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REPORT

To the Honorable Mayor and City Council
From the City Manager

October 25, 2004

Subject
Follow-up Information Concerning Cryptosporidium in Recycled Water

Recommendation
Receive requested follow-up information – No City Council action required

Background

In November 2003 the City Council was presented with a copy of the attached abstract entitled "Infectious Cryptosporidium parvum Oocysts in Final Reclaimed Effluent" from the publication *Applied and Environmental Microbiology*, dated August 2003. Subsequently, Mayor Ira requested that staff provide follow-up information to the City Council.

Cryptosporidium and Giardia are protozoan parasites affecting the gastrointestinal tract of humans and animals. They are shed in feces in the form of an oocyst (Cryptosporidium) or cyst (Giardia). These protozoans can remain dormant for long periods in the oocyst/cyst form. They become active upon entering a host.

During this protective state (i.e. oocyst/cyst), Cryptosporidium and Giardia are particularly difficult to remove from water systems. Ordinary water disinfection techniques cannot kill oocysts/cysts, and even the best filtration systems occasionally allow a few organisms to pass through. For a more in-depth discussion of Cryptosporidium infection, see the attached *Fact Sheet for the general public* by the Center for Disease Control (CDC).

Since the 1980's, Cryptosporidium and Giardia have become an increasing concern for drinking water industry professionals. The problem became most visible when the Milwaukee, Wisconsin municipal drinking water system suffered a severe Cryptosporidium outbreak in 1993. Over 400,000 persons fell ill and 70 individuals died as a result of this outbreak.

After the Milwaukee incident, the EPA began requiring under the Information Collection Rule (ICR) that municipal drinking water systems serving over 100,000 people test their source waters for Cryptosporidium. However, the methods at that time proved inadequate to detect and enumerate Cryptosporidium. As a result, the EPA initiated in 1996 the proposed development of a new method to overcome the deficiencies of the ICR rule. The attached two-part paper on Cryptosporidium by the San Francisco Public Utilities Commission provides a comprehensive overview of relevant information of Redwood City's drinking water supply. For a discussion on their perspective on the ICR, see page 7 of 13 – "Detection" section.

Health problems from Cryptosporidium and Giardia occur only from drinking the water, not from incidental contact. Most mountain streams contain these contaminants making it unsafe to drink. However, people swim in this water with no ill affects. By comparison, the

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amount of Cryptosporidium and Giardia in stream water far exceeds the quantities that might occur in treated recycled water, as the findings of medical studies would indicate.

In California, the treatment and use of recycled water for non-drinking uses is carefully regulated by the California Department of Health Services (DHS) and the California Regional Water Quality Control Board (RWQCB). California's regulations are some of the most stringent in the world. Recycled water treatment systems are designed to provide sufficient disinfection and operational safeguards to meet California's strict "Title 22" requirements. Before constructing a recycled water system, an engineering report that includes a detailed description of the project, the enforceable administrative procedures of the project and the design requirements must be approved by DHS. DHS requires that the system include multiple reliability physical barriers (filtration) to ensure that the water produced is safe for its intended use.

Pursuant to the recently approved *Agreement for Production and Delivery of Recycled Water between the South Bayside System Authority and the City of Redwood City*, SBSA is designing and will construct new, permanent recycled water treatment (filtration and disinfection improvements), storage and pumping facilities for the City's Recycled Water Project. Concurrently, a draft Engineering Report for the project has been submitted to the DHS staff. DHS conditional approval of the Engineering Report is anticipated in the near future, and it is expected that they will focus their comments on the City's proposed cross connection prevention program as a key element of protecting the public drinking water system – and thus protecting the public from exposure to Cryptosporidium and Giardia.

The SBSA treatment plant will produce recycled water in continuous compliance with Title 22 requirements for disinfected tertiary recycled water, DHS' highest recycled water quality standard, which has been in place for several years. The present standard does not specifically address Cryptosporidium, even though removal and inactivation is probably occurring in treatment plants.

SBSA's recycled water production will be managed by rigorous operational procedures and processes that continuously meet the requirements of DHS. In addition to satisfying DHS monitoring and reporting requirements, SBSA will also have a detailed operational monitoring system that will further enhance system reliability. SBSA is already experienced in producing high quality recycled water. Since 2000, SBSA has produced tertiary treated recycled water without incident for the First Step Recycled Water Project.

The intended use of recycled water in Redwood City is for landscape irrigation and industrial uses only; it will not be consumed by humans. With proper irrigation scheduling and best management practices, the water will be applied during nighttime hours, thus minimizing the potential for anyone to come into contact with it.

Redwood City Public Works Services and SBSA will not rely on regulations alone to guide the safe and reliable operation of the recycled water system. Research and studies regarding the safe and effective use of recycled water are continually being conducted worldwide. Staff is – and will continue to be – vigilant in reviewing information generated on all aspects and issues related to the use of recycled water. Both entities belong to several organizations that share data and monitor research. Staff will track specific research projects that may provide new information and guidance for the implementation and operation of the system in the future.

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Members of the community have raised the question of monitoring and testing for Cryptosporidium in the recycled water that will be produced by SBSA and distributed to customers by Redwood City. Staff recommends that no operating decisions be made at this time, but that the issues raised be left on the table for consideration after the DHS has responded to the Engineering Report, and then within the context of the project operations plan that will flow out of the Engineering Report and the system design. Since the initial deliveries of recycled water are anticipated in the summer of 2006, there will likely be additional external information available to include in the formulation of monitoring and testing protocols.

Peter Ingram
Director, Public Works Services

Ed Everett
City Manager

Attachments

1. Abstract entitled "Infectious Cryptosporidium parvum Oocysts in Final Reclaimed Effluent" from the publication *Applied and Environmental Microbiology*, dated August 2003
2. *Fact Sheet for the general public* by the Center for Disease Control (CDC)
3. Two-part paper on Cryptosporidium by the San Francisco Public Utilities Commission

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Infectious *Cryptosporidium parvum* Oocysts in Final Reclaimed Effluent

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Water samples collected throughout several reclamation facilities were analyzed for the presence of infectious *Cryptosporidium parvum* by the focus detection method–most-probable-number cell culture technique. Results revealed the presence of infectious *C. parvum* oocysts in 40% of the final disinfected effluent samples. Sampled effluent contained on average seven infectious oocysts per 100 liters. Thus, reclaimed water is not pathogen free but contains infectious *C. parvum*.

Reclaimed water (treated wastewater) is being utilized in the United States and throughout the world as an alternative nonpotable water source. In the United States, 18 states currently have standards and another 18 have guidelines for reclaimed water (8). These standards, for the most part, are based on total suspended solids and fecal coliforms. A variety of microbial pathogens are present in wastewater and can be detected in reclaimed water. Therefore, advanced treatment, including filtration and disinfection, is required to produce reclaimed water that does not have a negative impact on public health. In regulatory language, this means that pathogens are to be less than the limit of detection of the assay (8).

Cryptosporidium parvum, a coccidian protozoan parasite, is a potential contaminant of reclaimed water. *C. parvum* oocysts have been found to be persistent in the environment and resistant to chlorination. Because of this, physical removal by chemical pretreatment and filtration is the primary means of reducing the level of oocysts in environmental water (6). A possible risk to human health exists if filtration fails to function efficiently. This risk is greater still with reclaimed water, as to date no monitoring for *C. parvum* oocysts has been required and little information is available on the filtration efficiency in these facilities. Recently, in the state of Florida, monitoring for protozoan parasites, including *Cryptosporidium*, once every 2 years for larger facilities and once every 5 years for smaller facilities has been mandated. Sampling is recommended at a single point following disinfection (2).

In one study, *C. parvum* oocysts were detected in untreated wastewater (67% of the samples were positive) and in reclaimed water (25% of final effluent samples were positive) (5). However, only the presence of the oocysts was evaluated using fluorescence microscopy. Robertson et al. evaluated wastewater samples for viable *C. parvum* by using vital stains; 35% of the influent samples and 46% of the effluent samples contained viable oocysts (4). In the last few years, the focus detection method–most-probable-number (FDM-MPN) cell culture technique has been developed to test the oocyst infectivity because the previously employed methods did not accurately reflect the infectious nature of the oocysts (7). The objective of the present study was to demonstrate the presence of infectious *C. parvum* oocysts in final reclaimed effluent from six reclamation facilities in the United States by using the FDM-MPN cell culture technique.

Samples were collected from influent, secondary effluent, postfiltration, and final disinfected effluent waters. Six reclamation facilities in the United States, utilizing a variety of filtration systems (shallow- or deep-bed sand and anthracite filters or fabric disk filters) and disinfection methods (chlorine gas or UV radiation), were monitored. Three facilities were monitored five times over a 1-year time period. Three additional facilities were monitored over a 5-month time period. One to 400 liters of sample, depending on the site, was filtered through Envirochek HV filters (Pall Gelman Laboratories, Ann Arbor, Mich.). After filtration, elution, and centrifugation using the guidelines provided by EPA method 1623 (9), oocysts were concentrated into a pellet by immunomagnetic separation (Dynabeads Anti-Crypto Kit; Dynal Biotech, Inc., Lake Success, N.Y.).

