CRYPTOSPORIDIUM: A Drinking Water Supply Concern

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ABSTRACT

This document is a review of the literature concerning the protozoan Cryptosporidium. Several waterborne outbreaks of Cryptosporidiosis have occurred over the past ten years in the United States and a great deal of concern has been raised about this organism and drinking water supplies. Sections of the document cover the background, organism, occurrence in water, regulation and research needs of Cryptosporidium.

Current information on Cryptosporidium indicates we have only a limited knowledge of this organism. The parasite is very small (2 to 6 μm) and is found in all types of surface water throughout the world. Cryptosporidium shares some of the same characteristics a Giardia, but inactivation and removal appear to be much more difficult to achieve for Cryptosporidium.

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I. BACKGROUND

A. Introduction

Cryptosporidiosis had been recognized as a disease in humans for only five years when a major waterborne outbreak occurred in the United States. The pathogen, Cryptosporidium, is now known to be transmitted through water (Rose, 1990). This document examines the nature of the Cryptosporidium organism, its occurrence in the environment and regulations to protect humans against infection by it. Methods now need to be developed to prevent future waterborne outbreaks of this pathogen.

B. Recent Attention

Cryptosporidium came to national attention this year in Milwaukee, Wisconsin. This tiny protozoan has been found to be a causative agent for gastrointestinal disease in humans and sickened 400,000 people in Milwaukee during April, 1993 (Personal Communication, Lisa Almodovar, Environmental Scientist, U.S. Environmental Protection Agency, Washington, D.C., October, 1993). The protozoan was traced to a water filtration plant that served a portion of Milwaukee with drinking water. An investigation found there was a strong likelihood the organism passed through the filtration process and entered the water supply distribution system (Fox, 1993). The actual origin of this organism has been speculated to have come from animal operations located in the tributaries of Milwaukee River. These tributaries drain directly into Lake Michigan, just north of where the water intake is located (Personal Communication, Joan B. Rose, Assistant Professor, Department of Environmental and Occupational Health, University of South Florida, April, 1993).

C. Past Outbreaks

This has not been the first waterborne municipal outbreak of Cryptosporidium in the United States. There were well documented outbreaks in Braun Station, Texas (1984), Carrollton, Georgia (1987), and Medford/Talent,

Oregon (1991-92). However, it must be noted that this organism was not known to cause human illness until 1976 and there may be earlier waterborne outbreaks that could be associated with Crytosporidium (Juranek, 1993). In the Texas case, approximately 34 percent of the 5,900 exposed population was affected. The probable cause was felt to be sewage contamination due to the presence of a second pathogen in the water supply. The second waterborne outbreak in Georgia affected 40 percent of the 32,400 exposed population and was considered to be related to problems with the water purification process (Rose, 1990). In the final case of Oregon, 43 cases of cryptosporidiosis were associated with a water system serving 3,000 people. Operational and mechanical problems were found in one of the town's water filtration plants and appeared to be linked with the outbreak of Cryptosporidium (Leland et al., 1993).

