that have an exemption to filtration to implement *Cryptosporidium*-specific treatment in addition to chemical disinfection (e.g. chlorination) due to *Cryptosporidium*'s chlorine tolerance. EPA regulations have been implemented in stages on the basis of water system size. Certain water systems (those supplying fewer than 10 000 persons) were not required to implement *Cryptosporidium* treatment until 1 October 2014, with an allowance for an extension when capital improvements were necessary.

Cryptosporidium-specific municipal water testing was performed in Baker City, Oregon during April 2010–March 2011; two water samples were tested monthly for *Cryptosporidium*, and three oocysts were detected in the 24, 10-l samples. On the basis of population, test results, and need for capital improvements, Baker City received an extension for *Cryptosporidium*-specific treatment from Oregon's Drinking Water Services until October 2016 [17, 18].

On 29 July 2013, the Baker County Health Department (BCHD) received notification of a positive *Cryptosporidium* laboratory report from a faecal specimen submitted by an ill patient treated at the local medical centre. Two additional *Cryptosporidium* laboratory reports were received on 30 July, after which BCHD notified Oregon Health Authority (OHA) of a cryptosporidiosis outbreak. Laboratory-confirmed cryptosporidiosis case patients or (if aged <18 years) their family members were interviewed by BCHD about exposures using a general case-investigation form to identify potential sources of infection, vehicles of transmission, and the possibility of ongoing transmission. The case-investigation form asked about exposure to risk factors commonly associated with *Cryptosporidium* infection including travel, recreational water exposure, consumption of unpasteurized milk or juice, contact with daycare attendees, sick people, or sick animals, occupational animal exposure and source of drinking water.

Initial interviews of confirmed case patients identified no common exposures, and no travel outside of the county was reported. BCHD staff also reported hearing many anecdotal reports of cryptosporidiosis-compatible illnesses from Baker City residents distributed throughout the city. The lack of other common exposures suggested drinking water was the likely source. On 31 July, a boil-water advisory was issued, and public health officials initiated an investigation.

During the first week of August, in order to better understand the geography of the outbreak, OHA epidemiologists conducted rapid assessment telephone surveys among residents of both Baker City and a neighboring city, LaGrande, which uses a separate community water supply. Respondents were interviewed using a standardized questionnaire to ask about recent diarrhoeal illness in their households. In Baker City, 36 (20%) of 179 respondents reported $\geqslant 3$ days of diarrhoea during the previous week, compared with two (1%) of 176 respondents in LaGrande, suggesting the outbreak was limited to Baker City. A convenience sample door-to-door survey of Baker City households revealed a 26% crude attack rate. On the basis of these preliminary findings, public health personnel performed additional investigations, the objectives of which were to confirm drinking water as the outbreak source, assess outbreak extent, and evaluate adequacy of control measures.

METHODS

Setting

Baker City, population 9828, located in eastern Oregon, relies on an unfiltered surface water supply.

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The watershed includes ~10 000 acres (40 km^2) of mountainous terrain located northeast of the city. One ridge of the Elk Horn Mountains contains the western watershed boundary. The remaining watershed boundaries are marked by signs and fencing. Cattle grazing allotments border a substantial portion of the watershed. Surface water can enter any of 11 watershed diversions and travels about 10–20 miles (16–32 km) through one of two underground transmission lines to a water treatment plant outside the city where the water is chlorinated before distribution (Fig. 1). A combination of chlorination and disinfectant contact time was provided prior to the first user, achieving a minimum inactivation of 99·9% of *Giardia* cysts, which also inactivates bacteria and viruses but not *Cryptosporidium*. When the outbreak occurred, Baker City did not perform *Cryptosporidium*-specific treatment of the water supply.