Half of the concentrated pellet was analyzed by the FDM-MPN cell culture technique (7). (The other half of the concentrated pellet was processed by microscopic screening of the sample after staining with monoclonal antibodies [anti-*Cryptosporidium*; Waterborne Inc., New Orleans, La.] tagged with fluorescein isothiocyanate, using an indirect fluorescent-antibody assay [IFA] to determine total counts of oocysts.) The concentrate was first bleach treated at room temperature for 8 min with a 10.5% solution of 4% sodium hypochlorite in phosphate-buffered saline (PBS; pH 7.2) to eliminate bacterial contamination as well as to trigger excystation of the oocysts. The sample was then washed once with PBS and centrifuged, after which the pellet was suspended in 1 ml of prewarmed growth medium (RPMI 1640 [Fisher Scientific, Pittsburgh, Pa.] plus

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TABLE 1. Occurrence of *Cryptosporidium parvum* oocysts in various phases of wastewater treatment[a]

Sample	No. of samples	% Positive for *C. parvum*		Oocyst level				Arithmetic mean ± SD	
				Minimum		Maximum			
		Total oocysts	Infectious oocysts	Total oocysts	Infectious oocysts	Total oocysts	Infectious oocysts	Total oocysts	Infectious oocysts
Influent	18							6,910 ± 7,731	
Secondary effluent	18							112 ± 153	
Postfiltration	17							37 ± 73	
Final disinfected effluent	15							28 ± 52	

[a] All concentrations are determined per 100 liters of sample. Percent positives were calculated from values above the limit of detection. Total oocyst counts represent actual counts; infectious oocyst counts are MPN results.

additives) and placed directly on human ileocecal adenocarcinoma HCT-8 cell monolayers in eight-well chamber slides. The slides were incubated at 37°C in a 5% CO_2 incubator. After 90 min, additional growth medium was added to each well, and the slides were incubated for another 40 to 48 h.

After incubation, the slides were removed, washed with PBS, and fixed in 100% methanol. The monolayers were rehydrated for 30 min in blocking buffer (PBS with 2% goat serum [Atlanta Biologicals, Norcross, Ga.] and 10% of a 0.002% solution of Tween 20) and stained with rat anti-*C. parvum* sporozoite antibody (Waterborne Inc.) followed by fluorescein isothiocyanate-labeled anti-rat immunoglobulin G (Sigma Aldrich, Inc., St. Louis, Mo.). The slides were evaluated under an Olympus BH-2 epifluorescence microscope at 200× and 400× magnification (excitation, 340 to 380 nm; 420-nm barrier or suppression filter) for the presence of infectious foci.

The number of positive wells for each sample was entered into the MPN program, downloaded from the EPA website, to determine the number of infectious oocysts per milliliter (8). When no infectious foci were observed, the MPN program determined the detection limit for the assay. The number of infectious oocysts per 100 liters was determined from the initial volume collected and the concentrate volume analyzed after immunomagnetic separation.

C. parvum oocysts were found in all sites monitored throughout the treatment process (Table 1). As well, and more importantly, infectious *C. parvum* oocysts were found in all sampling sites (Table 1). Average concentrations of 6,910 oocysts/100 liters by IFA and 993 infectious oocysts/100 liters by MPN were found in the influent (raw wastewater). Therefore, roughly 14% of all oocysts observed were infectious in nature. At the conclusion of treatment, average concentrations of 28 oocysts/100 liters by IFA and 7 infectious oocysts/100 liters by FDM-MPN were detected. Roughly 25% of the oocysts detected were infectious in nature. Average recovery efficiencies of 5.5% from influent samples for four trials (standard deviation, ±1.3), 15.3% from secondary effluent samples for four trials (standard deviation, ±2.9), and 15% from postfiltered and final disinfected effluent samples for 12 trials (standard deviation, ±11.2) have been observed in our laboratory using gamma-irradiated oocysts labeled with Texas Red. Thus, it is important to note that higher concentrations of infectious oocysts may be present in all samples, but especially final disinfected reclaimed effluent samples, since recovery efficiencies are not 100%.

During the past decade, there has been an increase in awareness of the risk of illness resulting from *C. parvum* because of outbreaks such as that in Milwaukee, Wisconsin, in 1993 (3). By 1995, surveillance for cryptosporidiosis in the human population had begun in the United States. Between 1995 and 1998, the mean incidence per 100,000 ranged from 0.9 to 3 (1). The relationship to water transmission is not known. In 1999, Florida began to require periodic sampling for *Cryptosporidium* and *Giardia* in reclaimed water systems (10). In this paper, we report initial findings of infectious *C. parvum* oocysts in final reclaimed effluent as determined by the FDM-MPN method. Additional monitoring to produce a more statistically significant database and research to determine the best treatment processes are suggested as the next steps. Eventually, standards for monitoring of reclaimed water for *Cryptosporidium* should be considered. The FDM-MPN method will be a useful tool for future monitoring requirements to determine the presence of infectious oocysts and the associated health risk.

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Cryptosporidium Infection
Cryptospordiosis (KRIP-toe-spo-rid-ee-OH-sis)

What is cryptosporidiosis?

Cryptosporidiosis is a diarrheal disease caused by microscopic parasites of the genus *Cryptosporidium*. Once an animal or person is infected, the parasite lives in the intestine and passes in the stool. The parasite is protected by an outer shell that allows it to survive outside the body for long periods of time and makes it very resistant to chlorine-based disinfectants. Both the disease and the parasite are commonly known as "crypto."

During the past two decades, crypto has become recognized as one of the most common causes of waterborne disease within humans in the United States. The parasite may be found in drinking water and recreational water in every region of the United States and throughout the world.

How is cryptosporidiosis spread?

Cryptosporidium lives in the intestine of infected humans or animals. Millions of crypto germs can be released in a bowel movement from an infected human or animal. Consequently, *Cryptosporidium* is found in soil, food, water, or surfaces that have been contaminated with infected human or animal feces. If a person swallows the parasite they become infected. You **cannot** become infected through contact with blood. The parasite can be spread by

- Accidentally putting something into your mouth or swallowing something that has come into contact with feces of a person or animal infected with *Cryptosporidium*.
- Swallowing recreational water contaminated with *Cryptosporidium* (Recreational water includes water in swimming pools, hot tubs, jacuzzis, fountains, lakes, rivers, springs, ponds, or streams that can be contaminated with sewage or feces from humans or animals.) **Note:** *Cryptosporidium* can survive for days in swimming pools with adequate chlorine levels.
- Eating uncooked food contaminated with *Cryptosporidium*. Thoroughly wash with clean, safe water all vegetables and fruits you plan to eat raw. See below for information on making water safe.
- Accidentally swallowing *Cryptosporidium* picked up from surfaces (such as bathroom fixtures, changing tables, diaper pails, or toys) contaminated with feces from an infected person.

What are the symptoms of cryptosporidiosis?

The most common symptom of cryptosporidiosis is watery diarrhea. Other symptoms include:

- Dehydration
- Weight loss
- Stomach cramps or pain
- Fever
- Nausea
- Vomiting

Some people with crypto will have no symptoms at all. While the small intestine is the site most commonly affected, *Cryptosporidium* infections could possibly affect other areas of the digestive or the respiratory tract.

How long after infection do symptoms appear?

Symptoms of cryptosporidiosis generally begin 2 to 10 days (average 7 days) after becoming infected with the parasite.

How long will symptoms last?

In persons with healthy immune systems, symptoms usually last about 1 to 2 weeks. The symptoms may go in cycles in which you may seem to get better for a few days, then feel worse again before the illness ends.

If I have been diagnosed with *Cryptosporidium*, should I worry about spreading the infection to others?

Yes, *Cryptosporidium* can be very contagious. Follow these guidelines to avoid spreading the disease to others:

1. Wash your hands with soap and water after using the toilet, changing diapers, and before eating or preparing food.
2. Do not swim in recreational water (pools, hot tubs, lakes or rivers, the ocean, etc.) if you have cryptosporidiosis and for at least 2 weeks after diarrhea stops. You can pass *Cryptosporidium* in your stool and contaminate water for several weeks after your symptoms have ended. This has resulted in outbreaks of cryptosporidiosis among recreational water users. **Note:** Cryptosporidium can be spread in a chlorinated pool because it is resistant to chlorine and, therefore, can live for days in chlorine-treated swimming pools.
3. Avoid fecal exposure during sexual activity.

Who is most at risk for cryptosporidiosis?

People who are most likely to become infected with *Cryptosporidium* include:

- Children who attend day care centers, including diaper-aged children
- Child care workers
- Parents of infected children
- International travelers
- Backpackers, hikers, and campers who drink unfiltered, untreated water
- Swimmers who swallow water while swimming in swimming pools, lakes, rivers, ponds, and streams
- People who drink from shallow, unprotected wells
- People who swallow water from contaminated sources.

Contaminated water includes water that has not been boiled or filtered. Several community-wide outbreaks of cryptosporidiosis have been linked to drinking municipal water or recreational water contaminated with *Cryptosporidium*.

Who is most at risk for getting seriously ill with cryptosporidiosis?

Although Crypto can infect all people, some groups are more likely to develop more serious illness.

- Young children and pregnant women may be more susceptible to the dehydration resulting from diarrhea and should drink plenty of fluids while ill.