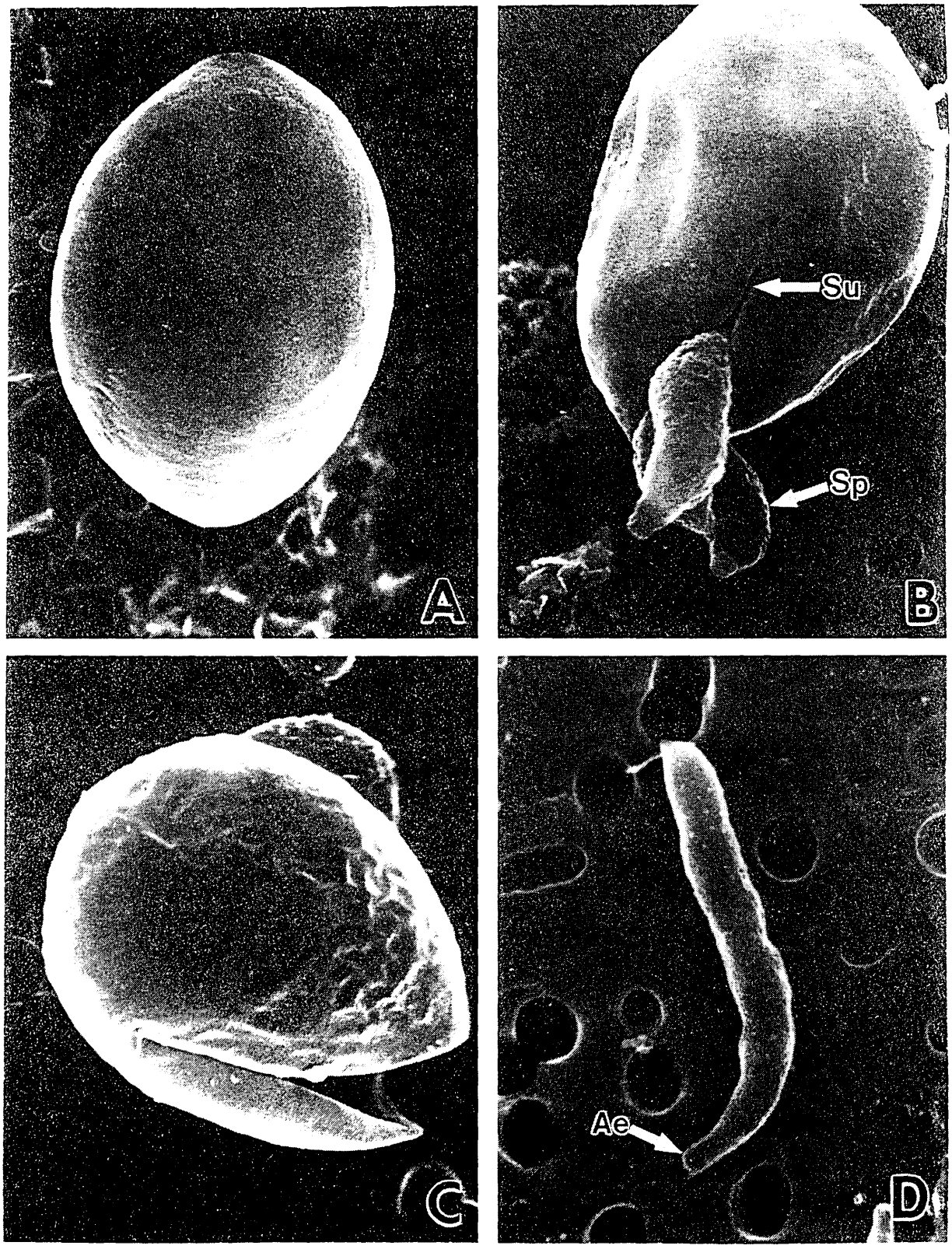
D. Characteristics

The genus Cryptosporidium, Greek for hidden spore, are small 2 to 6 μm protozoan parasites. Figure 1 shows microscopic close-ups of the oocyst and sporozoites of Cryptosporidium parvum. From 1955 until 1976 these organisms were thought only to be a pathogen of animals, particularly farm livestock. However, since 1976 human infection has been documented in over 30 countries in 6 continents (Soave, 1989). After the host is infected, oocysts are usually formed and released from the gastrointestinal walls and shed in large numbers with the feces. These oocysts are very resistant to environmental elements and the disease spreads by animal to human, person to person, and environmental (water and food) transmission. Water appears to be one important medium in transmitting the disease from animal to human hosts (Casemore, 1989).

Cryptosporidiosis in humans is characterized by nausea, diarrhea, abdominal pain, low grade fever, and weight loss. In a healthy human adult the symptoms usually only last for 10 to 14 days, and the disease will subside on its own. However, if the immune system is suppressed - - as in the case of AIDS, cancer

Figure 1. *Cryptosporidium parvum*

A. Intact oocyst
B. Three sporozoites emerging from oocyst
C. Empty oocyst
D. Sporozoite (enlarged 16,000 times)



Source: Fayer, et al., 1990

treatment, or organ-transplant patients - - the disease can be life-threating. There is currently no known drug for the effective treatment of cryptosporidiosis (Juranek, 1993).

E. Species affected

Cryptosporidium has been identified in many animals including fish, reptiles, birds, and mammals. This parasite is very common in calves. The disease ranges from 10 to 80% in young calves with diarrhea. Even healthy cattle have been found to be infected with this parasite (Chermette and Boufassa-Ouzrout, 1988).

World-wide distribution of Cryptosporidium is evident by the number of species affected and the number of cases reported from different countries. Based on a review by Chermette and Boufassa-Ouzrout (1988), the number of affected animal species totaled 47. The species most often reported infected was cattle, closely followed by humans. Only one report of Cryptosporidium was documented for buffalo, mouflon (wild sheep), raccoon, mouse, squirrel, chinchilla, lemur, peacock, goose, lizard, chameleon, tortoise, and two fish genera (Naso, and Cichlidae).

Cross transmission of this parasite occurs for a wide range of animal species. The 1988 review by Chermette and Boufassa-Ouzrout, based on experimental results, found cattle to transmit Cryptosporidium to 10 other species, man to 8 species, goat and chicken to 3 species, and cervidae (deer), guinea-pig, and horse to 1 species.

II. ORGANISM

A. Taxonomy

Cryptosporidium is classified as part of the Apicomplexa Phylum and in the Cryptosporidiidae Family. The genera in this phylum are classified together

because as part or all of their life cycle they develop in the digestive tract of vertebrates and are referred to as coccidia. Species have been named for the host where the organism was first found. There are 21 species of this parasite but only 6 are considered valid species based on recent reviews and cross transmission studies. This genus was first described by Ernest E. Tyzzer in 1907. He found this parasite in the gastric gland of laboratory mice and also described the transmission of the disease. Cryptosporidium parvum appears to be one of the few species that is infectious for all species of mammals including humans (Fayer et al., 1990).

