THE POTENTIAL FOR CRYPTOSPORIDIUM IN MISSISSIPPI'S DRINKING WATER

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INTRODUCTION

Cryptosporidium parvum is a one-celled parasite which has been recognized as a human pathogen since 1976. However, only within the last decade has attention been focused on cryptosporidiosis as a potential waterborne disease, when *Cryptosporidium* was linked to several municipal outbreaks of intestinal illness, including the 1993 incident in Milwaukee in which over 400,000 persons were infected. Cryptosporidiosis is an acute diarrheal illness in humans, against which there is currently no effective medical treatment. The parasite is spread by the ingestion of oocysts excreted in the feces of infected individuals or animals and can be transmitted through the ingestion of contaminated food or water. In immunocompetent individuals the symptoms are self-limiting and normally last from 5 to 14 days. For the immunocompromised individuals (including but not limited to the young and elderly, transplant patients, and HIV-infected individuals), the illness can be debilitating and may even be fatal. Surveillance of raw water sources has confirmed that oocysts of *Cryptosporidium* are ubiquitous in surface waters. The number of oocysts may be considerably larger if the raw water source has been contaminated by raw sewage, treated wastewater, or runoff from livestock or wildlife grazing areas. Contamination of drinking water has not been limited to facilities obtaining their raw water source from surface water. Several outbreaks of cryptosporidiosis have been contributed to groundwaters in which the well had been contaminated by either raw sewage or agricultural runoff. The protective shell of the oocysts is very resistant to levels of chlorine typically used for disinfection. While the physical removal of *Cryptosporidium* through the use of filtration has been effective when rigorously applied, many cities/communities in Mississippi do not use filtration in their water treatment processes. All outbreaks of cryptosporidiosis occurred in which the facilities were meeting all current state and/or federal standards for drinking water quality.

PRESENCE OF CRYPTOSPORIDIUM OOCYSTS IN WATER

The American Water System (AWS) has conducted extensive monitoring of its operations since 1988 using the immunofluorescence antibody (IFA) method. Surveys of surface water supplies found *Cryptosporidium* oocysts in 60.2 percent (range 51.5 - 87%) of the samples tested. (LeChevallier et al.: 1991a; LeChevallier and Norton 1995) The AWS analysis of 67 raw water sites revealed that only two sources consistently tested negative for *Cryptosporidium*. In the sites that tested positive, 86.6 percent were multiple-positive. In the AWS study and others, it was found that the majority of sites tested positive for *Cryptosporidium* 60 to 80 percent of the time (e.g., three to five times positive based on five samples tested). The frequency of the detection of *Cryptosporidium* was higher than that of *Giardia*, which had the majority of sites testing positive in the frequency range of 40 to 60 percent. (Table 1)

The frequency of oocyst recovery and the numbers of oocysts recovered tend to be higher in waters receiving sewage or agricultural discharges than in pristine waters (Hansen and Ongerth 1991; LeChevallier et al. 1991a; Rose et al. 1991). Rose et al. (1991) found a greater prevalence of *Cryptosporidium* in river and lake samples that received either sewage, agricultural, or domestic animal discharge. Oocysts were detected in 39% of all pristine water samples with an average of 20 oocysts/100L compared to a *Cryptosporidium* recovery in 68% of the polluted water samples with an average of 91 oocysts/100L. In a study of intake water for 66 surface water treatment plants (in 14 mostly east-Midwest US states, plus 1 in Alberta, 1 in California), the highest parasite densities (*Cryptosporidium* and *Giardia*) were found in the heavily impacted Mississippi, Missouri, and Ohio rivers, with oocyst levels ranging from 10 to 484 oocyst/L (LeChevallier et al. 1991a). Chauret et al. (1995) reported the average concentration of *Cryptosporidium* oocysts recovered from sampling sites in or downstream of the city of Ottawa was 1.71 times greater than from upstream sampling stations, suggesting urban input was a significant contributor, although the average number of *Giardia* cysts did not differ between the same sites. The highest peaks in recovery of both parasites occurred at sampling sites in/downstream of the city. Hansen and Ongerth (1991) recorded their highest oocyst recoveries downstream of numerous dairy farms, nearly a 10-fold difference compared to upstream stations on the same watershed.