> If you have a severely weakened immune system, talk to your health care provider for additional guidance. You can also call the CDC AIDS HOTLINE toll-free at 1-800-342-2437. Ask for more information on cryptosporidiosis, or go to the CDC fact sheet *Preventing Cryptosporidiosis: A Guide for People with Compromised Immune Systems* available by visiting http://www.cdc.gov/ncidod/dpd/parasites/cryptosporidiosis/factsht_crypto_prevent_ci.htm

- If you have a severely weakened immune system, you are at risk for more serious disease. Your symptoms may be more severe and could lead to serious or life-threatening illness. Examples of persons with weakened immune systems include those with HIV/AIDS; cancer and transplant patients who are taking certain immunosuppressive drugs; and those with inherited diseases that affect the immune system.

What should I do if I think I may have cryptosporidiosis?

If you suspect that you have cryptosporidiosis, see your health care provider.

How is a cryptosporidiosis diagnosed?

Your health care provider will ask you to submit stool samples to see if you are infected. Because testing for Crypto can be difficult, you may be asked to submit several stool specimens over several days. Tests for Crypto are not routinely done in most laboratories; therefore, your health care provider should specifically request testing for the parasite.

What is the treatment for cryptosporidiosis?

Although there is no standard treatment for cryptosporidiosis, the symptoms can be treated. Most people who have a healthy immune system will recover without treatment. If you have diarrhea, drink plenty of fluids to prevent dehydration. Rapid loss of fluids from diarrhea may be especially life threatening to babies; therefore, parents should talk to their health care provider about fluid replacement therapy options for infants. Antidiarrheal medicine may help slow down diarrhea, but talk to your health care provider before taking it. A new drug, nitazoxanide, has been approved for treatment of diarrhea caused by *Cryptosporidium* in healthy children less than 12 years old. Consult with your health care provider for more information.

People who are in poor health or who have a weakened immune system are at higher risk for more severe and more prolonged illness. For persons with AIDS, anti-retroviral therapy that improves immune status will also decrease or eliminate symptoms of Crypto. However, even if symptoms disappear, cryptosporidiosis is usually not curable and the symptoms may return if the immune status worsens. See your health care provider to discuss anti-retroviral therapy used to improve your immune status.

How can I prevent cryptosporidiosis?

Practice good hygiene.

1. Wash hands thoroughly with soap and water. a. Wash hands after using the toilet and before handling or eating food (especially for persons with diarrhea). b. Wash hands after every diaper change, especially if you work with diaper-aged children, even if you are wearing gloves.
2. Protect others by not swimming if you are experiencing diarrhea (essential for children in diapers).

Avoid water that might be contaminated.

1. Do not swallow recreational water.
2. Do not drink untreated water from shallow wells, lakes, rivers, springs, ponds, and streams.
3. Do not drink untreated water during community-wide outbreaks of disease caused by contaminated drinking water.
4. Do not use untreated ice or drinking water when traveling in countries where the

> For information on recreational water-related illnesses, visit CDC's Healthy Swimming website at http://www.cdc.gov/healthyswimming.

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water supply might be unsafe.

In the United States, nationally distributed brands of bottled or canned carbonated soft drinks are safe to drink. Commercially packaged non-carbonated soft drinks and fruit juices that do not require refrigeration until after they are opened (those that are stored unrefrigerated on grocery shelves) also are safe.

For information on choosing safe bottled water, see the CDC fact sheet entitled "Preventing Cryptosporidiosis: A Guide to Water Filters and Bottled Water," available by visiting http://www.cdc.gov/ncidod/dpd/parasites/cryptosporidiosis/

If you are unable to avoid using or drinking water that might be contaminated, then you can make the water safe to drink by doing one of the following:

- Heat the water to a rolling boil for at least 1 minute. OR
- Use a filter that has an absolute pore size of at least 1 micron or one that has been NSF rated for "cyst removal."

For information on choosing a water filter, see the CDC fact sheet entitled "Preventing Cryptosporidiosis: A Guide to Water Filters and Bottled Water," available by visiting http://www.cdc.gov/ncidod/dpd/parasites/cryptosporidiosis/

Do not rely on chemicals to disinfect water and kill *Cryptosporidium.* Because it has a thick outer shell, this particular parasite is highly resistant to disinfectants such as chlorine and iodine.

Avoid food that might be contaminated.

1. Wash and/or peel all raw vegetables and fruits before eating.
2. Use safe, uncontaminated water to wash all food that is to be eaten raw.
3. Avoid eating uncooked foods when traveling in countries with minimal water treatment and sanitation systems.

Take extra care when traveling.

If you travel to developing nations, you may be at a greater risk for *Cryptosporidium* infection because of poorer water treatment and food sanitation. Warnings about food, drinks, and swimming are even more important when visiting developing countries. Avoid foods and drinks, in particular raw fruits and vegetables, tap water, or ice made from tap water, unpasteurized milk or dairy products, and items purchased from street vendors. These items may be contaminated with *Cryptosporidium.* Steaming-hot foods, fruits you peel yourself, bottled and canned processed drinks, and hot coffee or hot tea are probably safe. Talk with your health care provider about other guidelines for travel abroad.

Avoid fecal exposure during sexual activity.

DEPARTMENT OF HEALTH AND HUMAN SERVICES
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SAN FRANCISCO Public Utilities Commission

Cryptosporidium (part 1 of 2)

This paper summarizes relevant information and current research issues on *Cryptosporidium* relevant to its public health significance in water supplied. From this assessment, suggestions are made for actions to be taken by the San Francisco Public Utilities Commission

Background

To safeguard public health, regulations have been promulgated regarding drinking water authorized by the 1986 Amendments to the Safe Drinking Water Act. A pertinent piece of legislation is the Surface Water Treatment Rule, which was enacted by both the United States Environmental Protection Agency and the State Department of Health Services (DHS) in June 1989 and 1991, respectively. San Francisco is under a compliance order to meet this regulation by 1999. The purpose of the Safe Drinking Water Treatment Rule is to minimize microbial risk due to parasites (i.e., *Giardia*), bacteria (i.e., *Legionella*) and viruses from surface water supplies. While this rule does not place limits on *Cryptosporidium* due to lack of information, it has, however, become of great interest due to recent outbreaks in England and in North America. *Cryptosporidium* will be regulated under the Enhanced Surface Water Treatment Rule (interim rule to be promulgated in 1998 with a long-term version to be promulgated in 2002); watershed monitoring will be an essential element as well as removal or inactivation requirements.

History

Cryptosporidium was first described in 1907 by Ernest Edward Tizzer. His work was not regarded as important at the time, and half a century passed before *Cryptosporidium* became of minor interest in association with the incidence of cryptosporidiosis in turkeys. Interest in *Cryptosporidium* heightened in 1971 when *Cryptosporidium* was found to be associated with diarrhea in cows.[54] In 1976, the first cases of human cryptosporidiosis were reported. After that, relatively few cases were reported until 1982, when cryptosporidiosis was associated with protracted diarrhea in patients with acquired immune deficiency syndrome (AIDS).[7,18,41] This finding stimulated intense medical and veterinary interest in the epidemiology, diagnosis, treatment, and prevention of cryptosporidiosis.

The first reported human outbreak of cryptosporidiosis due to water supply occurred in Texas in 1984 concurrently with an outbreak of Norwalk virus. This was followed by the second largest North American outbreak in Carrolton, Georgia, in 1987, where over 13,000 people were affected.[28] Two outbreaks of *Cryptosporidium* occurred in the United Kingdom in 1988; the larger in December 1988 affected approximately 5,000 people.[42] Since this time, several smaller outbreaks have occurred in the United

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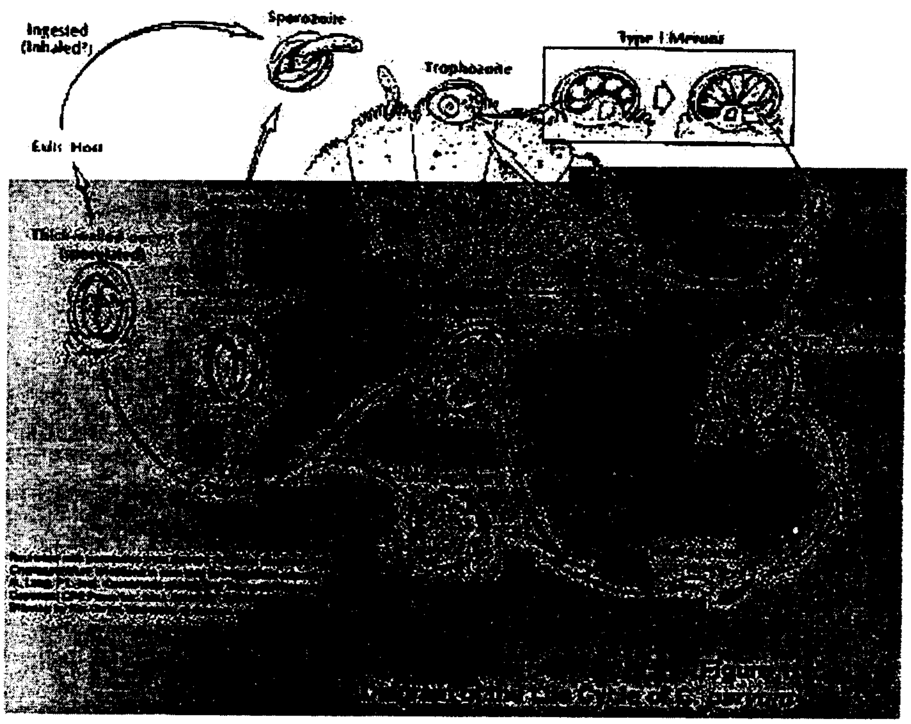
Kingdom.[27,28] In April 1993, the largest North American outbreak affecting almost 400,000 people occurred in Milwaukee, Wisconsin.[39] This outbreak has attracted much national attention and the effects of the outbreak were still experienced even a year later.[33,50,58] In early 1994, an outbreak occurred in the Las Vegas area affecting approximately 78 people. Water was speculated to be the cause.[23] In 1996, several outbreaks occurred in Canada including approximately 14,500 cases in Kelowna and British Columbia.[15] In 1997, an outbreak affecting four suburbs in London, England infecting at least 345 people. The cases were strongly associated with drinking water.[59] Most water supply related incidents of *Cryptosporidium* have occurred during the spring and in filtered supplies.