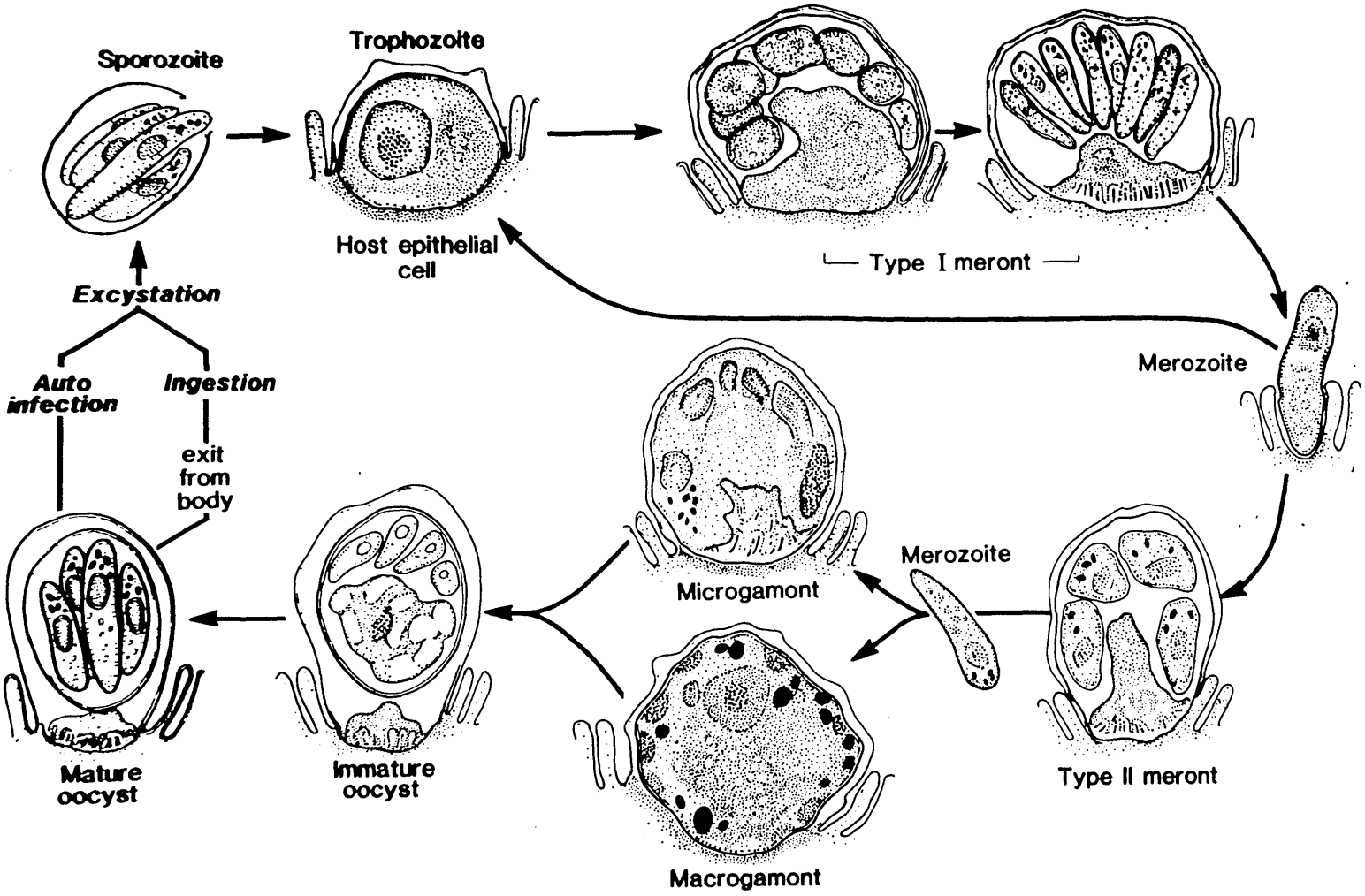
B. Life cycle

The life cycle of Cryptosporidium in mammals begins with the infectious stage when the oocyst is ingested or inhaled from such sources as food, water, or the general environment. After release of the infective sporozoites (excystation), four sporozoites (per oocyst) infect the walls of the gastrointestinal tract. Sporozoites change into trophozoite and through asexual multiplication (Type I meront) form merozoites. The merozoites infect the host cells and some (Type II meront) produce micro and macrogametocytes. These gametocytes undergo sexual reproduction and become oocysts to complete the life cycle. Most oocysts leave the body from the gastrointestinal tract by being excreted with the feces or from the respiratory tract by being carried out with respiratory or nasal secretions. Oocyst shedding in humans occurs from 5 to 28 days from the time of ingestion (Current, 1989 and Fayer et al., 1990). Figure 2 shows the life cycle of Cryptosporidium.

C. Viability

The oocyst of Cryptosporidium have been found to be very resistant to environmental elements. Oocysts have been found viable after 2 to 6 months at temperatures of 4°C or storage in potassium dichromate solution for 120 days. However, temperatures of 65°C for 30 minutes or −18°C for 24 hours will render

Figure 2. Life Cycle of Cryptosporidium



Source: Fayer, et al., 1990

them non-viable. Most disinfectants currently used have very little effect on this parasite during a short exposure period. The most effective disinfectants include formaldehyde, cresylic acid, hydrogen peroxide, chlorine dioxide, ammonia, and ozone (Chermette and Boufassa-Ouzrout, 1988, Fayer et al., 1990, and Rose, 1990).

D. Infective dose

The actual infective dose of Cryptosporidium is not known for humans but appears to be a low number of oocysts. In a study of mice inoculated with the parasite, only 100 were needed to become infective. Further investigations determined that exposure to 10 oocysts produced the disease in primates. One other test involving lambs found that 5 oocysts caused 100% infection. The number of oocysts that it takes for an individual to become infected varies with factors such as host age, immune status, and oocyst vigor (Rose, 1988 and Drinking Water Inspectorate, 1992).

III. Occurrence in Water

A. Detection methods

Cryptosporidium is detected in a similar fashion as Giardia. Giardia is a larger (8 to 10 μm) protozoan parasite that can be transmitted through water and also produces an environmentally stable cyst that can be resistant to the water treatment process (Rose, 1990). The detection process includes concentration, extraction, purification, detection, identification and quantification. Currently, there are only 5 laboratories in the United States certified to test for Cryptosporidium (Miller, 1993). Large volumes (100 to 1000 gallons) of water are filtered through spun polypropylene cartridge filters. The filter length is typically 10-inches with a pore size of 1-μm and is connected to an on-line flow meter. Flow rates range from 5 to 11 gallons per minute (gpm) for raw water and from 10 to 20 gpm for finished water. Filters are shipped to the laboratory on ice or

treated with formalin before transport. Sediment from the filter is extracted by back-flushing and further rinsing after the filter has been cut in half. Particles captured in the filter are concentrated and purified by centrifuge or density gradients. Samples are stored in a solution of 10% formalin at 40°C until microscopic examination. Detection, identification and quantification of the cysts are conducted microscopically. There are recovery problems associated with the concentration and gradient methods. DiGiano et al. (1991) found recovery efficiency to be 37.6% for C. parvum in a study of selected utilities in North Carolina. Generally, efficiency ranges from 9 to 59% and underestimates the actual level of contamination. Modification to the centrifuge and density gradient methods have been developed to better concentrate the sample but the major focus has been on the development of new detection methods (Rose, 1986; Fayer et al., 1990 and Benton et al., 1991).