Environmental and water system investigations

Epidemiologists, environmental health specialists, and water system operators examined Baker City watershed maps and performed watershed inspections on 31 July, 3 August, and 22 August, seeking evidence of water contamination or prohibited entry of livestock on watershed lands. Investigators took photographs of the watershed; however, no survey equipment was used during watershed inspections. Investigators reviewed rainfall data from the National Center for Environmental Information, recorded in inches per 24 h, during the months before the outbreak because meteorological events can be a contributing factor during disease outbreaks. OHA Drinking Water Services (DWS) reviewed Baker City's water testing policies and procedures, and turbidity and coliform count data regarding water samples collected during July 2013.

Laboratory examination of water sampling

Baker City's water department (BCWD) collected untreated and treated water samples for *Cryptosporidium*-specific testing at a local laboratory using EPA Method 1623 [19], which involves passing water through a filter to concentrate and recover oocysts; eluting filtered materials and separating oocysts from extraneous materials; staining them; and microscopically examining samples. On 31 July, BCWD collected seven, 10-l water samples as follows: one untreated water sample from a suspect surface water diversion point (suspicious because of its close proximity to a herd of goats), one sample from one of two underground transmission lines, and five treated water samples from five distribution sites in Baker City. On 4 August, BCWD collected six untreated water samples from six surface water diversions and four treated samples (one from the city's reservoir and three from Baker City sites). OHA established criteria for lifting the boil-water advisory based on expert recommendation. BCWD continued testing water samples during the outbreak to determine when the advisory could be lifted.

OHA epidemiologists collected two untreated water samples (114 l and 120 l) from the suspect surface water diversion on 3 August, and two treated water samples (71 l and 130 l) on 4 August by dead-end ultrafiltration (DEUF) [20]. DEUF uses dialysis filters with pore sizes ranging from 0·01 to 0·1 μm to rapidly collect high-volume samples and trap submicron particles in addition to larger particles including *Cryptosporidium* oocysts, typically 4–6 μm in diameter. The used filters were shipped to the Centers for Disease Control and Prevention (CDC) for *Cryptosporidium* testing. DEUF samples were filtered, processed, and analysed according to procedures described by Mull and Hill [20, 21].

Laboratory: human and animal samples

During the rapid assessment of the health status of Baker City residents, symptomatic persons were asked to provide a stool specimen for testing at the state laboratory. BCHD also requested stool samples from persons who contacted the health department to report illness. Nine *Cryptosporidium*-positive human stool samples were sent to CDC for genotyping and subtyping.

During watershed inspections, OHA epidemiologists collected 149 ruminant (cattle, goat, elk) faecal samples for microscopic evaluation and polymerase chain reaction (PCR) testing to determine genotype of any recovered pathogens at CDC.

Epidemiological investigation and statistical analysis

We surveyed Baker City residents to assess the community attack rate using a standardized questionnaire. The questionnaires collected data regarding age, sex, symptom profiles, illness onset date and symptom duration, health care-seeking behaviour, self-reported immunodeficiency, and ingestion of Baker City water (measured in glasses of municipal water per

