Public Health Significance of Waterborne Pathogens[1]

G. Fred Lee, Ph.D., P.E., D.E.E. and Anne Jones-Lee, Ph.D.
G. Fred Lee & Associates
El Macero, CA
(916) 753-9630

Executive Summary

The risk of adverse human health impact from waterborne microbial pathogenic agents is potentially highly significant for Californians, especially relative to the risks from residual, unregulated chemical contaminants in domestic water supplies. Of particular concern are the cyst-forming protozoans that cause giardiasis and cryptosporidiosis, and the enteroviruses. In addition to causing gastroenteritis, enteroviruses can cause a variety of other diseases, including meningitis, upper respiratory tract infections, and encephalitis.

While often not at the forefront of public concern today, pathogens in water supplies still cause major disease outbreaks. For example, in the spring of 1993, about 370,000 cases of waterborne disease were reported in Milwaukee, Wisconsin due to inadequate treatment of a domestic water supply that contained the protozoan, *Cryptosporidium*; approximately 20 deaths were estimated to have resulted. That outbreak, the largest outbreak of waterborne disease in the history of the US, brought to national attention that even today, large numbers of people can become ill at one time due to the presence of human enteric pathogens in a domestic water supply that had been considered "safe." The Centers for Disease Control and Prevention have estimated that there are on the order of 940,000 cases of waterborne enteric (intestinal) diseases in the US annually, with 900 deaths resulting. Recent modeling efforts have indicated that in the US population, there may be a lifetime risk of death from exposure to waterborne virus as high as 1 in 20.

Even though major outbreaks of waterborne disease of the Milwaukee type are comparatively rare, there is substantial evidence that human enteric pathogens that are frequently present in domestic water supplies are responsible for low-level incidence of chronic gastroenteritis (upset stomach, vomiting, diarrhea) as well as other "mild illness" in people. While gastroenteritis and other such "mild illness" are rarely debilitating to healthy adults for more than a few hours to a few days, enteric pathogens can cause severe illness, even death, for young children, the elderly, or those with compromised immune systems.

Contact recreation in coastal marine and fresh waters is an area of public health concern. There have been numerous studies that question and indeed denounce the reliability of the coliform group as an indicator of the sanitary quality of bathing/swimming waters and the associated risks to swimmers and other users of beach waters. It appears from the information available today that body contact with waters that meet the fecal coliform and enterococci bacterial standards does not represent a significant public health threat risk. However, there continues to be concern about body contact with grossly polluted waters in which large amounts of domestic wastewaters are present. The magnitude of the risk associated with body contact in such waters is unknown at this time, but it does not appear to be a significantly greater than swimming in other waters.

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[1] Report to California Environmental Protection Agency Comparative Risk Project, December 1993

The increased efforts to reclaim and reuse wastewaters and gray waters pose additional public health concerns. This concern is heightened by the fact that the indicators of the "sanitary quality" of waters, the coliforms and fecal coliforms, are unreliable indicators of the presence of a number of key pathogenic agents including enteric viruses and cyst-forming protozoans. Wastewater "reclamation" does not have a specific meaning in terms of degree of treatment for different reclamation projects. Some reuses of wastewater are allowed with very little additional treatment beyond conventional sewage treatment, to address enteric viruses and cyst-forming protozoans. Even after what is considered to be good conventional domestic wastewater treatment and chlorination (chloramination), domestic wastewaters released to surface waters in nearby streams, lakes, estuaries or coastal marine waters, still contain large numbers of enteroviruses and pathogenic protozoans that can readily cause human disease upon ingestion and, to a lesser extent, body contact with these waters. The California Department of Health Services (DHS) does not adequately regulate all so-called reclaimed wastewaters to the same degree of public health protection. There are some domestic wastewaters that receive little or no regulation. Further, DHS has not yet focused its regulatory program for reclaimed wastewaters on the control of the cyst-forming and oocyst-forming pathogenic protozoans that are known to cause significant disease in humans. With the State's emphasis on increasing the amount of reclaimed wastewaters used in California it is important that the regulatory framework be developed and most importantly adequately funded to be reliably implemented to provide a high degree of protection of public health from pathogenic agents in reclaimed wastewaters directly or indirectly reused.

It is concluded that much greater attention needs to be given to the control of waterborne pathogens in domestic water supplies in California to reduce the potential for major (Milwaukee-type) disease outbreaks, as well as the endemic waterborne disease occurrences to a much greater degree than is being accomplished today. Waterborne microbial pathogens should be given a high priority for regulatory activity, research funding, and control.

Introduction

In 1993 the California Environmental Protection Agency (Cal/EPA) initiated its Comparative Risk Project with the objective of identifying and ranking environmental risks of significance to public health and environmental quality. This activity was undertaken to provide input to Cal/EPA, other regulatory agencies, and the State legislature and governor's office for the development of priorities for funding to address environmental problems, and where necessary, to develop additional regulations to improve protection of public health and the environment.