Detection is most commonly conducted by microscopic examination of the concentrated sample using indirect immunofluorescent techniques but this method is slow (1 to 1.5 hours per sample) and very tedious. There are six other techniques that are being explored, including florescent staining with a cool slow-scan charge coupled device (CCD), immunogold label, flow cytometer, particle counter, dielectrophoresis (migration to an electrode), and gene probe. All of these new approaches are experimental and progress is being made in the performance and speed of existing methods (Benton et al., 1991 and Drinking Water Inspectorate, 1992).

B. Distribution in water

Oocysts of Cryptosporidium enter the environment through infected human and animal feces. Methods for detection of this parasite in water was first developed in 1985 and only a limited number of studies have been conducted over this short time period. The average number of oocysts have been reported to range from 4 to 1297 oocysts/ℓ in treated wastewater and 4 to 5180/ℓ in raw

wastewater. Reservoir and lake average oocyst numbers range from 0.58 to 0.91/ℓ, while river and stream average oocyst numbers range from 0.94 to 1.30/ℓ (Rose, 1990). Pristine rivers have average oocyst numbers ranging from 0.02 to 0.08/ℓ and drinking water has oocyst numbers ranging from 0.001 to 0.006/ℓ (Rose, 1990 and Fayer et al., 1990). The results of sampling for Cryptosporidium appear to indicate that the conventional (four stage) drinking water treatment process removes most (approximately 99%) of the oocysts. Figure 3 shows the average number of Cryptosporidium oocysts found in different water bodies.

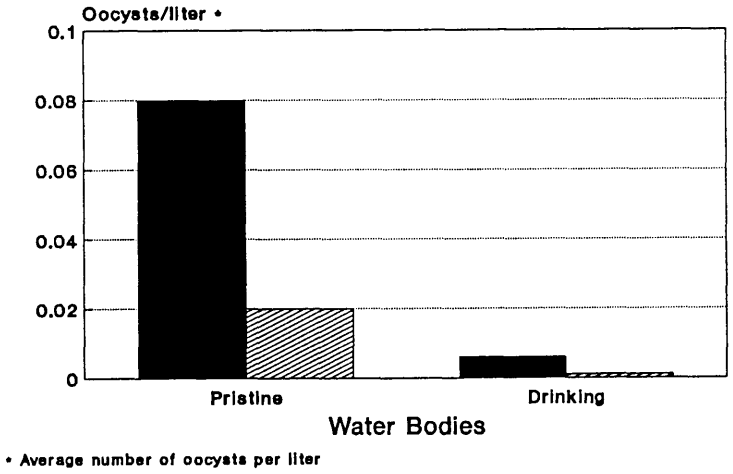
A study of six utilities in North Carolina found that C. parvum was not detected in finished water samples taken both in the spring and summer. However, C. parvum was detected in the raw water samples from three utilities. Cryptosporidium concentrations ranged from 0 to 0.92 oocysts/ℓ and fell well within the range of oocysts present in reservoirs and lakes as seen in Figure 3. Statistical analyses of protozoan, bacterial and turbidity water quality parameters found no significant positive association (DiGiano et al., 1991).

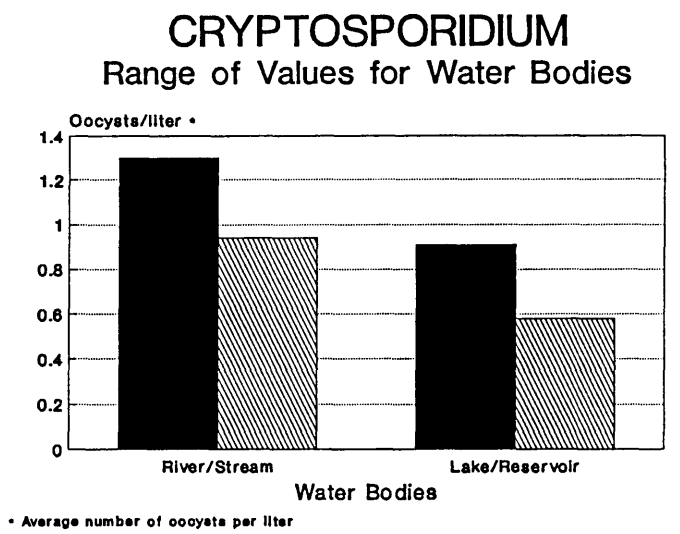
There have been reports of strong correlation between Giardia cysts and Cryptosporidium oocysts during peaks of contamination. Recent findings of LeChevallier and Norton (1992) from three water utilities found the highest correlation coefficient (0.683) was between Giardia and total coliform. All correlation coefficients for Cryptosporidium and six common water quality parameters were less than those of Giardia. As in the case of Giardia, the highest correlation was between Cryptosporidium and total coliform.