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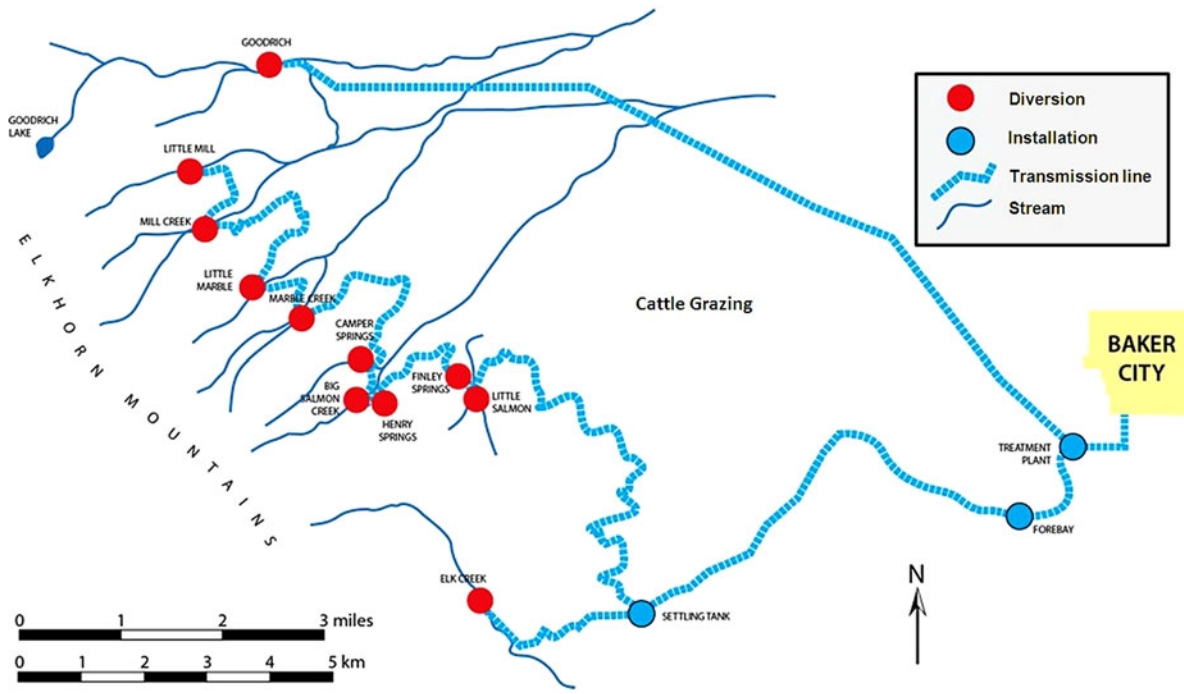

Fig. 1. Schematic diagram of Baker City's watershed. A diversion is any transfer of water across watershed boundaries through a man-made pipeline or canal. Installations are man-made structures connected to the water system, Baker City, Oregon, 2013. (Figure created by Bill Keene.)

day) before and after outbreak identification. Respondents were also asked about awareness of and compliance with the boil-water advisory. We defined presumptive cryptosporidiosis as onset of an acute diarrhoeal illness lasting ⩾3 days after 30 June 2013, in a Baker City resident.

By using Baker City's 2010 census, an estimated 20% incidence of cryptosporidiosis based on the results of the rapid assessment telephone survey and a 0·05 significance level, we determined that a survey sample size of ~240 persons was needed to estimate the attack rate with a 5% margin of error. We used tax-lot data from the Baker County Assessor, to assign a number to each of Baker City's 4222 housing units by using a random number generator and sorted housing units by this random number. Assuming a response rate of ~65%, we attempted to visit the first 380 households randomly assigned. Two-member interview teams administered door-to-door questionnaires in Baker City during August and attempted to contact each selected household two times on separate days and at different times of day. One person from each housing unit visited was selected by using the next birthday method [22]. An adult proxy provided answers if the selected person was aged <12 years. Responses were collected using paper questionnaires and then transferred to a FileMaker Pro electronic database.

The weighted attack rate, weighted percentages, and confidence intervals were calculated, taking into account the two-stage sampling design by using SAS v. 9·3 (SAS Institute Inc., USA). We investigated associations between presumptive cryptosporidiosis and age, sex, and amount of Baker City tap water consumed daily by logistic regression by using survey procedures.

RESULTS

Environmental and water system investigations

During watershed inspections on 31 July, 3 August, and 22 August, OHA epidemiologists observed downed and damaged fencing surrounding the watershed documented through photographs. They reported goat, elk, and cattle faeces within watershed boundaries; cattle were grazing about 150–250 yards (137–229 m) from watershed limits.

Rainfall in Baker City was ~39% below average during January–June 2013 [23, 24]. On 19 June, 1·3 inches of rainfall was recorded, marking the highest single-day rainfall total in Baker City since 1984 [24, 25].