Most environmental surveys have assessed both *Cryptosporidium* oocyst and *Giardia* cyst presence. Oocysts tend to be detected more frequently and in higher numbers in untreated surface waters (LeChevallier et al. 1991a; Rose et al. 1991; Chauret et al. 1995). The levels of *Cryptosporidium* (44/100L for lake/reservoir samples and 43/100L for river/stream samples) was observed to be more than 10 times greater than *Giardia* (3/100L and 4/100L for lake/reservoir and river/stream samples, respectively). The studies by AWS (LeChevallier et al. 1991a; LeChevallier and Norton 1995) comprise the largest single database of survey information. Samples from 72 surface water treatment plants in 67 surface water locations have been examined, with most of the sites included in both studies, so that 5 or more analyses have been performed on both raw and treated waters for 94% of the systems, over the 1988-1990 and 1991-1993 study periods. An interesting finding is that occurrence of *Giardia* and *Cryptosporidium* in surface water was lower in the second study than in the first (*Giardia* present in 45% and 81% of the samples, respectively; *Cryptosporidium* present in 51.5% and 87% of the samples, respectively). The authors note that a British study also reported a decline in oocyst levels in 3 of 4 watersheds over a 3-year period, although recoveries in the fourth watershed increased (Poulton et al. 1992, as cited by LeChevallier and Norton 1995). This raises the possibility of cyclic variations in the levels of oocysts and cysts in the environment, although clearly more investigative work is required to form definitive conclusions. Cyclic phenomena are well-known for waterborne pathogens (e.g., influenza viruses, *Vibrio cholerae*).

It has been noted by LeChevallier that the variation at which *Cryptosporidium* is found in raw source water is of importance. If a water system's source site has a low frequency of oocysts occurrence, the system may become nonchalant in its concern of oocysts because of its low detection. However, during periods of peak oocyst densities, these treatment systems will need to provide nearly the same amount of treatment as those plants that regularly experience high oocyst concentrations in their source waters. Treatment plants should be designed and operated at levels that can provide protection against the occurrence of peak oocyst concentrations which can overcome the treatment barriers of even a regulatory compliant system, resulting in increased risk of waterborne illness.

LeChevallier et al. (1991a) attempted statistical modeling, using raw water parameters to predict protozoan parasite levels in waters, and found that about 50% of the variation in oocyst and cyst levels could be attributed to water quality and the level of watershed protection. Given the large array of potentially perturbing factors, the most logical approach to protozoan surveying, e.g., for water treatment facilities concerned about source water quality, would seem to be watershed-based. Some surveys have focused on single watersheds, attempting to describe potential controlling factors within that system.

Hansen and Ongerth (1991) compared two Washington state watersheds, both with similar forested, mountainous uppermost reaches, providing presumably similar animal habitats, but with very dissimilar human and domestic animal-related activities in the lower watersheds. One was the watershed for the Seattle Water Department, which is closed to the public, and while subject to logging, any associated road building, sanitation, etc. is carefully monitored. In the other, there are areas of intense recreational use, agricultural usage (dairy farming), logging, and three significant human communities. Watershed character and degree of watershed protection were judged important controllers of oocyst levels. Intensity of the human and domestic animal activities in the second watershed increased oocyst concentrations in the water by as much as 10-15-fold, compared with the more protected watershed. The study also concluded that oocyst presence was not intermittent, but continuous in the watersheds. Wild animal populations were presumed to contribute oocysts in the upper watershed areas, and this was complemented by contributions from human-related activities further downstream. Oocyst production from the protected watershed was estimated at an average of 0.2×10^7 oocysts/sq mile/day; the more-impacted watershed was estimated to produce 1.9×10^8 oocysts/sq mile/day on average. Peak production in the dairy-farming area when surface runoff was at its highest (late June) was estimated at 1.4×10^9 oocysts/sq mile/day.

A study of two unprotected watersheds in British Columbia indicated that peak oocyst (and *Giardia* cyst) concentrations coincided with calving activity (Ong et al. 1996). A series of samples collected up- and downstream of a cattle ranch in one of the watersheds showed that the downstream location had significantly higher oocyst and cyst numbers. Despite being topographically similar and geographically adjacent, differences in patterns of parasite contamination (the study was largely based *Giardia* distribution) and cattle management practices contributed to making the two watersheds unique and distinct in terms of protozoan presence.

SIGNIFICANT OUTBREAKS OF CRYPTOSPORIDIOSIS

Although high levels of *Cryptosporidium* are found in the environment, water treatment facilities have been able to significantly limit the risk of infection by this pathogen. However, either treatment deficiencies or breakdowns of a system have allowed *Cryptosporidium* to enter the distribution system at such levels to infect the population. With the exception of one outbreak, the levels of oocysts present have been at significant levels to cause illness in all ages and health of the population. The following cases of cryptosporidiosis demonstrate the impact of an outbreak, the necessity of strict control of a treatment system, and what levels of treatment are required. Table 2 contains a summary of all recorded U.S. *Cryptosporidium* outbreaks.