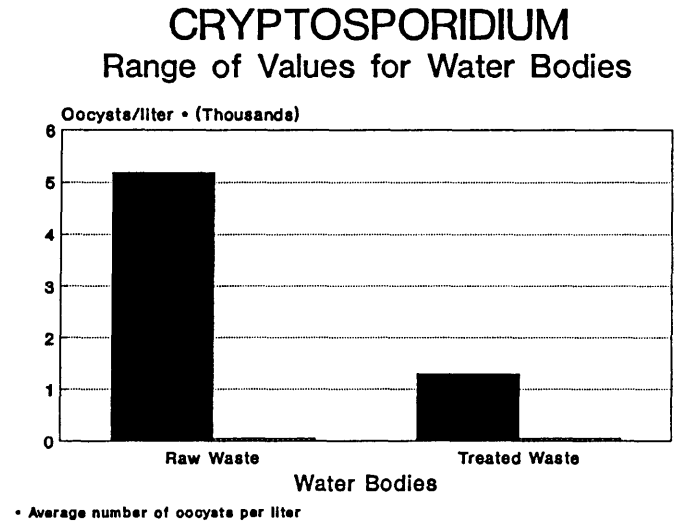
C. Water treatment

The purpose of water treatment is to prevent transmission of diseases. Treatment includes the processes of coagulation, flocculation, sedimentation, filtration, and disinfection. Only a limited amount of information is available concerning Cryptosporidium and each of these processes.

Figure 3. Distribution of Cryptosporidium in Different Water Bodies







Source: Data from Rose, 1990 and Fayer, et al., 1990

Pilot studies of granular activated carbon (GAC)-sand filtration of oocysts found a >99.99% (5.3 to 5.7 log) removal of Cryptosporidium. The filters were operated at from 1.9 to 5.0 meters per hour (m/h) and consisted of 300 to 500 mm of sand and 500 to 600 mm of GAC. Other laboratory studies determined that increasing the sand depth from 100 millimeters (mm) to 600 mm combined with coagulant provided almost a 35% (0.45 to >5.0 log) increase in the removal of oocysts. Coagulant jar tests (settling for 1 hr.) indicated a removal of between 99.2 to 99.8% (2.0-2.7 log). Full scale water treatment trials at three plants found the oocyst removal rate to vary from 99.0 to 99.9% (2.0-2.5 log) and the raw to finished water at 12 plants had an average removal rate of 95% (1.3 log). Overall, oocyst removal ranged from 96.6 to 99.8% (1.5-2.7 log) from this limited data base. A comparison with a wastewater treatment plant found oocyst counts reduced on average by 87 to 99%. Full scale water plant studies have shown that oocyst passage has the highest potential just after the backwash stage when the filter is being broken in or "ripening" (Benton et al., 1991 and Drinking Water Inspectorate, 1992).

A study of sedimentation basins from 12 water utilities determined that a 95% (1.3 log) removal took place. The floc blanket clarifier had the highest removal of 98.9% (1.9 log). Chemical, coagulant jar tests determined that alum and polymer allowed to settle for 30 minutes gave the best results of four coagulates tested in removing oocysts from the water column (Benton et al., 1991).

Many small communities are switching to slow sand filtration because of the potential of Giardia in the source waters. One system evaluated had a filter area of 774 square meters (m^2) and flow rate ranged from 0.19 to 0.40 m/h. Cryptosporidium was present in 46% of the filtered water samples but only one oocyst was identified in the post-chlorinated filtered water. Oocyst removal ranged from 2 to 68% (0.14-0.50 log) from this study. The filter age and flow rates had no detectable effect on removal of oocysts, turbidity, or bacteria. Other

studies have found the oocyst removal rates to be higher, more in the range of 92.0 to 99.6% (1.1-2.4 log). Slow sand filtration was concluded to be effective on removal of Giardia cysts but not Cryptosporidium oocysts based on current plant designs (Benton et al., 1991 and Drinking Water Inspectorate, 1992).

Disinfection is usually the final step during the water treatment process. Chlorine concentrations normally used in water plants (free chlorine residual 0.2-0.5 mg/ℓ) do not kill Cryptosporidium. Laboratory work has found chlorine to be effective at concentrations of 8,000 to 16,000 mg/ℓ but these levels are not practical. A recent study has suggested that a high number of oocysts are non-viable or empty after conventional treatment and chlorination. If the oocyst is somehow stressed by the environment in some manner and the sporozoites are released, then the exposed sporozoites would be susceptible to chlorination (Fayer et al., 1990; Benton et al., 1991 and Drinking Water Inspectorate, 1992).

Ozonation has been found to be effective in killing oocysts of this parasite at concentrations utilized by water plants. This method has become popular due to its ability to improve coagulation, reduce production of chlorination by-products and improve taste and odor control. The current problem lies with the variety of methods used to determine viability. There appears to be little consistency in the test results so far. Studies have determined that ozone values of 5 to 15 mg/ℓ are needed to inactivate the oocysts. However, maintaining a constant residual level is a problem because of the very unstable nature of ozone. Combination of ozone with hydrogen peroxide or chlorine has not shown any advantage over ozone treatment alone. An in-house pilot plant to test ozone effectiveness for killing Cryptosporidium has been constructed in Cincinnati, Ohio, by the Environmental Protection Agency (EPA) - Risk Reduction Engineering Laboratory. This pilot plant should help determine if ozone is a safe and effective disinfectant for this parasite (Benton et al., 1991 and Drinking Water Inspectorate, 1992).

Other disinfectants such as ammonia, iodine, bromine, iodine bromide, and ultraviolet irradiation have not been found to be effective in killing Cryptosporidium oocysts at residual levels acceptable to water plants. However, a chlorine dioxide concentration of 0.43 mg/ℓ significantly reduced the number of living oocysts but did not totally eliminate all of the active oocysts (Drinking Water Inspectorate, 1992).