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Oregon DWS reported two inadequacies during review of the city's water sampling techniques. First, rather than testing water combined from both transmission lines, the sample point only captured water from one surface water transmission line. Second, rather than testing for thermotolerant coliform (commonly referred to as faecal coliform in the United States) counts as required by United States federal and Oregon state regulations [maximum contaminant level: 20 colony-forming units (c.f.u.)/100 ml], the city was testing raw water samples for *Escherichia coli* counts before and during the outbreak.

No spikes in turbidity or *E.coli* counts were noted before the outbreak. The highest *E.coli* count during July 2013 was 4 c.f.u./100 ml (no maximum contaminant level has been established for *E. coli*), and the highest turbidity level from continuous readings was 0·236 nephelometric turbidity units (NTU) (maximum contaminant level: 5 NTU).

Laboratory: water sampling

Untreated water samples from 4/7 surface water diversions and 6/9 treated water samples from Baker City distribution locations were positive for *Cryptosporidium*. One of four positive surface water samples was reported to have 913 oocysts/10 l, prompting Baker City to stop using water from this diversion. Of four DEUF samples, one treated water sample was positive for *Cryptosporidium* by fluorescence microscopy (four oocysts observed), but negative by PCR.

Laboratory: human and animal samples

A total of 23 laboratory-confirmed cryptosporidiosis cases were identified during the outbreak. Molecular results indicated *C. parvum* IIaA15G2R1 subtype in all nine human isolates that were sent to CDC.

One of 81 goat faecal samples tested was positive for *Cryptosporidium ubiquitum*. One of 64 elk faecal samples was positive for *Cryptosporidium* with species unknown, but negative for *C. parvum* and *C. hominis* by PCR. Four cattle faecal samples were negative.

Epidemiological investigation and statistical analysis

Of 380 households visited, 206 (54·2%) completed the survey; no one answered at 84 homes visited (22%), 46 residents refused (12%), 27 homes were vacant (7%), and at 17 homes there was no response due to other reasons (4%). Seven surveys were missing as a result of clerical error; 199 were available for analysis. Three surveys were missing illness duration and thus removed from attack rate calculations.

Of 50 presumptively ill persons (25·1% of surveyed population), 27 (54%) were female; median age was 49 (range 2–89) years; and six (12%) had an immunodeficiency. Symptom onset ranged from 1 July (4 weeks before the outbreak was detected) to 10 August (Fig. 2). Median symptom duration was 6 (range 3–50) days. Ten (20%) persons had sought medical care; three (6%) had sought treatment at an emergency department; and three (6%) had been admitted to a hospital. However, none had laboratory-confirmed cryptosporidiosis.

The weighted attack rate was 28·3% [95% confidence interval (CI) 22·1–33·6]. On the basis of Baker City's 2010 census, ~2780 persons became ill during the outbreak. Presumptive cryptosporidiosis was not significantly associated with sex, age, or daily tap water consumption (Table 1).

All household members interviewed reported having heard about the boil-water advisory. The majority (88%) reported hearing about the advisory from an unofficial source (e.g. family, friend, neighbour, or social media), and 67% used bottled water as their primary water source during the advisory (Table 2). Of 77·7% who boiled water ⩾1 time during the advisory, 96% did so for at least the recommended time of 1 min. Certain residents (7·5%, 95% CI 3·5–11·4) continued to drink unfiltered tap water throughout the outbreak.

Control measures

The boil-water advisory was put in place on 31 July. After receiving results of water testing from water samples obtained on 31 July and 4 August, OHA established criteria for lifting the boil-water advisory on 8 August; OHA recommended the city perform twice-weekly testing of water samples from each watershed diversion being used, obtained ⩾24 h apart, until test results were negative for *Cryptosporidium* on two consecutive samples. This criteria was met on 20 August and the boil-water advisory was lifted. The Baker City Council voted to install a *Cryptosporidium*-specific treatment facility ahead of the October 2016 deadline because of the outbreak. The surface water diversion with the highest oocyst count remained offline until Baker City began UV water disinfection on 25 March 2014. DWS required