Milwaukee, Wisconsin

In April 1993, Milwaukee experienced the largest U.S. outbreak of a waterborne disease. Epidemiological studies conducted by city, state, and federal agencies indicated that the outbreak could be attributed to the presence of large amounts of *Cryptosporidium* in the drinking water. The Milwaukee Water Works (MWW) supplies drinking water to the greater Milwaukee area by means of two water-treatment plants, both of which obtain water from Lake Michigan. Operating records for the southern plant revealed an increase in treated water turbidity, beginning March 21 and increasing significantly between March 23 through April 5 to the point that a boil water advisory was issued April 7, and temporary closure of the plant on April 9.

Both plants were using chlorine and polyaluminum chloride coagulant to treat the water, then rapid mixing, mechanical flocculation, sedimentation, and rapid sand filtration. The treated water is stored in a large clearwell at each plant before distribution. There was no breakdown of mechanical equipment at the southern plant, rather the failure to maintain low-turbidity treated water was related to difficulties with flocculation procedures. Between Jan. 1983 and Jan. 1993, treated water at the plant did not exceed 0.4 ntu; during Feb. 1993-April 1993 treated water never exceeded 0.25 ntu until March 18, when it increased to 0.35 ntu. From March 23 to April 1, maximal daily turbidity was consistently ≥ 0.45 ntu, with peaks of 1.7 ntu occurring March 28 and 30. Difficulties were experienced in determining the correct coagulant dosage at the southern plant. Although turbidity was much improved on April 1 with use of polyaluminum chloride, the southern utility then switched back to alum coagulant on April 2. Inspection of the plant also indicated that a streaming-current monitor, which can aid operators in adjusting coagulant dose, was incorrectly installed and thus not in use. Continuous turbidity monitors were also not operative. Turbidity was monitored once every eight hours. From February to April 1993, the turbidity of treated water at the northern plant did not exceed 0.45 ntu. Also, during this period, samples of treated water from both plants were negative for coliforms and were within the limits set by the Wisconsin Department of Natural Resources for water quality.

After discovery of these problems, the streaming-current monitor was installed properly, and recycling of filter backwash water, a practice that had been in place, was discontinued. In addition, continuous turbidity monitors were installed for each individual filter bed; these sound an alarm and the system automatically shuts down if filtered water turbidity exceeds 0.3 ntu. Particle counting of raw and filtered water has also been instituted. The pattern of the outbreak suggested that oocysts must have entered the water supply before the increase in treated water turbidity was apparent. The oocyst source and time of entry into the water supply were never precisely defined. Possible sources and contributing factors, however, included cattle along two rivers that feed into the Milwaukee harbor, slaughterhouses, human sewage, and unusually heavy rain and snow runoff into Lake Michigan. (MacKenzie et al. 1994; Fox and Lytle 1996)

Las Vegas, Nevada

During the period of January to May 1994, Las Vegas experienced an outbreak of cryptosporidiosis in the AIDS population of the city. The Centers for Disease Control and Prevention (CDC) assisted in determining the cause of the outbreak and statistically linked the disease to drinking tap water. This is the first documented outbreak of cryptosporidiosis in a drinking water system with no apparent treatment deficiencies or breakdowns.

The Southern Nevada Water System (SNWS) serves the majority of the Las Vegas valley with drinking water. SNWS obtains influent water from Lake Mead and processes it by prechlorination, aeration, addition of ferric chloride, flash and rapid mixing, flocculation, direct filtration, addition of zinc orthophosphate, and post chlorination. Filter backwash water is recycled to the beginning of the treatment plant after plain sedimentation in clarifiers. The quality of the influent into the treatment plant is considered essentially pristine. The average turbidity of the raw water from January 1993 to June 1995 was 0.14 ntu, with a high of 0.3 ntu and a low of 0.1 ntu. Because of the low turbidity, SNWS used online particle counters for measurement of influent and effluent water quality. During the previously mentioned time period, the raw water particle counts were in the range of 2.5-150 μm and averaged 346 particles/mL. The finished water had an average turbidity of 0.09 ntu and particle counts of 31 particles/mL. During the outbreak, the Clark County Health District and SNWS sampled the water at points in the distribution system and in the finished water. The average turbidity in the distribution system was 0.15 ntu, and neither agency detected *Cryptosporidium* in the distribution system or in the finished water.