D. Origin of oocysts

Cryptosporidium can be found in all types of surface waters throughout the world but the parasite is usually not evident in ground water. However, a few cases of Cryptosporidium have been reported in shallow wells although these cases are suspected of being contaminated by surface sources.

Surveys of 28 states found river samples to contain oocysts/ℓ ranging from <0.01 to 242. Some rivers always showed positive results while others did not show any pattern. Cryptosporidium could be identified in waters that were not influenced by humans but numbers increased where a river was classified as industrial or where sewage effluent sources were present. A further study of protected and unprotected water sources found a clear relationship between oocyst numbers and human/animal activity (Drinking Water Inspectorate, 1992).

No significant correlation between Cryptosporidium oocyst concentration and daily river flow has been established but seasonal patterns with peak numbers in spring, summer, and autumn have been observed. The lowest oocyst concentration was found during the winter months (Benton, et al., 1991).

The application of animal and human wastewater is becoming a wide-spread means of utilizing waste as a resource and may also be an important source of human infection. When treated wastewater is spread on the land or discharged to

the water, cryptosporidiosis can be transmitted directly to man or through the food chain to indigenous wildlife. The wildlife can transmit the infection to farm livestock and pets. These domesticated animals can transmit the disease directly or indirectly to man. Man can also be infected by his recreational use of land and water. He can be infected by transmission of the oocysts that is carried from the recreational land into an adjacent water course and downstream to a water treatment plant intake (Casemore, 1988). One other source of infection can result from the introduction of imported exotic livestock. Figure 4 provides the routes of infection for Cryptosporidium. After reviewing all the available information on Cryptosporidium, the United Kingdom Research Steering Committee found "no evidence was obtained which suggested that water was a more likely source of infection than the other risk exposures" (Drinking Water Inspect., 1992).

IV. Regulation

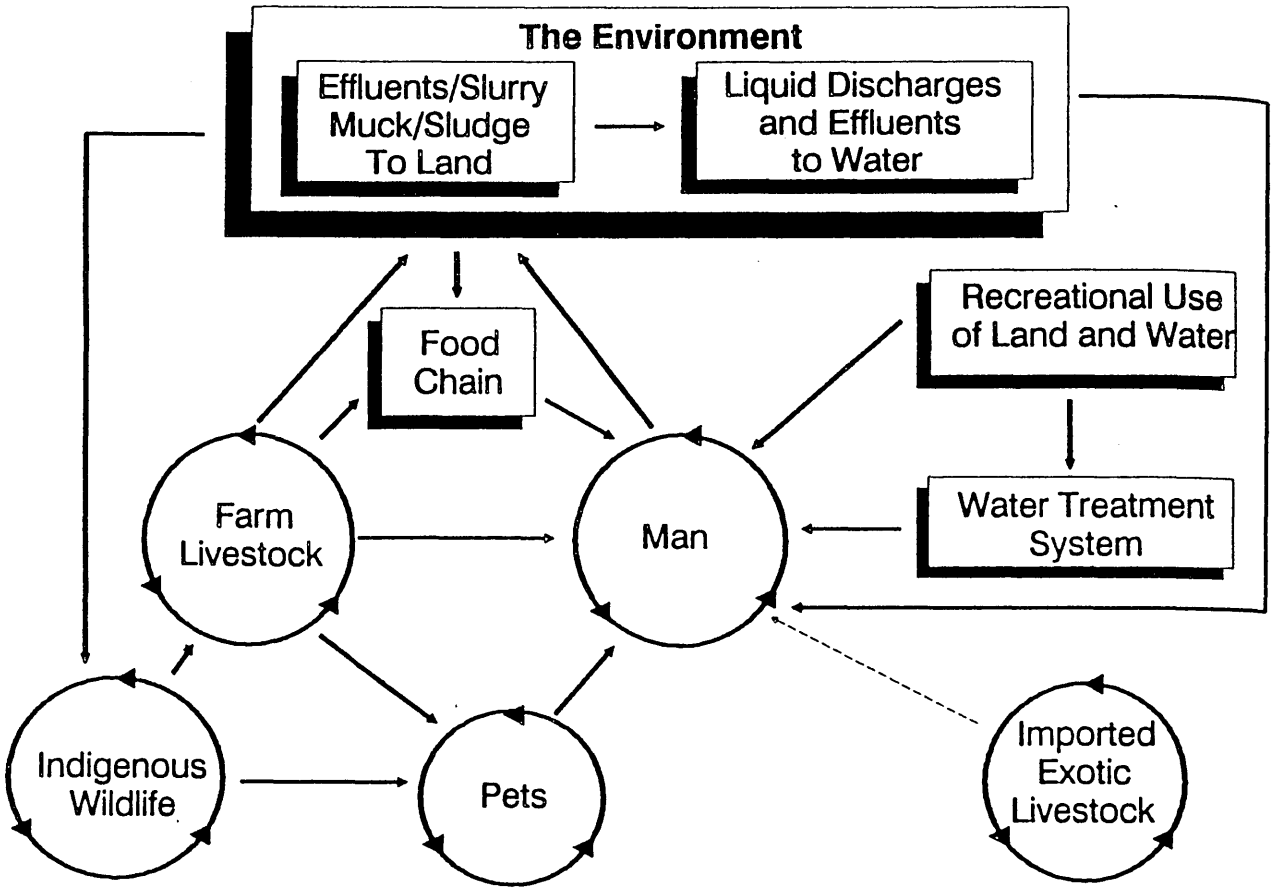
A. Current

Cryptosporidium is not currently regulated by the EPA under the Drinking Water Priority List. The only regulation in place is one for Giardia cysts and viruses that is contained in the Surface Water Treatment Rule. This rule was published in 1989 without any reference to Cryptosporidium because little was known about the organism at that time. Current evidence suggest that rules set for Giardia may not be adequate for Cryptosporidium in reducing the risk of this parasite from infecting the public (Pontius, 1993a).