The Organism

Description

Cryptosporidium is an oval-shaped protozoan parasite found in man, mammals, birds, fish, and reptiles. *Cryptosporidium* has a complicated life cycle (Figure 1) which goes through many forms, the most relevant form being a 4 to 6 Fm diameter oocyst, which contains the infective sporozoites.[16,20] Although the number of species of *Cryptosporidium* is open to questions, only one, *C. parvum*, appears responsible for significant human health concerns.



Cryptosporidium oocysts are resistant to adverse environmental factors and can survive for months under optimum environmental conditions.[46] The released infective sporozoites do not survive well.

The Disease

In humans, cryptosporidiosis results in a self-limiting but unpleasant diarrhea in

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immunocompetent individuals with an incubation period of 2 to 10 days. Some of the associated symptoms include anorexia, weight loss, dehydration, abdominal cramping, and vomiting (i.e., headache, aching muscles, fever). On average, the symptoms last for 12 days with rare instances lasting as long as 4 weeks.[4,7,14] In patients with depressed immunity due to disease (i.e., HIV infection, chemotherapy, etc.) or congenitally depressed immunity (e.g., hypogammaglobuinemia), similar symptoms are observed. The duration, however, can be much longer and some individuals never clear *Cryptosporidium* from their systems. In cases where suppression of the immune system cannot be reversed (e.g., by stopping immune suppressant therapy) these symptoms may persist until death.[6,11,24]

Prevalence

Methods for determining the prevalence of infection with Cryptosporidium have been undergoing rapid change. Interpretation of the results is not without controversy. Nevertheless, human cryptosporidiosis has been identified on all six continents.3,5,14,55 Among people with gastrointestinal complaints, the prevalence of Cryptosporidium oocysts in patient's stools range from 1 to 4 percent in developed countries and up to 16 percent in developing countries. Specific North American surveys indicated similar levels. For example, in British Columbia, Canada, the prevalence was 0.6 percent, in Massachusetts it was 2.8 percent, and in South Carolina 4.3 percent. In England, Cryptosporidium is the fourth most common cause of diarrhea.53

In the immunocompromised population, particularly those infected with HIV, the prevalence is higher. Estimates of the percent of HIV-infected patients with cryptosporidiosis range from 1 to 2 percent up to 10 percent. Of AIDS patients with diarrhea, Cryptosporidium has been identified as an agent in 10 to 15 percent of the cases.6,55

Immunity

Exposure to *Cryptosporidium* does not necessarily lead to clinical disease. There is some indication that prior exposure results in protective immunity from cryptosporidiosis, though the duration of this immunity is unknown. Serological testing has found *Cryptosporidium*-associated antibodies in 25 to 35 percent of people tested in North America, indicative of a moderate level of *Cryptosporidium* exposure.[55] With the more widespread use of cocktail therapy, the health of AIDS patients has been improving. It is unclear what impact this will have on their susceptibility to cryptosporidiosis.

Treatment

Over 90 antimicrobial agents have been used against *Cryptosporidium* in animals and man, but no specific effective treatment for cryptosporidiosis has yet been found.[20] While this is not of great importance among immunocompetent individuals (except for days of work lost) where the infection is self-limiting, it is vital for immunosuppressed patients. Several clinical trials are currently evaluating some promising agents including letrazuril, azithromycin, paramomycin, and a hyperimmune bovine colostral immunoglobulin. The last mentioned agent shows great promise; it is being evaluated at San Francisco General Hospital.[41]

Transmission

Accurate identification of the modes of transmission is of critical importance in evaluating the risks associated with cryptosporidiosis.

Sources

Reservoirs for *Cryptosporidium* include mammals, birds, fish, and reptiles. Species shed by one host can infect other hosts (e.g., cattle can infect humans). Animals that can carry *Cryptosporidium* include cattle, pigs, cats, deer, guinea pigs, mice, rats, and sheep. Young animals that are most likely to develop symptomatic infections and shed high quantities of infective oocysts.

Exposure Routes

There are a variety of exposure routes. Cryptosporidiosis is normally transmitted by the fecal-oral route, when oocysts excreted by an infected animal or human are ingested by a susceptible person. A number of transmission routes exist because oocysts are capable of infecting other hosts immediately when released into the environment and after surviving in the environment for a period of time. These routes are:

- From Animals - Transmission from animals to man has been documented by veterinarians and others working closely with sheep and cows. Gulls have been shown to be carriers.[52] Pet animals such as dogs and cats have also been implicated in human cases.[44]

- Person-to-Person - Person-to-person transmission is important. Cryptosporidiosis transmission can occur easily within families, play groups, nursery schools, day care centers, hospitals, and other institutions where precautions are not taken. Sexual transmission is also suspected, particularly in the gay community.[26]

- From Water - Several major outbreaks in the last 10 years have shown that cryptosporidiosis can be contracted from contaminated water. Wastewater plants are not wholly effective in removing *Cryptosporidium*.[56] Recreational contact with contaminated water in reservoirs, rivers, and other waters has been documented as a transmission source. Included in this category is an incident where 17 people contracted cryptosporidiosis while at a local wave pool.[35]

- Airborne - Some indications exist that airborne spread of *Cryptosporidium* occurs, although these have not been well documented.

- Other - There have been a few reports of infection with *Cryptosporidium* following consumption of raw milk and raw sausages. In 1993, 160 people contracted cryptosporidiosis due to drinking contaminated apple cider at an agricultural fair in Maine.[37] This has not been previously thought to be a significant route.

Infectivity

Uncertainty exists concerning the dose required to induce infection (not even

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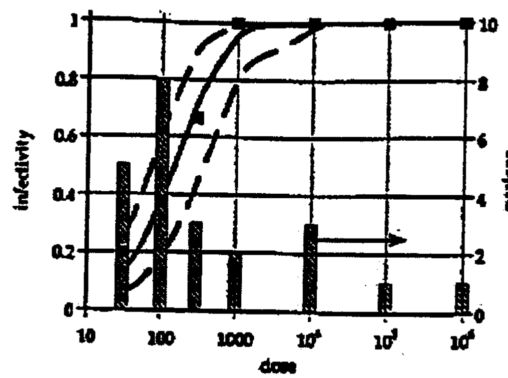
considering virulence differences for different strains). While most indications suggest that the dose required to induce infection is between 1 to 100 oocysts,[3,21,41] one study indicated that doses of 10,000 oocysts were not capable of inducing infections in adult monkeys. Recently, Dupont and his colleagues completed a human feeding study which determined that the dose at which 20 percent of the subjects were infected was 30 oocysts while a 40 percent infection rate of the subjects was 100 oocysts (Figure 2). From this information, Haas and Rose propose that the minimum infectious dose is 1 oocyst.[27]



Footnote: Lines show 95% confidence intervals to fitted dose-response curve.
Bars show number of subjects used per dose.
Reference: 27

Figure 2
Dose Response Data of Dupont
Fit to Exponential Model

The immunocompromised apparently are the most susceptible population. There is some indication that deficiencies in the immune system during pregnancy make pregnant women more susceptible to a prolonged bout of cryptosporidiosis. It is reported that when CD4 counts (CD4 counts indicate the level of T-helper cells in the immune system) are less than 180, the host will usually be unable to clear the disease.[34,41] The CD4 counts for normal individuals typically are between 800 and 900.

Significant virulence differences exist between strains of *Cryptosporidium*. For example, comparing two different isolates showed a similar rate of infection but twice the incidence of diarrheal illness.[12]

Relative Public Health Significance

Assessing the relative public health significance of *Cryptosporidium* is complex because of the different responses between immunocompetent and immuno-compromised individuals. Sexually transmitted diseases typically account for the highest incidence of infectious diseases followed by gastrointestinal illnesses.