During the outbreak, 78 people became infected with cryptosporidiosis -- 65 adults and 13 children. Of those infected, 61 adults and 2 children were HIV-infected, with the majority advancing to the various associated debilitating diseases. Possible sources of contamination included an industrial and treated wastewater discharge to the lake located 7 miles from the raw water intake, sewage from boats at a nearby marina, and the annual turnover of the lake caused by the weakening of the lake's thermocline. Possible treatment deficiencies considered were the passing of oocysts through the filter units and the recycling of the backwash water to the head of the plant (Roefer et al. 1996)

Walla Walla County, Washington

In 1994, a cryptosporidiosis outbreak in Walla Walla County resulted in 86 confirmed cases corresponding to people of all ages living throughout a particular water distribution system serving a population of 227. The source of the outbreak was indicated to be well water by epidemiologic and environmental investigations. The epidemiologic evidence also pointed to a greater risk of contracting the illness with consumption of greater quantities of unboiled well water.

The water supply consisted of two artesian wells; well 1 was 500 ft deep, and well 2 was 600 ft deep. The water supply was generally untreated; immediately prior to the outbreak, however, the water was chlorinated because fecal coliform had been detected. The wells are near cattle-grazing areas and were adjacent to an irrigation system that distributes treated wastewater. The wastewater undergoes secondary treatment, sand filtration, and chlorination. Upon inspection, treated wastewater from the damaged irrigation system was observed to seep into well 1. *Cryptosporidium* was found in well 1 water and in the treated wastewater. After the outbreak, the irrigation system was repaired, and well 1 was decommissioned. The well water for the community now comes entirely from well 2. (Solo-Gabriele and Neumeister 1996)

Braun Station, Texas

In 1984, two distinct outbreaks of diarrheal illness occurred in this San Antonio suburb with a population of 5,900. One outbreak occurred in May, the other in July. An epidemiologic study strongly implicated the community's water supply as the source of illness. Approximately 2,000 people became ill during the outbreaks. *Cryptosporidium* oocysts were found in stool specimens of 47 of 79 residents who became ill in July, and the pathogen was identified as the major cause of illness during the July outbreak. Investigation of the May outbreak, however, was conducted retrospectively. Analysis of serum samples collected in May indicated that the Norwalk virus could also have contributed to the diarrheal illness.

It is speculated that the outbreaks were caused by intermittent contamination for the community's water supply. The raw water source is well water, and the treatment is limited to chlorination. Raw water tested positive for fecal coliform; however, no *Cryptosporidium* oocysts were recovered from the raw water source. Dye tracer studies indicated that the well water was affected by the community's sewage system. The exact site of contamination was not identified. Since the outbreak, the Braun Station well has been decommissioned, and water is now supplied from the San Antonio treatment system. The raw water source for the San Antonio System is groundwater, and its treatment is limited to chlorination. (Solo-Gabriele and Neumeister 1996)

DISINFECTION AND REMOVAL OF OOCYSTS IN WATER TREATMENT

The drinking water industry has greatly increased the quality of water the population consumes and has significantly lowered the risk associated with waterborne illnesses. However, *Cryptosporidium* poses a new threat to the health of individuals consuming tap water. The physical characteristics of the oocysts are such that they are able to break through the treatment train or withstand the normal treatment that has virtually eliminated all other waterborne pathogens and viruses. The oocyst is extremely small, about one-fifth the size of *Giardia* and its protective shell is highly resistant to most disinfectants used in the water treatment industry. Table 3 summarizes the operation parameters of the surface water treatment plants during cryptosporidiosis outbreaks. Refer to Tables 4 and 5 for a comparison of various disinfectants and filtration methods.

Disinfection and Oocyst Viability

Few commercial disinfectants are effective against *Cryptosporidium* oocysts, nor is chlorination at normal drinking water treatment levels, so there is a need for alternate disinfection protocols. This would be required not only for drinking water, but in other areas in order to restrict the spread of infectious particles on farms, in homes, daycare centers, etc. Korich et al. (1990) noted that long-term exposure to 10% formalin, 5-10% ammonia, or 70-100% bleach is necessary to completely eliminate infectivity. Three percent chlorine as sodium hypochlorite for up to 18 h does not affect viability. Fayer (1995) reported that oocysts suspended in 5.25% aqueous sodium hypochlorite (full-strength Clorox bleach) for up to 2 hr still initiated infection in neonatal mice.