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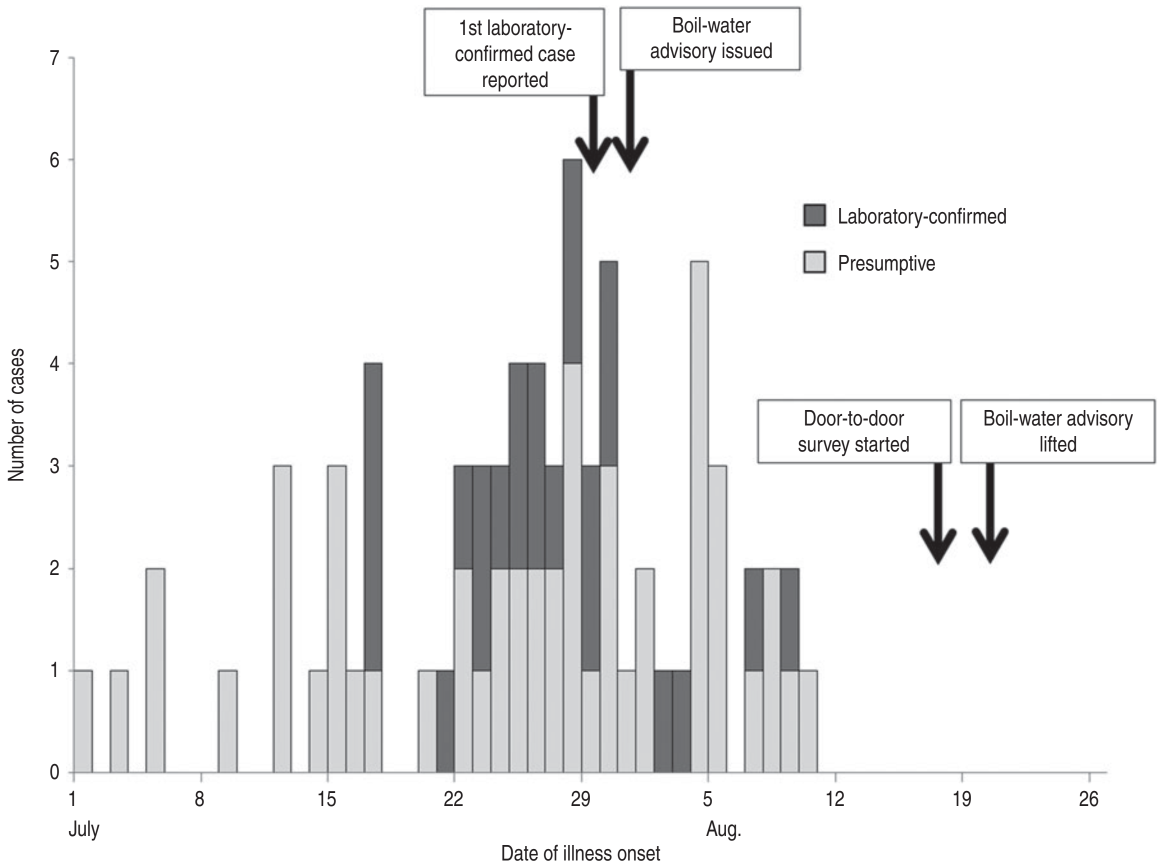

Fig. 2. Cryptosporidiosis outbreak epidemic curve: laboratory-confirmed cases and presumptive cases from door-to-door survey, by date of illness onset, Baker City, Oregon, 2013.

BCWD to collect and test 10-l, untreated water samples obtained from the combined pipeline for *Cryptosporidium*-specific testing using EPA Method 1623 twice weekly until the UV water treatment plan began operations. If two consecutive samples detected *Cryptosporidium*, the boil-water advisory would be reinstated. No additional testing for other waterborne chlorine-resistant pathogens has been performed. As of 1 May 2015, no additional cases of cryptosporidiosis have been reported in Baker County.