While risk assessment today typically focuses on estimating the risk of disease (adverse impact on human health) associated with chemicals in the air, water, soil, and food of people and terrestrial and aquatic life, there is increasing recognition that the risks from waterborne microbial pathogens need to be given higher priority in regulatory programs, especially for domestic water supplies. Craun (1986) estimated that only about 8% of the diseases associated with domestic water supplies are related to chemical agents; more than 90% are due to microbial agents. He noted that little attention has been given to microbial agents in drinking water as human health hazards compared with the attention given to the potential for chemical contaminants in water supplies to be adverse to human health.

While waterborne diseases are typically considered to be problems of underdeveloped countries with inadequate sanitary practices, there is increasing recognition that industrialized, developed countries also have significant public health problems caused by use of untreated, partially treated, or inadequately treated domestic water supplies. The incidence of major outbreaks of the classical waterborne bacterial diseases, such as typhoid fever and cholera, has become very low in the US since the initiation of chlorination of domestic water supplies in the 1920's. However, outbreaks of waterborne microbial diseases still occur as a result of consumption of untreated, inadequately treated, and conventionally treated domestic water supplies in the US and other countries.

The most common waterborne microbial disease is acute gastroenteritis illness (AGI) (CDC, 1990). Most cases contracted through drinking water cause morbidity (gastroenteritis) although mortality has also resulted in immuno-compromised hosts. Since reporting of waterborne diseases is voluntary, the incidence of such diseases is undoubtedly greater than officially recorded. According to CDC (1990), only about one-quarter of the incidents of waterborne diseases are reported each year. CDC (1990) recounted difficulties in keeping an accurate record of water-associated disease. These include the willingness of consumers to seek medical attention, proper diagnosis of the causative agent of the illness, limitations of clinical laboratory tests, identification of environmental source (since waterborne diseases tend to be sporadic, self-limiting, and restricted to one-time events), and the identification of a waterborne disease is usually made epidemiologically. Therefore, according to the CDC (1990), it is doubtful that more aggressive reporting practices alone would accurately reflect the real occurrence of water-associated diseases.

It has been known for more than 50 years that the conventional disinfection of domestic water supplies (accomplished by addition of chlorine to 1 mg/L chlorine or so) is highly effective against certain gram negative, intestinal bacteria, such as the coliforms and the *Salmonella* bacteria that can cause typhoid fever. It has also been long-recognized, however, that that level of chlorination for the conventional contact time is not adequate to control many enteroviruses and is significantly deficient in controlling cyst-forming and oocyst-forming pathogenic protozoans that are ubiquitous in domestic water supply raw waters. The practice

of flocculation and filtration as part of municipal water treatment of surface waters significantly reduces the numbers of cyst-forming and oocyst-forming protozoans and enteroviruses to reduce to infrequent major outbreaks of waterborne disease from those organisms.

The "sanitary quality" of domestic water supplies has been and continues to be assessed by the concentrations of fecal coliforms. It has been known for many years that domestic water containing no more than the allowed level of fecal coliforms would allow a calculable risk of waterborne disease from conventional enteric disease organisms among the population consuming the water. Further it has been known that the fecal coliform standards used are not reliable for assessing the public health risk of waterborne disease caused by enteroviruses or pathogenic protozoans. Given the known shortcomings of the standards by which the sanitary quality of domestic water supplies is judged, the recent outbreak of cryptosporidiosis in Milwaukee was not unexpected.

There has been considerable interest in formulating risk assessment methodology for microbial pathogens in drinking water. Haas *et al.* (1993) discussed a risk assessment approach for evaluating the water quality significance of enteroviruses in drinking water. They pointed out that the methods used for water treatment do not sterilize drinking water, nor do they necessarily reduce the concentrations of waterborne pathogens to zero in the treated water. There will always be some residual risk of microbial infection associated with drinking treated water. Of particular concern in this regard are the enteroviruses that are suspected to be a major waterborne cause of gastroenteritis. The risk assessment methodology employed by Haas *et al.* for microbial agents is similar to the approach typically used for risk assessments for chemical agents.

Sobsey *et al.* (1993) also developed a conceptual framework for assessing risks associated with microbial agents in drinking water. Haas *et al.* and Sobsey *et al.* are well on their way toward developing risk assessment methodology that will enable better assessments of the human health risk of microbial disease due to inadequate treatment of drinking waters.

This paper presents an overview discussion of the current state of knowledge on the significance of waterborne microbial pathogens in causing disease in humans. Emphasis is on providing information that can be used in the Cal/EPA Comparative Risk Project to assign a comparative risk ranking to waterborne pathogens that reach humans through water supplies and other waters.