B. Future

The EPA Advisory Committee for Disinfectants/Disinfection By-Products has reviewed all the information pertaining to Cryptosporidium and found there is not enough information about the occurrence of this parasite in water. Other issues the committee is discussing include watershed protection measures for unfiltered supplies, more effective disinfectants, and better detection methods. An

Figure 4. Infection Routes of Cryptosporidium



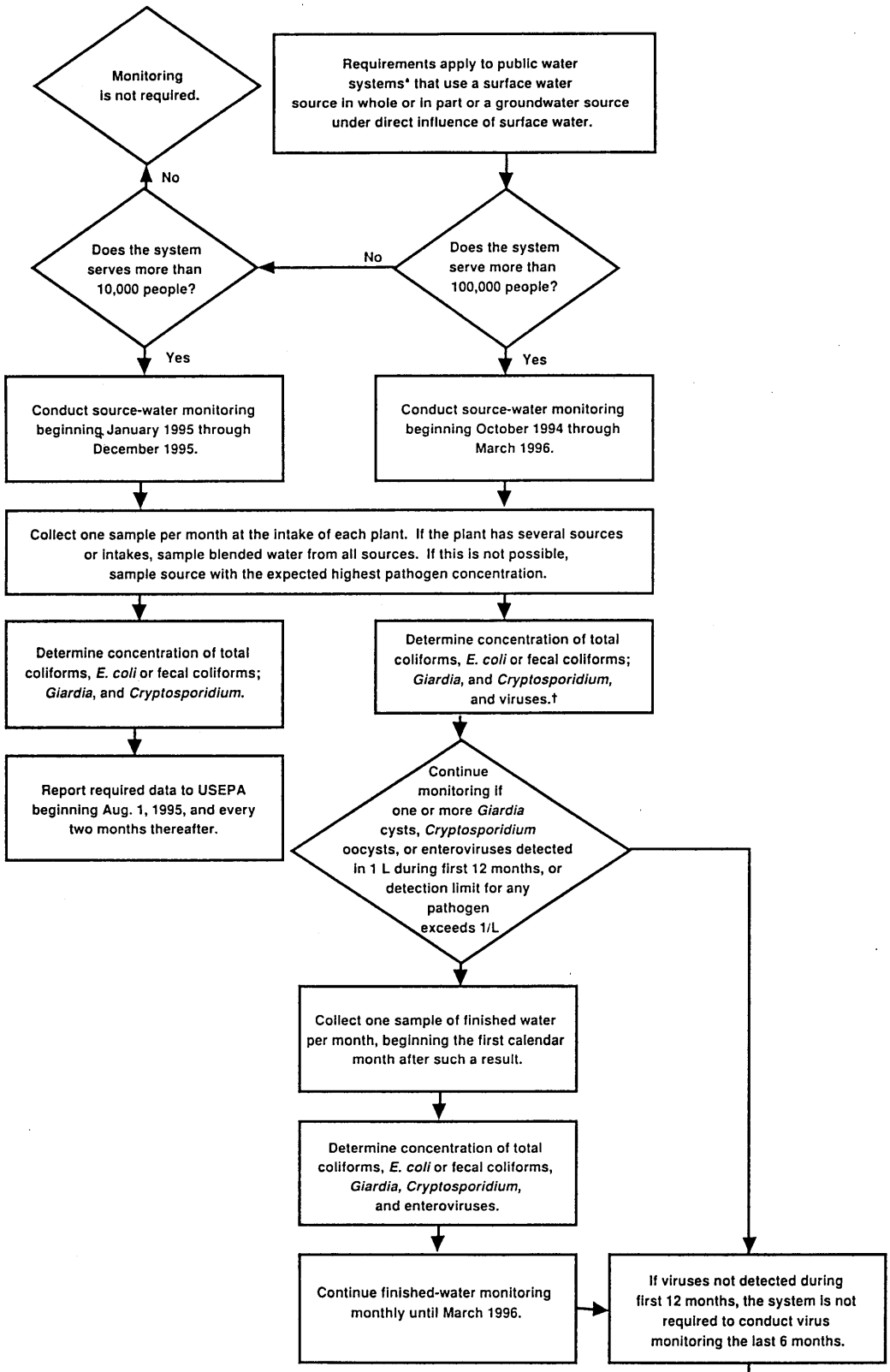
Source: Casemore, 1988

Information Collection Rule (ICR) is currently under development by EPA and will require certain water systems to monitor for Cryptosporidium and other water quality parameters. This rule is expected to be proposed in December 1993 and finalized in June 1994 (Pontius, 1993a). Large water supply systems (> 100,000 people) will be required to monitor for total coliforms, E. coli, or fecal coliform; Giardia, Cryptosporidium, and viruses covering a 18 month period (monthly sampling) starting in October 1994. Smaller water supply systems (> 10,000 people) will be required to monitor for total coliforms, E. coli, or fecal coliform; Giardia and Cryptosporidium covering a 12 month period (bimonthly sampling) starting in January 1995 (Pontius, 1993b). Figure 5 defines the monitoring requirement for Cryptosporidium and other microbes under the ICR.