DISCUSSION

Baker City's communitywide outbreak is the first reported cryptosporidiosis outbreak detected in a US municipal drinking water system in ~20 years. *Cryptosporidium* is well-suited to waterborne transmission because it has a low infectious dose, is excreted in substantial amounts for long periods, and has an environmentally hardy form (oocyst) that is immediately infectious upon excretion. Additionally, oocysts' small size can pass through certain filtration systems and their extreme chlorine tolerance renders treatment with chemical water disinfectants ineffective. Since the last cryptosporidiosis outbreak associated with community surface water-supplied drinking water systems in the United States was reported to CDC in 1994, the majority of reported cryptosporidiosis outbreaks have been associated with treated recreational water venues [26–32].

The Baker City outbreak highlights the need for continued vigilance in maintaining multiple barriers to drinking water safety. EPA recommends the multiple-barrier approach [33] to ensure a safe drinking water supply, which consists of the following: (1) risk prevention, including source water protection; (2) risk management; (3) monitoring and compliance; and (4) individual actions. Review of Baker City's outbreak identified deficiencies at each barrier that contributed to outbreak occurrence and serves as a reminder of each barrier's importance.

Although signs and fences mark Baker City's watershed boundaries, they were inadequate to protect the surface water from contamination. Although genotyping data of *Cryptosporidium* in water samples were not

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Table 1. *Presumptive cryptosporidiosis weighted attack rate, by sex, age group, and cups of Baker City water consumed daily for sampled Baker City residents (n = 196), Baker City, Oregon, 2013*

Risk factor	No. ill	Weighted attack rate (95% CI)	OR (95% CI)
Sex			
Male	23/87	29·8 (19·7–37·6)	Ref.
Female	27/109	27·0 (18·4–33·8)	0·9 (0·4–1·8)
Age group (yr)			
<18	8/30	28·9 (11·1–42.)	Ref.
19–45	12/33	37·2 (22·5–47·4)	1·5 (0·5–4·6)
46–65	19/71	27·8 (16·4–36·7)	0·9 (0·3–2·7)
>65	11/62	17·4 (7·9–25·3)	0·5 (0·2–1·6)
Baker City water consumed daily (cups/day), *n* = 194			
0–5	22/95	26·2 (16·7–33·6)	Ref.
5·5–10	14/62	23·0 (12·2–30·6)	0·8 (0·3–2·0)
>10	13/37	38·5 (21·7–51·1)	1·8 (0·7–4·5)

OR, odds ratio; CI, confidence interval; Ref., reference.

available to link with clinical specimens, molecular studies of human stool samples and the environmental investigation provided circumstantial evidence that implicated cattle as the probable contamination source. All human specimens tested positive for the same *Cryptosporidium* genotype and subtype, *C. parvum* IIaA15G2R1, a common subtype found in the United States and the predominant endemic subtype in pre-weaned calves [11]. Investigators witnessed cattle grazing on land adjacent to the watershed and there is a high likelihood that nursing calves were also present in the herd since spring-born calves nurse for 3–8 months [34]. Dried cattle faeces were observed within watershed boundaries. Risk prevention through reinforcement of watershed barriers to prevent cattle breaches might decrease this source of surface water contamination. Meteorological conditions might have contributed to contamination because drought conditions can alter water flow and concentrate contaminants in water. The substantial amount of precipitation during June might have washed animal faeces into watershed intakes.

Risk management involves water treatment to remove and inactivate contaminants in source water; the Baker City outbreak emphasizes the importance of water regulations that require treatment to control *Cryptosporidium*. Although Baker City chlorinated its water supply, water filtration or UV treatment to specifically target *Cryptosporidium* contamination was not required when the outbreak began. Before the most recent EPA rule, 60 water systems serving ~10 million persons in the United States met specific filtration avoidance criteria and distributed unfiltered surface water [16]. Now the majority of systems comparable to Baker City have added *Cryptosporidium* treatment [16] and only one system has a variance (Portland, Oregon) [35].