Major Facts

- Several points frame the question of public health significance:

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- The prevalence of cryptosporidiosis is between 1 and 4 percent of the total population in North America.[55]

- A number of waterborne disease outbreaks have been associated with *Cryptosporidium*.[38]

- Cryptosporidiosis is usually self-limiting, except in immunocompromised individuals.[41]

- Groups at risk include:
    - Animal handlers
    - Health care workers
    - Day care center children/employees
    - Consumers of contaminated water
    - Travelers to developing countries
    - Immunodeficient and immunosuppressed persons

        - Congenital deficiency
        - Acquired deficiency
        - Immunosuppressive therapy
        - Malnourished

- Incidence of cryptosporidiosis amongst AIDS patients is not well known, but is estimated to be between 1 and 10 percent.[6,41] Of these infected patients, it is not known how many may die directly from cryptosporidiosis, but numbers as high as 20 percent have been speculated.[55]

- No therapeutic agent has been found to treat cryptosporidiosis.

- In some cases where *Cryptosporidium* has been detected, other pathogenic organisms have also been detected (e.g., *Giardia*, rotavirus).[14]

Other Infectious Organisms

Cryptosporidium is not the only organism which causes diarrheal symptoms.[5,11,14,26,36,42] Immunocompromised individuals, particularly with those with AIDS, can be infected by a variety of other diarrhea causing organisms, including:

- Cytomegalovirus
- *Mycobacterium avium*
- *Salmonella*
- *Entomoeba histolytica*
- *Giardia lamblia*
- Herpes simplex
- *Campylobacter jejuni*
- *Isopora belli*
- *Campylobacter difficile*
- *Candida*
- *Strongyloides*

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- *Enterocytozoon bieneusi*

Some of these organisms (e.g., cytomegalovirus and *Isopora belli*) have been detected concurrently with *Cryptosporidium* during bouts of infectious diarrhea.[11,26,36,42]

Summary

Cryptosporidium is one of several agents involved in infectious diarrhea and is particularly devastating for immunocompromised individuals who are unable to clear the disease. While the incidence of reported cryptosporidiosis appears to be low, this may be underestimated due to factors such as lack of reporting by doctors and lack of diagnosis. The treatment of cryptosporidiosis has been relatively unsuccessful, although there appears to be some promise in use of a hyperimmune bovine colostrum.

Water Treatment

Occurrence in Water

Cryptosporidium is shed from infected individuals in their stools. Concentrations of infective oocysts are very high in the stools with levels on the order of one million oocysts per day being estimated. *Cryptosporidium* can be transmitted directly from person to person through the fecal-oral route. *Cryptosporidium* can also find its way into the environment and, hence, into drinking water sources.

Detection

Because the conventional indicators of microbial water quality (e.g., coliforms and heterotrophic plate counts) do not necessarily correlate with the presence or concentrations of *Cryptosporidium* and because the minimum infective dose is thought to be very low, detection of low *Cryptosporidium* concentrations is necessary. To accomplish this, methods have been developed that rely on concentrating large volumes of water (i.e., 100 to 1000 gallons) into a small pellet (ASTM Method P229). The method is detailed in the proposed Information Collection Rule. The basis of the procedure is as follows:

- *Sampling* - Water is taken from the source by pumping into a filter housing containing a polypropylene yarn cartridge filter.[54] The volume of water passed through the filter is measured using a water meter.
- *Concentration* - After transport to the laboratory, the particles trapped on the filter are eluted using large volumes of detergent. The eluate is then centrifuged to concentrate and separate out particles denser than the oocysts.[48,54]
- *Identification* - Microscopic examination of the concentrated sample relies on actual measurement of size and the use of fluorescent antibody stains to identify the oocysts.[16] A distinguishing feature of *Cryptosporidium* is the fold in the oocysts.

There are several problems with current detection methods.[1,2,47,48]

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- The species of *Cryptosporidium* cannot be distinguished using conventional methods.
- Some of the antibodies used for detection may cross-react with other organisms (e.g., yeasts) so that enumeration of oocysts may include species (or other organisms) that are not infectious to humans.[14,48]
- Detection of the oocysts does not indicate whether they are viable (i.e., capable of inducing infection).
- There is no method for assessing the virulence (i.e., the severity of the disease produced) of a particular strain of *Cryptosporidium*.
- Current concentration techniques result in recoveries in the range of only 20 to 70 percent with the efficiency being a function of the water matrix.[48]
- Variations between laboratories for identical samples can be as high as 100 percent, even through improvements to standardized procedures used for the EPA's Information Collection Rule sampling, these wide variations have somewhat reduced.

Development work has been conducted on better concentration techniques (e.g., immunomagnetic separation), specific identifications with DNA probe technology (i.e., using polymerase chain reaction) , and assessment of viability (i.e., through ELISA/RT-PCR or PI/DAPI staining).

Due to the significant uncertainties in the methods, the numerical values produced are only rough estimates. This creates challenges for communicating data to the general public.

There is some indication that particle counting may be a useful surrogate for assessing efficiency of *Cryptosporidium* removal by water treatment processes.

North American Source Waters

Typical geometric average concentrations for various water types have been as follows:[48]

- Lakes - 0.44 oocysts per liter
- Rivers - 0.43 oocysts per liter
- Springs - 0.04 oocysts per liter
- Groundwater - 0.003 oocysts per liter

In North American waters, the values of *Cryptosporidium* range from 0.002 to 5,800 oocysts per liter, depending on the source. These values will vary depending on the watershed characteristics of the water source. Concentrations of *Cryptosporidium* oocysts in source water tend to be higher than *Giardia*.[2,48]

North American Treated Waters

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Cryptosporidium oocysts have been detected in treated waters in the western United States. These values tend to be low, averaging 0.001 oocysts per liter in filtered waters and 0.006 oocysts per liter in non-filtered waters. In waterborne outbreaks *Cryptosporidium* oocyst concentrations in the treated water were much higher than these values. For example, in the Carrolton, Georgia outbreak, treated water oocyst levels were 2.2 per liter. After the outbreak in Milwaukee, treated water oocysts levels reached 0.16 per liter. However, there is significant uncertainty as to how high the levels were during the outbreak.

Outbreaks have been more often associated with filtered waters than unfiltered waters, and usually with agricultural (particularly animal wastes) contamination of drinking water sources. In a filtration process, *Cryptosporidium* oocysts, *Giardia* cysts, other pathogens and debris are concentrated in the filters so that breakthrough of the accumulated material can increase the risk of *Cryptosporidium* infections.

Effectiveness of Water Treatment Processes

The two basic mechanisms for eliminating pathogenic organisms during water treatment are: chemical inactivation and physical removal. The former is accomplished through disinfection, and the latter through coagulation and filtration.

Disinfection

Chlorine is not effective for inactivating *Cryptosporidium* oocysts. It has been reported that oocysts exposed to undiluted household bleach (5% NaOCl) for several hours were still capable of inducing infection.[51] Chlorine dioxide appears to be effective, but at doses far higher than would be reasonable in water treatment, especially in light of the concern over the chlorine dioxide by-products chlorite and chlorate.[24] Ozone is effective for inactivating *Cryptosporidium* but requires Ct values 10 to 20 times greater than for *Giardia*.[22] Ultraviolet light is effective at inactivating *Cryptosporidium* though at very high doses.[32] Ct values for various disinfectants against *Cryptosporidium* and *Giardia* are presented in Table 1.[3,22,24,54] Sequential use of these disinfectants, however, results in synergestic effects.

Table 1
Comparative Ct Values for Parasites

	Ct Product	
Disinfectant	**Giardia**	**Cryptosporidium**
Chloramine	1,230	14,400
Chlorine	80	14,400
Chlorine Dioxide	15	160
Ozone	0.95	5 to 10

1. Assume 2-logs inactivation and 10°C.
2. Units in mg/l-min.

Even though ozone appears to be effective for *Cryptosporidium* inactivation, there is a major concern regarding its use. Due to its powerful oxidizing ability, it breaks down the naturally occurring organic matter in water, causing it to become a nutrient source for bacteria. It is possible, then, that the use of ozone, while inactivating *Cryptosporidium*, could stimulate the growth of bacteria in the distribution system. Some of these bacteria may cause disease, particularly in immunocompromised individuals.

Filtration

Removal of *Cryptosporidium* by filtration is approximately 99 percent or 2 logs of reduction. Although levels as high as 99.9 percent or 3 logs of reduction have been reported. At times oocysts can be detected in filtered water; their breakthrough can be attributed to a variety of factors, including:

- Increases in source water concentrations of *Cryptosporidium*.
- Recycling filter washwater in the plant enabling concentrated slugs of *Cryptosporidium* to pass through the filters.
- Operational factors such as improper filter washing, rapid flow changes, improper coagulation, etc.

Most waterborne *Cryptosporidium* outbreaks have been associated with operational problems rather than inherent treatment deficiencies.

Regulatory Stance

The regulatory stance varies considerably. The activities of the United Kingdom Drinking Water Inspectorate, the United States Environmental Protection Agency, the California Department of Health Services, and Canadian Authorities are summarized below.

United Kingdom

Regulatory authorities in the United Kingdom have the most extensive experience with the issue because of the number of outbreaks experienced. Their stance on *Cryptosporidium* is summarized in two major documents: The Badenoch Report entitled "*Cryptosporidium in Water Supplies*" (July 1990) and the Drinking Water Inspectorate's report "*Cryptosporidium in Water Supplies: Progress With the National Research Program*" (July 1992). The basic recommendation of these reports is that water treatment plants need to optimize their practices with respect to coagulation, filtration, and recycling of filter washwater.[8] The Drinking Water Inspectorate is leading an aggressive research program to address the major research needs.