Although oocysts are very chlorine-resistant in disinfection studies, there is limited evidence that in actual water treatment practice, chlorine disinfection has some benefit. Oocysts shaken with sand for 5 min, then chlorine-exposed for 5 min, experienced significant decreases in viability, suggesting the abrasive action during shaking contributed to oocyst damage and death (Parker and Smith 1993). Similar abrasive effects during rapid sand filtration could complement the effect of subsequent chlorination. Ozone and chlorine dioxide treatments more effectively inactivate oocysts than do chlorine or monochloramine (Peeters et al. 1989; Korich et al. 1990). Exposure to 1 mg/L ozone for 5 min (maintained constant throughout) or 1.3 mg/L chlorine dioxide (initial concentration) for 60 min, achieved >90% inactivation, whereas 90 min exposure to 80 mg/L (initial concentration) of either chlorine or monochloramine was required for the same degree of inactivation (Korich et al. 1990). The CT value is the disinfectant concentration (C, mg/L) and time (T, min) required to inactivate a certain population percentage under specific conditions (i.e., pH, temperature) according to the Chick-Watson model of disinfection kinetics. The data allowed approximate CT values of between 5 and 10 for ozone, 78 for chlorine dioxide, and 7200 for chlorine and monochloramine to be estimated, for 99% inactivation at 25·C in buffered (pH 7.0) demand-free water (Korich et al. 1990). For comparison, CT values for 99% inactivation of the bacterium *Escherichia coli* by ozone range from 0.001-0.2, by chlorine about 0.04; and values of 0.04-0.42 have been reported for ozone inactivation of enteric viruses (Bitton 1994). Hence, Korich et al. (1990) concluded that disinfection, except for perhaps ozone treatment, cannot be relied upon as a sole water treatment with respect to oocyst inactivation. Ozone is currently used to treat water, likely more in Europe than in North America, but it is probably employed most commonly as an oxidant, or to control taste and odor problems, rather than as a primary disinfectant.

Finch et al. (1993) found in vitro excystation consistently underestimated oocyst inactivation by ozone, compared with an in vivo infectivity test (neonatal CD-1 mice); further, as the degree of inactivation increased, excystation and infectivity test results diverged further. CT values of 3.5 and 7 mg-min/L were determined for 99% inactivation, for demand-free buffered water at 22· and 7·C, respectively. The values increased to 5 and 10 mg-min/L, respectively, for 99.9% inactivation. However, the kinetics of *Cryptosporidium* oocyst inactivation deviated from the simple, first-order Chick-Watson model and were better described by a nonlinear Hom model. Fitting to the Hom model produces a family of unique C and T values for each inactivation level, rather than a simple CT product (Finch et al. 1993).

Physical Treatment Processes and Oocyst Removal

As has been revealed by the research on *Cryptosporidium*, the ineffectiveness of water treatment disinfection practices against *Cryptosporidium* oocysts dictates that physical treatments are critical to oocyst removal from raw waters. Further examination of water treatment facilities by AWS found oocysts in 27 to 35 percent of filtered drinking water samples. A treatment plant's compliance with the criteria of the Surface Water Treatment Rule (SWTR) did not ensure the removal of oocysts from the drinking water (LeChevallier et al. 1991a; LeChevallier and Norton 1995). Seventy-eight to nearly ninety-nine percent of the plants with parasitic-positive effluents were meeting the 0.5 ntu requirements of the SWTR, with the average turbidity level for all parasitic-positive was 0.19 ntu. The presence of oocysts in the effluent was independent of the treatment process and the operational practices. The majority of the systems applied disinfection practices at the SWTR minimum requirement of a 0.5-log disinfection level, with 75 percent of the plants applying disinfection levels that reduce the annual risk of infection to $<10^{-4}$.

Further analysis of selected treatment systems revealed fluctuations in the removal efficiencies of individual filters within a system for *Giardia* and *Cryptosporidium*. Although the combined filter performance produced effluents with low turbidity levels (<0.5 ntu), the variations in particle counts between the individual filters could vary by a factor of 10^3. The reduction in oocysts levels was shown to be directly related to the removal of turbidity or final particle counts. Particle counts $>5\mu m$ were shown to be a sensitive indicator of filter performance. Significant increases in particle count levels were observed during periods of relatively small increases in the turbidity of the effluent. During normal operation, high oocysts levels were reported during the filter ripening period; however, oocysts were also detected in the effluent during 'mid-runs' of the filters.