Active monitoring of water systems, using easy to measure parameters such as turbidity, allows for adjustments to help maintain a dependable, safe water supply. In Baker City, water turbidity and *E. coli* counts did not change substantially before the outbreak; thus, officials were not alerted to faecal contamination in treated water. Although the outbreak provided the opportunity to improve water testing practices by ensuring sampling locations included a blend of all surface water sources and adding thermotolerant coliform testing, these improvements might not reliably signal *Cryptosporidium* contamination.

Effective actions at the individual level rely on timely consumer notification of health risks. In Baker City, delays in outbreak detection by laboratory-based surveillance were apparent, evidenced by the outbreak going unnoticed for ~4 weeks. When laboratory-confirmed cases were reported, public health officials recognized the outbreak promptly and responded quickly with a boil-water advisory, potentially curtailing additional illnesses before water contamination was confirmed. This public health response was consistent with recommendations that during community-wide outbreaks, control measures should be implemented rapidly rather than waiting for identification of a specific transmission source [36]. Although the majority of residents initially were informed about the boil-water advisory through informal channels, the message was disseminated

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Table 2. *Household survey information about information source, water source, and water treatment, Baker City, Oregon, 2013*

Survey response	Frequency ($n = 199$)	Percentage (95% CI)
Remembered primary advisory information source	182	91·5 (87·5–95·4)
Primary source of information about advisory		
Family, friend, or neighbor	104	57·1 (49·9–64·4)
Co-worker	30	16·5 (11·0–21·9)
Social media	14	7·7 (3·8–11·6)
Newspaper*	10	5·5 (2·6–8·8)
Grocery store or other local business	8	4·4 (1·4–7·4)
Radio announcement*	4	2·2 (0·1–4·3)
Text message	4	2·2 (0·1–4·3)
Reverse 9–1–1 telephone call*	3	1·6 (0–3·5)
Health system*	3	1·6 (0–3·5)
TV announcement*	1	0·5 (0–1·6)
Website or blog	1	0·5 (0–1·6)
Bought bottled water during advisory	162	82·7 (77·3–88·0)
Boiled water at least once during advisory	153	77·7 (71·8–83·5)
Reported primary water source during advisory	174	87·4 (82·8–92·1)
Primary water source during advisory	($n = 174$)	
Bottled water	117	67·0 (60·2–74·3)
Boiled water	26	14·9 (9·6–20·3)
Unfiltered tap water	13	7·5 (3·5–11·4)
Water brought from neighbouring city	9	5·2 (1·8–8·5)
Private well	7	4·0 (1·1–7·0%)
Other source	2	1·1% (0·0–2·7)
Duration of boiling water	($n = 153$)	
⩾5 min	72	47·1 (39·1–55·0)
2–4 min	41	26·8 (19·7–33·9)
1 min	34	22·2 (15·6–28·9)
Few seconds after it starts to boil	5	3·3 (0·4–6·1)
Until just starts to boil	1	0·7 (0–1·9)
Frequency of boiling water†	($n = 105$)	
Almost always (76–100% of the time)	66	62·9 (53·5–72·2)
Some of the time (26–75% of the time)	39	37·1 (27·8–46·5)

CI, Confidence interval.
* Denotes official sources of information.
† Reported estimated percentage of time household boiled water during advisory.

throughout the community and verified by official sources. During the boil-water advisory, 67% of residents reported use of bottled water and 15% reported use of boiled water as their primary water sources demonstrating adherence to public health recommendations.

Outbreaks associated with drinking water can be difficult to detect; in this case, five laboratory-confirmed cases were the total signal through laboratory-based surveillance to public health. However, the community survey indicated 2780 (28% of the population) cases might have occurred. Similarly, during the Milwaukee outbreak, 285 patients had laboratory-confirmed cryptosporidiosis, whereas an estimated 403 000 persons (26% of the population) were affected [8]. Although 70% of the population is exposed to *Cryptosporidium* during their lifetime [37] and an estimated 748 000 cases occur annually [38], only 8951 cryptosporidiosis cases were reported in the United States during 2010 [14]. Underdiagnosis of *Cryptosporidium* likely contributes to underrecognition of outbreaks.