EPA

Cryptosporidium was not regulated under the 1989 Surface Water Treatment Rule due to the uncertainties surrounding *Cryptosporidium* (i.e., virulence, infective dose, inactivation, etc.). Source monitoring for *Cryptosporidium* will be required sometime in 1996 under the Information Collection Rule (ICR). Methodological difficulties with the detection method have slowed down promulgation of the ICR though monitoring finally

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began in 1997. The proposed interim Enhanced Surface Water Treatment Rule (ESWTR) [19] is in its final stages of revision pending comments to the Notice of Data Availability (November 4, 1997). Some significant items noted in the draft ESWTR Preamble (dated January 26, 1994) are:

- Differing pathogen densities in different waters accounts for the drive to develop site-specific treatment requirements.
- In light of current and anticipated research EPA senses that they will "soon be in better position to develop a suitable regulation for *Cryptosporidium*".
- There appears to be some conferred immunity associated with exposure to *Cryptosporidium*. A 2-log treatment requirement has been proposed as an option for sources with less than 1 oocyst per 100 liters, though there are other proposals.
- EPA recognizes that "unfiltered systems would appear to be particularly vulnerable...However, to date, filtered water supplies have been implicated in all identified waterborne *Cryptosporidium* outbreaks...(filtered) surface water may be more vulnerable to *Cryptosporidium* than unfiltered supplies with disinfection, depending on the quality of the source water..."

Great uncertainty still remains as EPA approaches a regulation. Consequently, they are soliciting input into the structuring of the long-term ESWTR. A major emphasis for unfiltered systems will be on watershed controls.

In the 1996 Amendments to the Safe Drinking Water Act, a special section detailed the conditions for a limited alternative to filtration. The text says:

> "...a State exercising primary enforcement responsibility for public water systems may, on a case-by-case basis, and after notice and opportunity for public comment, establish treatment requirements as an alternative to filtration in the case of systems having uninhabited, undeveloped watersheds in consolidated ownership, and having control over access to, and activities in, those watersheds, if the State determines (and the Administrator concurs) that the quality of the source water and the alternative treatment requirements established by the State ensure greater removal or inactivation efficiencies of pathogenic organisms for which national primary drinking water regulations have been promulgated or that are of public health concern than would be achieved by the combination of filtration and chlorine disinfection..."

California Department of Health Services (DHS)

DHS is concerned over the status of unfiltered supplies in the state. While anticipating that *Cryptosporidium* will need to be regulated in the near future, DHS will await for EPA's action. In the interim, DHS has issued a *Cryptosporidium* Action Plan which places heavy emphasis on treatment optimization.

Centers for Disease Control and Prevention (CDC)

In September 1994, CDC convened a meeting to address concerns over waterborne cryptosporidiosis involving representatives from regulatory and public health agencies, water utilities, and advocacy groups. The focus of the workshop was to avoid unnecessary alarm (i.e., premature or unwarranted boil water advisories) and preventing waterborne outbreaks. Four workgroups addressed the special topics: surveillance systems and epidemiological study designs, public health responses, immunocompromised persons, and water sampling methods and interpretation of results. A document published in 1995[10] noted that there was significant uncertainty regarding waterborne cryptosporidiosis and as such recommended increased surveillance and epidemiological investigations, methods development for *Cryptosporidium* detection in drinking water, and development of task forces for providing information to the immunocompromised as well as regional population.

Canadian Authorities

There are no current regulations for *Cryptosporidium* or *Giardia,* though *Giardia* has been identified as a public health concern. The only regulatory guidance on microbial water quality is for coliform levels in the distribution system. There are no current plans to regulate *Cryptosporidium*.

Summary

Of all the regulatory agencies contacted, EPA appears to be the most aggressive in pursuing a *Cryptosporidium* regulation, but is hampered by poor analytical methods. In the wake of the Las Vegas and Milwaukee outbreaks, EPA is continuing its efforts. Other organizations, due to the meagerness of available information, have decided not to regulate *Cryptosporidium* at this time.

Current Activities of the Water Industry

A number of water agencies in North America and Europe were contacted to determine their activities with respect to *Cryptosporidium*. There appears to be much interest in assessing *Cryptosporidium* levels and optimizing treatment practices to minimize its passage into the water supply.[2,3,43,45] Activities include:

- Monitoring of source and treated waters for *Cryptosporidium*,
- Optimizing coagulation practices,
- Monitoring turbidity of individual filter cells,
- Backwashing filters prior to restarting,
- Evaluating filter washwater treatment (i.e., clarification and/or disinfection),
- Setting limits for turbidity spikes occurring after filter restarts (i.e., ripening period),
- Controlling filters in a manner to avoid sudden flow changes,
- Optimizing disinfection, and
- Watershed management.

For unfiltered sources there has been a strong emphasis on watershed management,[45]

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though some (e.g., New York City and Boston) are receiving pressure to filter.[40,57] Interestingly, few recommendations have been made by the medical community for immunocompromised individuals to seek alternative water sources,[41] even in Milwaukee.[49,50]

Location:
http://sfwater.org/detail.cfm/MC_ID/10/MSC_ID/51/MTO_ID/71/C_ID/446

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SAN FRANCISCO Public Utilities Commission

Cryptosporidium (part 2 of 2)

In 1997, the SFPUC staff were part of a nationwide effort coordinated by the American Water Works Association Research Foundation (AWWARF) entitled Critical Evaluations of *Cryptosporidium* Research and Research needs. The document outlines a long-term research strategy for the water industry.

Individual agency activities as of December 1992 are summarized in Appendix A. References to *Cryptosporidium* concentrations are difficult to interpret due to differences in method and sample volume.

San Francisco Public Utilities Commission (SFPUC) Activities

The SFPUC has been aggressively pursuing the issue of *Cryptosporidium* in the following manner:

- Monitoring - Preliminary monitoring for *Giardia* and *Cryptosporidium* was conducted in 1990. This has been followed by an intensive 12-month monitoring program for all sources, both treatment plants, and two distribution system reservoirs. The program has been completed, although some monitoring continues.

- Consultations - A number of meetings have taken place with DHS staff regarding *Cryptosporidium*. In July 1992, the SFPUC met with health officials from the four Bay Area counties served by the SFPUC to discuss the significance of waterborne *Cryptosporidium*. In November 1992, SFPUC staff met with four water utilities to discuss their respective programs on *Cryptosporidium* (Appendix B). In January 1993, the SFPUC convened a workshop with regulatory authorities (i.e., DHS and EPA), public health officials, researchers and medical experts to discuss the incidence of cryptosporidiosis, its relative public health significance, current research, and potential studies to address the major uncertainties (Appendix C). A Bay Area workshop was held in June 1995 to evaluate a disease surveillance program and to discuss risk communication issues (Appendix D). The SFPUC conducted stakeholder interviews to assess public concern and attitudes towards costs of various treatment alternatives in 1995. Findings of these interviews indicated a low public awareness of *Cryptosporidium*, though high concern among water treatment and public health professionals. In addition, San Francisco supervisor Carole Migden formed a 17 member multi-disciplinary *Cryptosporidium* task force for the purpose of developing guidelines for public notification of immunocompromised individuals and the general public. Due to a concurrent risk communication effort by a consortium of water utilities and DHS, this committee never completed its work. In late-1996, the SFPUC began regular strategy sessions with the major unfiltered sources in the U.S. (i.e., Boston, New York City,

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Portland, Tacoma and Seattle).

- Treatment - The SFPUC is performing an evaluation of its filtration practices at the Harry Tracy and Sunol Water Treatment Plants to optimize particulate removal. Pilot studies at Hetch Hetchy evaluated optimization techniques for *Cryptosporidium* removal. Disinfection studies were performed at the University of Arizona evaluating the influence of existing physical and treatment conditions in the SFPUC Hetch Hetchy water delivery and treatment system on *Cryptosporidium*. These included pH changes (SFPUC water is increased from 7 to 10), pressure drops (there are two major powerhouses on the Hetch Hetchy Aqueduct that may rupture the oocysts), and sequential addition of disinfectants. These studies indicated that *Cryptosporidium* inactivation is currently negligible, but that sequentially adding chlorine followed by chloramine is capable of providing modest inactivation of *Cryptosporidium*. SFPUC testing showed up to 1 log (or 90 percent) *Cryptosporidium* inactivation was possible. The required ozone dose for inactivating *Cryptosporidium* in Hetch Hetchy has been determined to require a much longer reaction time than is conventionally used for ozonation. The risks of stimulating growth of opportunistic bacteria in consumer plumbing remains a concern with this option.

- *Watershed Protection* - In 1997, the SFPUC engaged in an intensive public process to modify grazing practices in the Alameda watersheds to limit microbial risks. A series of best management practices have now been adopted.

San Francisco Source and Treated Waters

The SFPUC has been intensively monitoring all three of its sources for *Cryptosporidium* and *Giardia* since January 1993. *Giardia* and *Cryptosporidium* have been detected in a few samples.

For monitoring, two methods have been used at different times. From January 1993 through October 1994, proposed Standard Method 9711B (without differential interferences contrast microscopy) was used. Since November 1994, the ICR method has been used. Using proposed Method 9711B, *Cryptosporidium* levels detected ranged from less than 0.1 to 0.8 oocysts per 100 liters in Hetch Hetchy water. *Cryptosporidium* was typically detected in approximately 30 percent of the samples collected.