In bench-scale studies with oocyst-seeded natural water, Plummer et al. (1995) recorded 0.6-0.8 log removal by coagulation and sedimentation, whereas with dissolved air flotation (DAF), an alternative method of clarification, better than 2 log oocyst removal was achievable. The researchers considered DAF to be the superior clarification process under the conditions tested. On the other hand, conclusions from large-scale pilot plant trials were that chemical coagulation-based treatment with either DAF or floc blanket clarification could achieve comparable oocyst removal with subsequent filtration, as long as the chemical coagulation treatment was operating well (Hall et al. 1995). The two clarified water streams could not be compared pre-filtration, because high coagulant metal ion levels interfered with oocyst detection. Hall and coworkers suggest that clarification method could thus be chosen on another basis, e.g., DAF for superior algae removal, without worry about negative impacts on oocyst removal. The significance of optimal coagulation was demonstrated in a pilot-scale study using multimedia filters (anthracite/silica sand/garnet sand) operating in direct mode. *Cryptosporidium* removals ranged from 2.7-3.1 logs over 4 runs under essentially similar conditions; but when a sub-optimal alum dose (5 rather than 10 mg/L) was used, oocyst removal dropped to 1.5 log (Ongerth and Pecoraro 1995).

Rapid filtration (5-30 m/h) is the normal practice in North American installations with conventional treatment, using coarser media (sand or multimedia, 0.5-2 mm effective size) and more frequent filter bed cleaning, by vigorous backwashing. These high-rate filters require considerably less space than slow sand filtration methods. Filter backwash water may contain substantial numbers of oocysts

(100s/L), and the recycling of untreated backwash water, as is practiced by some facilities, may constitute a significant source of *Cryptosporidium* to the plant intake (LeChevallier et al. 1991b). This is particularly critical because 15-60 min are typically required for rapid filter "ripening" after backwashing, and turbidity and particle breakthrough can occur during that time. This post-backwash period, then, has potential for oocyst breakthrough. Some plants practice a filter-to-waste protocol during this "ripening" period (LeChevallier et al. 1991b).

Nieminski and Ongerth (1995) evaluated protozoan cyst removal over 2 years in a full-scale (900 gal/min) and a pilot-scale (0.5 gal/min) facility, both operated in conventional or direct filtration (no sedimentation, flocculated water goes directly to filter) mode, using water seeded with killed *Giardia* cysts and *Cryptosporidium* oocysts. Average removals of oocysts at full-scale (2.25 or 2.79 log, by conventional or direct treatments) were less than at pilot-scale (2.98 or 2.97 log, by conventional or direct treatments). Conventional and direct filtration performances were similar at pilot-scale, but the full-scale plant performed better in direct mode, although this latter comparison was confounded by the necessity of comparing runs over different time periods and thus with differing raw water qualities. *Giardia* removal consistently exceeded *Cryptosporidium* removal, generally by 0.3-1.0 log. The greatest effector of performance, however, was water turbidity - - controlled by raw water quality (turbidity, algal content) and pre-filtration turbidity removal. When plant performance changed and water turbidity fluctuated, high variability in effluent oocyst and cyst concentration was observed. To remove protozoan (oo)cysts effectively, the water treatment process had to consistently produce 0.1-0.2 ntu water (Nieminski and Ongerth 1995).

Particle counting is considered a useful in-plant surrogate measure for indicating degree of cyst and oocyst removal by Nieminski and Ongerth (1995). In full scale and pilot scale studies of *Cryptosporidium* removal using conventional treatment and direct filtration, the results confirmed that oocyst removal could be directly correlated to the removal of particles in the oocyst size range (4 to 7 μm) (LeChevallier et al. 1991a; LeChevallier and Norton 1995). The removal of turbidity could also be used as a parameter to measure oocysts removal but at a lower accuracy than that of particle removal. Nieminski and Ongerth (1995) found that turbidity removal also paralleled oocyst and cyst removal, but was insufficiently sensitive other than as a rough performance indicator. Similar to the findings of environmental surveys, useful correlations of oocyst and cyst levels with bacterial levels were not apparent (Nieminski and Ongerth 1995).

Based on the AWS studies and the average oocysts level present in the raw water sources and assuming the accepted risk level for any waterborne pathogen infection applies to *Cryptosporidium*, we can determine the appropriated treatment levels required to ensure protection from illness. The average treatment requirement for *Cryptosporidium* based on the geometric mean, the arithmetic average, and maximum level was 4.49, 4.68, and 5.05 log, respectively (LeChevallier et al. 1991a; LeChevallier and Norton 1995). This is nearly a 2 log removal level greater than the minimum 3.0 log level of treatment outlined by the SWTR, and all the plants surveyed required more treatment than this minimum.