Economic and social ramifications of substantial outbreaks are important to consider, but often difficult to quantify. During 2008, a communitywide *Salmonella* Typhimurium outbreak associated with the public drinking water system in Alamosa, Colorado, resulted in estimated costs to residents of

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~\$850 000 and to businesses of ~\$625 000. One third of businesses surveyed reported closing for a mean length of 8·4 days during the outbreak [39]. Although investigators did not specifically evaluate economic and social consequences of the Baker City outbreak, anecdotal community experiences illustrate outbreak costs. Grocery stores were forced to dispose of produce that had been sprayed with city water. Certain restaurants closed during the boil-water advisory rather than install expensive water filters or perform additional water treatment. Restaurants that remained open often used disposable flatware and dishes rather than risk contamination during the dishwashing process. Hotels provided bottled water for patrons. One food processing plant was forced to dispose of products made with potentially contaminated water, which resulted in considerable financial losses and subsequent factory layoffs. Although investment costs in water system improvements to comply with more stringent drinking water regulations are often borne by community residents in the form of higher rates, costs of avoiding or delaying implementation of measures designed to protect public health might be considerably higher. An economic analysis evaluating costs attributable to implementing the EPA rule related to *Cryptosporidium*-specific treatment estimated the annual cost increase/household would be <\$7 for >90% of all households served by surface water and ground water under the direct influence of surface water [40].

Limitations of this investigation include a narrow presumptive case definition, which might have underestimated the size of the affected population. However, certain survey-identified cases might not have been *Cryptosporidium* infections because a background level of diarrhoeal illness was likely present. Residents who experienced illness might have been more likely to respond to the survey, which might result in an overestimate of the attack rate; to minimize bias, we contacted a random sample of households. However, our low survey response rate might have affected validity of results. Finally, the survey was not powered to detect differences in attack rates in groups, limiting our ability to associate illness incidence to amount of water consumed, age, or other individual characteristics or behaviours. Thus, data associating the outbreak to drinking water came from the initial assessments of community-wide diarrhoeal illness and the ensuing laboratory and environmental investigations.

Safe drinking water, among the most basic public health interventions enjoyed by the majority of communities in the United States, has resulted in substantial reductions in mortality in the United States during the 20th century [41]. The United States has made considerable progress during >40 years since passage of the 1974 Safe Drinking Water Act with regard to the distribution of high-quality, clean drinking water [42]. After Milwaukee's cryptosporidiosis outbreak during 1993, EPA increased efforts to protect surface water-supplied systems from microbial contamination and prevent *Cryptosporidium* from causing drinking water-related outbreaks [16, 43, 44]. The possibility exists that these regulatory efforts in the United State are responsible for the ~20 years separating the last reported drinking water-related cryptosporidiosis outbreak in Las Vegas, Nevada (1993–1994) [5] and Baker City's outbreak during 2013. Although the majority of public drinking water systems usually supply safe, clean water, public health agencies should be aware that drinking water-associated outbreaks continue to occur, can be difficult to detect, and have considerable health, economic, and social repercussions [8, 39, 45]. Baker City's outbreak serves as a reminder of why surface water regulations were implemented during 1989 and strengthened multiple times; surface water is inherently vulnerable to contamination. The outbreak underscores the vital importance of investments in improved water treatment and system upkeep. Proactive investments by community water systems to maintain and improve drinking water quality and continued vigilance by public health agencies are necessary to prevent, identify, and control community drinking water-related disease outbreaks.

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This report is dedicated to the memory of Bill Keene, a pioneering, passionate epidemiologist who worked for the state of Oregon until his unexpected death in December 2013. The Baker City outbreak was one of the last outbreaks in which he participated.

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The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

DECLARATION OF INTEREST

None.

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