With the ICR method, presumptive *Cryptosporidium* levels in Hetch Hetchy water ranged from 0.4 to 7 oocysts per 100 liters, approximately an order of magnitude greater than results obtained using proposed Method 9711B. Oocysts continued to be detected in about 30 percent of samples even though the median detection limit increased from 0.1 to 1 oocyst per 100 liters with the method change. The difference in results appears to be related to method changes rather than environmental changes (i.e., increased watershed contamination). See Appendix E for further discussion on method differences.

Cryptosporidium oocysts were also detected in some samples from San Antonio, Calaveras, and San Andreas Reservoirs (all of which are filtered) and in some finished waters. Three points should be noted. First, detection of oocysts in the treated water does not provide information about viability. There is a high likelihood that oocysts detected in finished waters are not viable.[53] Second, due to the small number of samples it is not clear whether these were unusual occurrences (the largest fraction of positive samples were performed by a different lab and collected by different personnel two years ago when methods were less rigorously defined). Third, it is not unusual to detect oocysts in the treated water.[2] In any case, the implication is clear: efforts should continue to focus on watershed management and treatment process optimization. These results are summarized in Table 2. The distribution of concentrations in Hetch Hetchy water is presented in Figure 3. Figure 4 shows that, despite a summertime increase in the number of positive samples, oocyst concentrations remain low year round. Appendix F contains a summary of *Cryptosporidium* and *Giardia* concentration seasonal trends for all of SFPUC source waters.

Infectious Diseases Reported in San Francisco Area

Data from the San Francisco Public Health Department (see Figure 5) indicates that over the past 7 years the incidence of reported cryptosporidiosis cases has ranged from 38 in 1989 (when monitoring began) to 144 in 1991 corresponding to a risk of 1 in 5,000. This compares with roughly 400 giardiasis cases, 200 salmonella cases, 300 shigella cases, and 700 campylobacter cases (all of which are treatable). Most of the San Francisco *Cryptosporidium* cases are attributed to AIDS patients and are not thought to be water related. The county environmental health officers of Alameda, San Francisco, San Mateo, and Santa Clara believe that cryptosporidiosis from drinking water is not a major concern.

A preliminary epidemiological assessment was conducted by the Community Disease Control Program of the City and County of San Francisco. Five hundred and thirty three (533) cryptosporidiosis cases were segregated according to areas served by filtered and unfiltered water. The incidence of cryptosporidiosis was four times higher in the filtered area than in the unfiltered area. Even though this study was biased towards males and patients with AIDS, it did not uncover an association between unfiltered Hetch Hetchy water and cryptosporidiosis. Further work would need to be done to assess the importance of unfiltered Hetch Hetchy water. The indications from this preliminary study, however, is that there is no "smoking gun" pointing to unfiltered Hetch Hetchy water.

Table 2
Summary of SFPUC Parasite Monitoring Results
1993-1996

		Giardia			Cryptosporidium		
Location	**Year**	**% Positive**	**Avg. Concentration (Per 100 L)**	**Avg. Detection Limit (Per 100 L)**	**% Positive**	**Avg. Concentration (Per 100 L)**	**Avg. Detection Limit (Per 100 L)**
Hetch Hetchy	1993	17	0.3	0.15	35	0.2	0.15
	1994	30	1.8	0.7	26	1.1	0.7
	1995	35	2.2	1.2	24	1.5	1.2
	1996	34	1.7	1.1	12	1.2	1.1

	Overall	30	1.7	0.8	24	1	0.8
Calaveras	1993	8	0.4	0.3	19	0.2	0.3
	1994	31	2.2	0.2	38	1.7	0.2
	1995	14	17.5	4.3	21	10.5	11.9
	1996	8	3.0	3.5	0	--	3.4
	Overall	14	5.3	1.7	20	3.2	3.5
San Antonio	1993	19	0.6	0.3	12	0.5	0.3
	1994	14	0.5	1.2	29	0.4	1.4
	1995	12	5.5	4.1	6	2.0	4.2
	1996	9	1.0	4.3	9	2.0	4.3
	Overall	15	1.6	2.1	13	0.8	2.2
San Andreas	1993	27	0.9	0.3	4	0.3	0.3
	1994	31	0.6	1.3	31	0.3	1.3
	1995	33	1.7	1.9	29	2.1	2.3
	1996	0	--	3.4	0	--	3.4
	Overall	25	1.1	1.5	15	1.2	1.5
University Mound Reservoir (Treated Water)	1993	0	--	0.2	0	--	0.2
	1994	0	--	0.4	17	0.3	0.4
	1995	17	1.6	1.8	0	--	1.7
	1996	17	2.4	1.0	0	--	1.2
	Overall	8	2.0	0.8	4	0.3	0.9
College Hill Reservoir (Treated Water)	1993	0	--	0.3	0	--	0.3
	1994	0	--	0.3	0	--	0.3
	1995	0	--	1.0	17	1.9	1.0
	1996	0	--	1.0	0	--	1.0
	Overall	0	--	0.6	4	1.9	0.6

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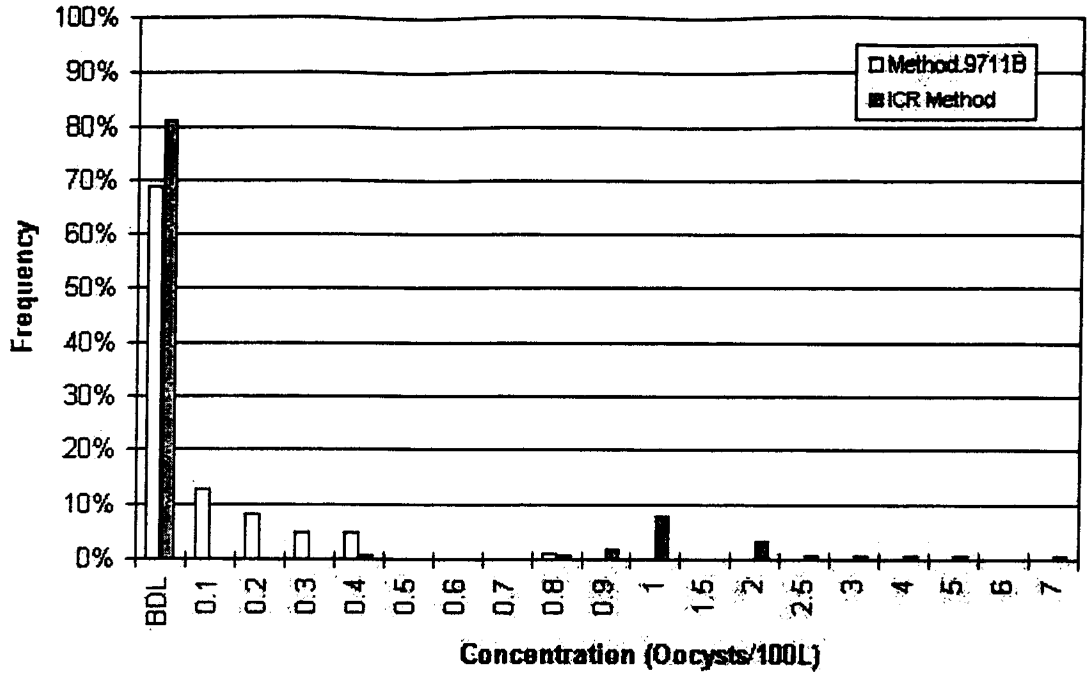

Figure 3
Distribution of *Cryptosporidium* in Hetch Hetchy Water

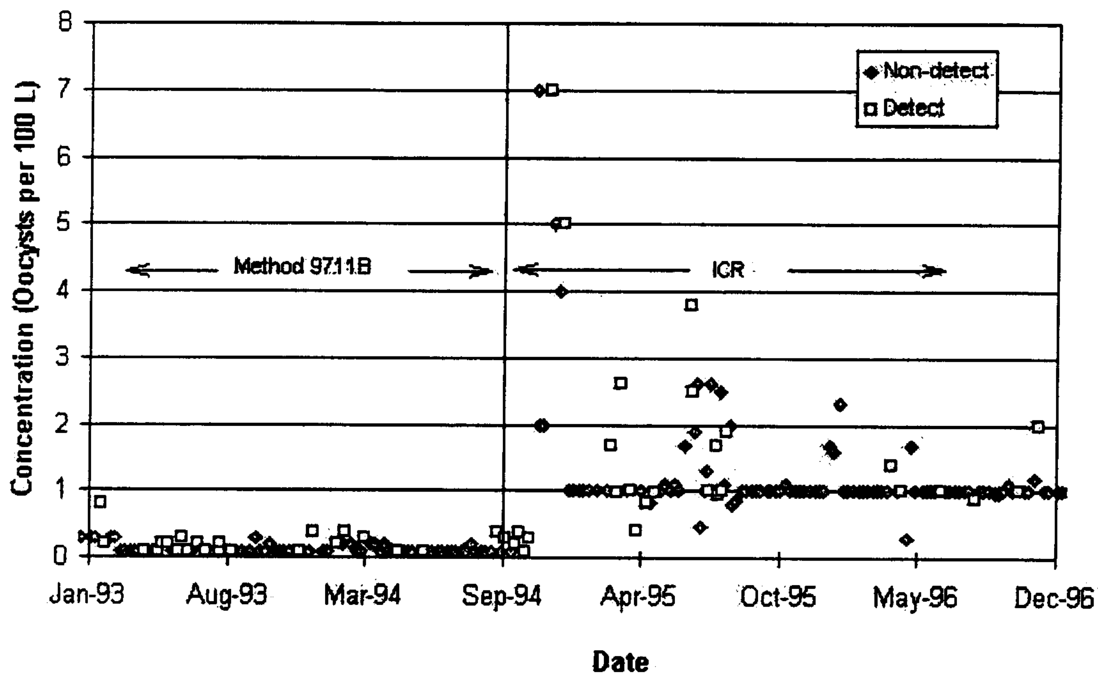

Figure 4
***Cryptosporidium* Levels In Hetch Hetchy Water**
(Presumptive Results)