DRINKING WATER QUALITY IN MISSISSIPPI

Currently, there are over 1300 municipal drinking water facilities in Mississippi and only three of these have a raw water source obtained from surface waters. All three use rapid mix, coagulation/flocculation, settling, filtration, and chlorination. Testing of Mississippi's surface waters for oocysts has been infrequent because the methods used in determining the presence of oocyst is not yet standardized and recovery efficiencies have been inconsistent. Recovery methods are also inhibited by the quality of the source water, such as turbidity which can make the recovery process tedious and time consuming. However, the testing that has been performed has revealed no occurrence of oocysts in the surface waters.

Of the systems using groundwater, the majority are obtaining their source water from wells at depths ranging from 600-2000 ft. The water at these depths is well protected from *Cryptosporidium*, because either the overlying soils act as a superior filter medium, or the aquifer is protected by an impermeable layer preventing the intrusion of oocysts. The surface water treatment plants have consistently maintained compliance, with average turbidity ranging from 0.05 -0.2 ntu for the both Jackson facilities, the Tishomingo, and Tupelo facilities (MSDH 1998). These levels of turbidity are less than that required by the Surface Water Treatment Rule (SWTR), which is currently 0.5 ntu as the 95th percentile monthly. The American Water Works Association (AWWA) recommends a level of 0.1 ntu to significantly reduce the risk of *Cryptosporidium* in drinking water.

The Jackson system is currently averaging a level of 0.1 ntu, with chlorine concentration leaving the plants at 2.2-2.8 mg/L; these levels are consistent at both water treatment facilities serving the system. The NE Mississippi Regional Water Supply District, which serves the City of Tupelo and surrounding areas, is making every effort to eliminate the risk of oocysts in the drinking water of that area (Maples 1998). The turbidity levels of the treated effluent is in the range of 0.04-0.06 ntu, considerably less than the recommended AWWA level. If the levels increase to greater than 0.1 ntu, the operators will shut down the facility until the situation can be remediated. The chlorine concentrations are 1.8-2.0 mg/L leaving the plant and every effort is made to keep a residual of 0.5 mg/L throughout the distribution system.

An area of concern is the number of privately owned drinking water wells in Mississippi; other than private household wells, these include wells serving trailer parks, recreational areas, retreat locations, etc. A number of factors could increase the risk of contamination of these systems; including, but not limited to, poor management of the system, the location of the system, and condition of the operational units. If these factors and others are not strictly controlled, *Cryptosporidium* could infiltrate into the source water or the distribution system through contact with contaminated sources, such as sewage or agricultural runoff, or even by means of backflow into the system during periods when the pressure in the distribution system is not maintained.

SUMMARY AND CONCLUSIONS

Currently, the potential for *Cryptosporidium* in Mississippi's drinking water is extremely small, considering the relative number of surface water treatment plants and the quality of the aquifer system that serves the state. While the surface water facilities are maintaining their strict levels of treatment, the systems can provide a treated water that is of little risk to the consumers. However, there are other sources of water that could pose a threat to the public if the same levels of protection are not applied to these systems as is applied to the public water systems. This is not to say that the risk of cryptosporidiosis will be eliminated, because the risk is possible due to the prevalence of oocysts in the environment. There is the possibility that an outbreak of cryptosporidiosis could occur which is not associated with drinking water, such as swimming pools, or recreational waters.

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Table 1: Occurrence of oocysts in various water sources.

Water Type	Samples (n)	% Positive	Range of Mean Oocyst Concentration (oocysts/L)	Reference Concentration (oocysts/L)	
River	11	100	2-112	25	Ongerth and Stibbs, 1987.
Stream/river	58	77.6	0.04-18	0.94(g)	Rose , 1988.
Stream/river	38	73.7	<0.001-44	0.66(g)	Rose et al., 1991.
River/lake	85	87.1	0.07-484 2.7(g)		LeChevallier et al., 1991a.
River/lake	262	51.5	0.065-65.1	2.4(g)	LeChevallier and Norton, 1995.
Rivers	41	78.8	<0.02-2.25	0.26	Chauret et al., 1995.
Surface waters	1173	4.5	NR	NR	Wallis et al., 1996.
Lake/reservoir	32	75	1.1-8.9	0.91(g)	Rose, 1988.
Lake	24	58.3	<0.001-3.8	1.03(g)	Rose et al., 1991.
Pristine river	59	32.2	NR	0.29	Rose et al., 1991.
Pristine lake	34	52.9	NR	0.093(g)	Rose et al., 1991.
Pristine spring	7	28.6	<0.003-0.13	0.04(g)	Rose et al., 1991.
Pristine lake	11	9.1	0-0.003	0.003	Roach et al., 1993.