C. Risk Assessment

Determination of the level of risk can help influence regulatory decisions to be made to minimize health risks from waterborne diseases. Many regulatory agencies have accepted risk assessment models to evaluate the importance of chemical pollutants in water. The EPA is coordinating a program to investigate methods, occurrence and risk assessment at their Environmental Monitoring Systems Laboratory in Cincinnati. A risk assessment model has been developed for Giardia to estimate the risk of infection after exposure to treated water containing varying levels of cysts. The two main components of the model are dose-response curve and the extent of exposure to the microbial agents. An exponential model was used with the following assumptions: 1) cyst exposure was randomly distributed; 2) each person consumed 2ℓ per day; and 3) all people were equally susceptible to a single exposure. Results of the model indicated that 1/10,000 annual risk of Giardia infection would result from exposure to an annual geometric mean of 0.007 cysts per 100ℓ. In order to achieve the 1/10,000 annual risk, treatment reduction on the order of 3 to 5 logs would be required. Factors that influenced the model the most were level of contamination in the water, level of cyst inactivation through chlorination, and length of exposure to the

Figure 5. Cryptosporidium and Other Microbial Monitoring Requirements



*A retailer may report a wholesaler's data when the wholesaler's source water is representative of the retailer's source water.

† If source water for each plant is tested for either total coliforms or fecal coliforms at least five times per week from February to August 1994, virus monitoring is not required if either total coliforms < 100 colonies/100 mL for at least 90 percent of the samples or fecal coliform is < 20 colonies/100 mL for at least 90 percent of the samples.

Source: Pontius, 1993b

population (Rose, 1988 and Benton et al., 1991).

This type of model is being developed for Cryptosporidium as a tool for interpreting water quality data and formulating regulations to protect human health. However, there are three missing pieces of information that are needed in order to run this model for Cryptosporidium. The missing data include infective dose, oocyst viability and oocyst inactivation through chlorination (Benton et al, 1991).

V. Research Needs

The occurrence of large outbreaks of Cryptosporidium in municipal water supplies within the last 10 years has focused a great deal of attention on this organism. Further research is needed in the areas of occurrence, detection, infective dose, removal, and disinfection. Isolation, identification, and enumeration of environmental and biological bottle samples is also required. Portions of the following information was taken from the Cryptosporidium Research Steering Committee report to the Secretary of State for the Environment and Secretary of the State for Wales (Drinking Water Inspectorate, 1992)

There is a limited amount of information on how many viable oocysts exist in different water courses. A much larger data set is needed to determine the true extent of this parasite. Studies are required in selected watersheds to determine the contribution from various sources. Addition work should be conducted on agricultural and municipal dischargers to document their contribution to the spread of the disease.

One of the most important areas, but the weakest, is detection. The effectiveness of current detection methods range from only 9 to 59% and the process is very time consuming. The six new methods described in the Detection Methods section should be investigated further to find a methodology that is

simple, quick, and has high efficiencies of recovering oocysts. Also a practical viability test needs to be developed and combined with a sound detection method.

The infective dose of Cryptosporidium in humans is not known at present and results of laboratory studies of other animals are very limited. Early work indicates that results are quite variable and very dependent on the animals utilized in the study. Human feeding studies would be ideal to answer this question but with no known effective treatment for the disease this approach is not reasonable. However, the development of an effective treatment for humans and animals is critically needed especially for immunosupressed individuals.

A great deal of effort is being focused on removal of Cryptosporidium. Most studies have shown the process of filtration appears to have the highest removal rate when combined with coagulation. Further work needs to concentrate on filter "ripening"and the effect of recycling water from the back washing and sludge treatment processes.

Disinfection research is also an issue that is currently being addressed. Of the disinfectants mentioned in the Water Treatment section only ozone and chlorine dioxide appear to be effective. These two disinfectants are not perfect and further studies are needed to understand their limitations. Also, a recent study found that environmentally stressed oocysts are much more susceptible to chlorination. Investigations into what environmental factors cause the stress on oocysts could help to make chlorine a better disinfectant in killing Cryptosporidium.

VI. Conclusions and Recommendations

The information that has been gathered on Cryptosporidium to date indicates that we have only a limited knowledge of this organism. This parasite is very small and appears to have a world-wide distribution. There are many animal host

species including humans and cross transmission is widespread. Cryptosporidosis is a short term illness in healthy humans but can be life-threating in individuals with suppressed immune systems.

Cryptosporidium has been found in all types of surface water throughout the world. Deep wells have shown no oocysts, but in some cases, shallow wells have been found to contain oocysts. Cryptosporidium shares some of the same characteristics as Giardia, but inactivation and removal appears to be much more difficult to achieve for Cryptosporidium. Of the four steps in water treatment, filtration and coagulation appear to have the highest removal rates. Disinfection in the form of chlorine at typical water treatment concentrations does not appear to kill Cryptosporidium. Ozone is a promising disinfectant in the destruction of this parasite but only pilot testing is currently being conducted.

Humans and animals infected with this disease are felt to contribute to the spread and further contamination from deposited feces and sewage. Oocysts of Cryptosporidium have been found in pristine waters but oocyst numbers increase where waters are influenced by human activity such as industrial or municipal point sources. Other studies suggest that agricultural non-point pollution sources such as animal operations may be as much of a concern as point sources.

Recommendations emphasize the need for more research into detection methods that have more timely and effective recovery rates; better treatment processes that further reduce the number of active oocysts; standard operational procedures for filtration especially the backwash and filter ripening processes; and specific watershed studies to determine the sources and amount of parasite contamination from each source.

Drinking water systems should rely on multi-barrier processes (i.e. source protection, coagulation, filtration and disinfection) to effectively reduce the risk

that Cryptosporidium will penetrate all of these barriers. However, human error and mechanical failure in the treatment operation must not be overlooked as potential weaknesses in the entire operation and continued training and monitoring must also be undertaken in order to reduce the risk from these sources.

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