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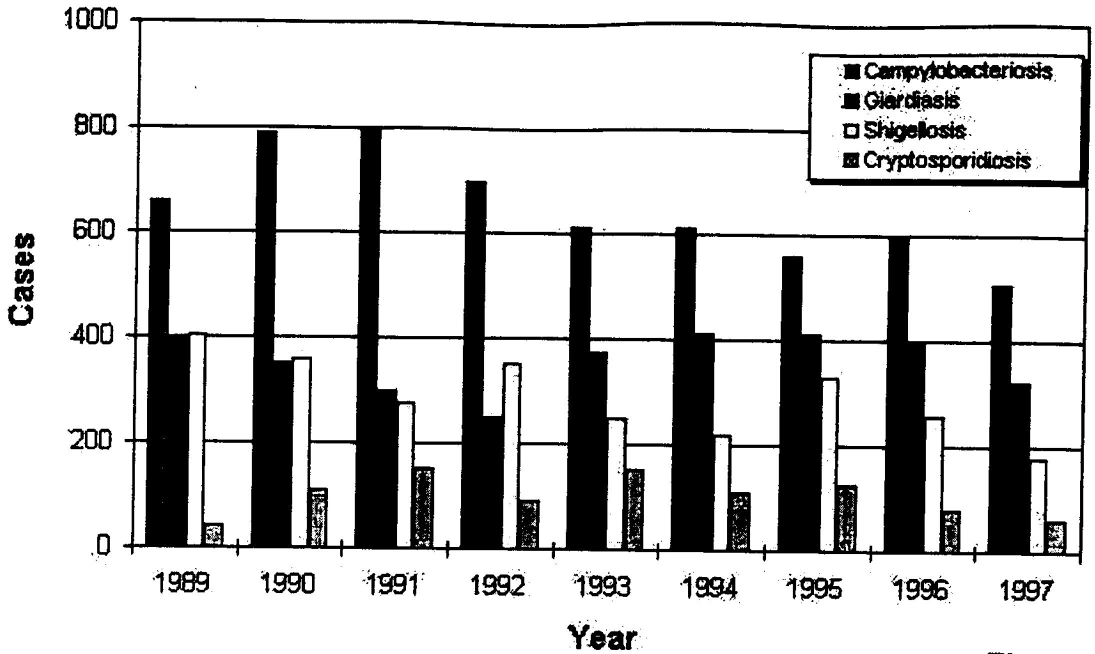

Figure 5
Infectious Disease in San Francisco

Research Needs

There are many unanswered questions concerning *Cryptosporidium* in potable waters that require investigation. The following are important to San Francisco:

- *Viability Assessment* - Some techniques have been developed in Scotland that allow viability assessment of detected oocysts. This technique is undergoing refinement[9,31] and should be used by San Francisco for assessing *Cryptosporidium* viability when it is detected in its source water.

- *Method Consistency* - Methods for detecting *Cryptosporidium* in source waters are highly variable and results are not readily reproduced within the same lab or between different laboratories (see Appendix E). Developing new methods that enable more consistent and sensitive results is needed.

- *Method Specificity* - Current detection methods fail to distinguish between species thought to be responsible for human disease and those that are thought not to cause disease in humans. Method development is needed to allow that differentiation.

- *Infective Dose* - While there is some indication that the infective dose for cryptosporidiosis is very low, it is not known whether different species of *Cryptosporidium* have different infectivity (though it seems likely). No information is available on the infectious dose for an immunocompetent person compared to an immunocompromised person. However, several ongoing studies may shed light on these questions. Feeding studies in Scotland with infection-free lambs suggest that doses as low as 5 oocysts per liter can cause 100 percent infection. A primate study in Kenya will soon be finalized. Initial results have been ambiguous since low oocyst doses induced disease in some primates while higher doses failed to produce any illness in other primates (maybe due to acquired immunity). A human feeding study in Texas evaluating the infectivity of various *Cryptosporidium* oocyst doses found 20 percent of the subjects were infected at the lowest dose (30 oocysts). A joint University of California at Davis and University of California at San Francisco study will evaluate the infective oocyst dose for immunocompromised primates to provide information on the minimum infective dose for immunocompromised populations.

- *Relative Exposure* - It is unclear how much of the cryptosporidiosis risk can be attributed to drinking water. Work is vitally needed that distinguishes the water contribution to cryptosporidiosis from other sources. This will enable better risk management and more efficient resource allocation.

- *Communication of Uncertainty* - Issues associated with detection, species differentiation, viability, infectivity, host susceptibility, compel the uncertainty associated with cryptosporidiosis risk in drinking water. Better methods are needed for quantitatively characterizing this uncertainty and communicating it in a manner that is comprehensible to the public and aids them in making their own personal risk management decisions.

- *Chemical Inactivation* - Further work needs to be done to evaluate the impacts of chlorine on environmentally-stressed oocysts which may be more susceptible to chlorine inactivation than fresh oocysts. The impact of sequencing disinfectants (e.g., chlorine followed by chloramine) needs to be evaluated further so as to refine the available alternatives for the SFPUC with regards to disinfection by-products.

- *Filtration* - While some preliminary work has been conducted on the removal of *Cryptosporidium* in water treatment processes, more is needed on the influence of filter media and filtration rates. An assessment of the importance of increased parasite loading during the backwash water operations such as recycling, and flow rate changes needs to be made. Work on *Cryptosporidium* removal is being completed under the auspices of AWWARF and by the British Drinking Water Inspectorate.

Current Action Plan

The SFPUC action plan is focused on providing information that will aid in the assessment and control of the risks associated with *Cryptosporidium*.

- *Monitoring* - SFPUC will continue its monitoring program for its major sources and start to monitor treated water samples in addition to the existing distribution system locations. The sample volumes have been increased to lower the detection limits.

- *Treatment Process Evaluation* - The two SFPUC filtration plants already conform to the recommendations of the Badenoch report and the Surface Water Treatment Rule. Nevertheless, an evaluation of operating practices (e.g., increasing plant

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flows, treating high turbidity water, washwater handling, etc.) is planned to determine how plant operations can adapt to adverse conditions and protect against parasite breakthrough. Major upgrades are under design at our Sunol Valley Water Treatment Plant.

- *Watershed Sanitary Survey* - A comprehensive watershed survey has been conducted which (1) identifies the origin of the *Cryptosporidium* oocysts (i.e., sampling major tributaries into reservoirs, camping areas, septic tanks, stables, etc.), (2) evaluates the transport and fate of the oocysts, and (3) determines the degree to which the oocyst sources can be controlled. The recommendations for watershed management are under development.

- *Risk Communication* - The SFPUC is developing an education plan for presenting information on risks and mitigative measures to sensitive populations.

These four activities are planned for completion by the end of 1998.

Possible Future Studies

In addition to the studies currently being conducted by the SFPUC, the following studies will also be valuable:

- *Exposure Assessment* - If a current seroprevalency research project examining the contributions of water to the degree of exposure of a population proves successful, it would be advisable for San Francisco to conduct similar studies to ascertain the contribution of exposure unfiltered water presents to the various affected populations. This may be the key piece of data needed to determine the relative significance of water in cryptosporidiosis cases.

- *Improved Sample Method Development* - In light of the importance of *Cryptosporidium* and the SFPUC's current unfiltered status, it may be prudent to join in efforts to further development of *Cryptosporidium* detection methods.

- *Assess Willingness to Pay* - Since some populations are more impacted than others, it may aid policymakers to quantify the amount various individuals are willing to pay for different treatment improvements (e.g., ozonation, filtration, and point of use devices). Such determinations need to use the rigorous methods developed in survey research.

- *Molecular Epidemiological Studies* - Using recently developed methods, it should be possible to type and subtype *Cryptosporidium parvum* isolates. This will allow matching of the organism shed by the infected person and the source of the organism. To address the waterborne route, SFPUC needs to start collecting and storing water samples until a case of cryptosporidiosis is reported. Once the organism from the infected person is isolated and typed, an attempt could be made to match this to an organism found in the stored water samples. If a positive match is made, this would implicate the water route. If the organism matched that from a pet, a member of a family, etc., then these would be the suspected routes of infection. Such a study would provide definitive answers to whether there is a link between the drinking water and cryptosporidiosis.

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