NR - not recorded; (g) - geometric mean.

Table 2: Summary of Outbreaks and Characteristics

Location	Date	Estimated No. Cases (Confirmed)	Raw Water Source	Suspected Sources of Contamination
Braun Station, TX	May-July 19984	2,000 (47)	Well	Raw sewage (a)
Albuquerque, NM	July-October 1986	(78)	Surface water	Surface runoff from livestock grazing areas
Carrolton, GA	January-February 1987	13,000	River	Raw sewage and runoff from cattle grazing areas
Berks County, PA	August 1991	551	Well	Septic tank effluent, nearby creek
Talent & Medford, OR (Jackson Co.)	January-June 1992	15,000	Spring/River	Surface water, treated wastewater(a), or runoff from agricultural areas
Milwaukee, WI	January-April 1993	403,000	Lake	Cattle wastes, slaughterhouse wastes, and sewage carried by rivers
Yakima County, WA	April 1993	7 (3)	Well	Infiltration of runoff from cattle, sheep, or elk grazing areas
Grand Marais, MN	August 1993	27 (5)	Lake	Backflow of sewage or septic tank effluent into distribution, raw water inlet lines, or both
Las Vegas, NV	January-April 1994	(78)	Lake	Treated wastewater, sewage from boats
Walla Walla County, WA	August-October 1994	85(15)	Well	Treated wastewater (a)
Alachua County, FL	July 1995	(72)	N.A. (b)	Backflow of contaminated water

(Solo-Gabriele and Neumeister, 1996)
a- Strong evidence to support effect of wastewater; b- Not applicable.

Table 3: Characteristics of surface water systems

Location	Type of System (MGD)	Effluent Turbidity ntu (a)	Type of Filter (back-wash recycle)	Chlorine Residual, mg/L	Micro-biological Quality (b)
Carrolton, GA	Community (8)	0.5 (5.0)	Rapid, dual-media (no)	1-1.5 (ClO_2)	T, Cr
Talent, OR	Community (1)	0.5 (2.2)	Rapid, dual-media (no)	1.2-2.3	
Milwaukee, WI	Community (375)	<0.4 (1.7)	Rapid, single-media (yes)	0.8-1.0	T, Cr
Grand Marais, MN	Noncommunity (<1)	NM	Pressure sand filter, single-media (no)	NA	R, Cr
Las Vegas, NV	Community (400)	<0.1 (<0.2)	Rapid, dual-media	1.4	

(Solo-Gabriele and Neumeister, 1996)
a-Ntu average prior to outbreak (peak ntu during outbreak); b- T=treated water quality, R=raw water quality, Cr=positive for *Cryptosporidium*. NM=not measured; NA=not available.

Table 4. Various disinfectants and reduction of oocysts.

Disinfectant	Dosage (mg/L)	Exposure time (min)	% Reduction of oocysts (a)	Reference
Ozone	1.0	5	>90	Korich et al., 1990.
Ozone	1.0	7.6	99.9	Finch et al., 1993.
Chlorine Dioxide	0.43	15	93.5	Peeters et al., 1989.
Chlorine Dioxide	1.3	60	90	Korich et al., 1990.
Chlorine	80.0	90	99	Korich et al., 1990.
Mono-Chloramine	80.0	90	90	Korich et al., 1990.
Free Chlorine	5.0	60	90	Venczel et al., 1997.
Sand & Chlorine(b)	1.0	5	68	Parker and Smith, 1993.

a- Based on reduction in viability or percent excystation; b- shaken with sand for 5 min., then post-chlorinated.

Table 5. Oocyst concentrations and treatment parameters in finished water.

Source water (a)	Filtration	Disinfectant Type (mg/L)	Turbidity NTU	Oocyst/ 100 L
River	conventional-rapid sand	chlorine (0.82)	0.24	0.73
River	direct (b)	chlorine (0.9)	0.5	0.57
River	dual media (c)	chlorine (1.01)	0.18	0.5
River	none	chloramine (1.1)	0.32	1.7
Spring	none	chlorine (0.4)	3.0	0.11

(Rose et al., 1991).
a-First two rivers in polluted category, last two rivers in pristine category; b-coagulant mixer inoperable; c-no coagualnts used.