Overview of the Significance of Water Supply Waterborne Pathogens

Rose *et al.* (1993) noted that inadequate attention is being given to characterizing the risk associated with pathogenic organisms - bacteria, viruses, and protozoa - in domestic water supplies. While risk assessment methodologies are being used widely for evaluation of the risk of acquiring cancer from disinfection by-products and other potential chemical carcinogens in domestic water supplies, those methodologies have not been used to the extent that they should be in assessing the potential threat to human health posed by microbial pathogens in drinking water. They pointed out that the reliance on the coliform bacteria to define all microbial risks has left a large gap in knowledge of the exposure of people to microbial agents in food and water.

According to Rose (1993) and Rose *et al.* (1993) the annual risk of enteric illness ranges from 1 per 1,000 people to 1 per 100 people, and that a significant percentage of these illnesses

may be due to organisms in water. Of particular concern is the apparently greater risk of the elderly population that is more susceptible to mortality associated with diarrhea. Rose *et al.* (1993) pointed out that a single low-dose exposure of microbial pathogens can cause adverse effects. Further, once an individual is infected, he or she may spread the disease to others. Rose (1993) reviewed the current state of information on public health hazard and exposure assessment for enteric, waterborne protozoans and stated,

> *"No doubt exists that Cryptosporidium and Giardia are the most significant cause of waterborne disease in the U.S. today."*

She pointed out that at this time it is not possible to fully characterize the risk associated with these organisms in domestic water supplies, and discussed the importance of adequate filtration in water treatment for controlling these organisms in domestic water supplies. Rose's (1993) review was written before the outbreak of cryptosporidiosis in Milwaukee in the spring of 1993. There, about 370,000 people became ill due to inadequate treatment of a domestic water supply that contained the protozoan, *Cryptosporidium*; approximately 20 deaths were estimated to have resulted. The health effects are reported to be lingering in many individuals (Milwaukee Journal, 1993). It is estimated that the *Cryptosporidium* outbreak in Milwaukee cost the city residents $54 million in lost wages, illness, etc. (Milwaukee Journal, 1993). Also, that city will have to spend an estimated $75 million to upgrade its water treatment plant to try to eliminate future incidents of this type. This situation provides a dramatic example of how domestic water supplies that have been inadequately treated (filtered) can serve as a vehicle for microbial protozoan pathogens.

Okun (1993a,b) discussed the importance of *Cryptosporidium* as a pathogen in domestic water supplies and indicated that *Cryptosporidium* oocysts are far-more resistant to chlorine than *Giardia*. In addition, cryptosporidiosis is far more serious than giardiasis, particularly in immuno-compromised individuals, such as HIV-positive individuals, those under radio- or chemotherapy, and young children; there is no treatment for the disease. Okun stated that surveys around the country have shown that about 80% of the surface water supplies, most of high quality, have *Cryptosporidium*, indicating that if there is inadequate water treatment, such as occurred in Milwaukee, major outbreaks of cryptosporidiosis can occur.

Regli (1993), of the US EPA Washington D.C., Office of Groundwater and Surface Water, noted that worldwide, the risk of illness from waterborne microbial pathogens is probably thousands- to millions-fold greater than that from chemical contaminants in drinking water. Most of that increased risk exists because of areas in which there is no, or inadequate, domestic water supply treatment. The current degree of water supply treatment practiced in the US and other developed countries greatly reduces the risk of contracting a waterborne microbial disease, but does not eliminate it. Regli (1993) pointed out that at this time there is increasing concern about the risks associated with *Cryptosporidium* since no dose--response curve is yet available for this organism. He stated,

> *"Waterborne disease outbreaks are commonly known to be caused by inadequate disinfection or failure in disinfection of surface water supplies,[11] whereas the epidemiologic evidence is not yet considered adequate to establish a causal link of cancer incidence with chlorinated drinking water.[12]"*

Bennett *et al.* (1987) reported on an expert panel's consensus findings of the occurrence of infections and parasitic diseases in the US as of the mid-1980's. They reported that at that time, there were an estimated 940,000 disease incidents caused annually by waterborne microbial pathogens in the US. They also estimated that there were approximately 900 deaths each year in the US due to waterborne pathogens. As part of preparation of this report, the

authors contacted the Centers for Disease Control to obtain updated information on the expected occurrence of illness from microbial pathogens in domestic water supplies. Goldstein (1993) indicated that the Bennett *et al.* estimates, based on data from the early to mid-1985, still represent the best estimate of CDC experts in the area of infectious diseases.

Haas *et al.* (1993) concluded from their modeling efforts with regard to risk to the US population from waterborne disease,

> *"In other words, there may be a lifetime risk of death as high as 1 in 20 from exposure to waterborne virus based on the above assumptions. This is clearly not negligible (particularly in view of the 10^{-4} to 10^{-6} lifetime risk that is often regarded as an action level for carcinogens), and must be considered in the risk management decision-making process with respect to drinking water treatment."*

Regulatory Considerations

The safety of domestic water supply is receiving increasing attention with the reauthorization of the Safe Drinking Water Act currently being considered by the federal Congress. Newman (1993) recently summarized issues in the reauthorization. A fundamental issue is that there is inadequate funding to provide for implementation of the current Safe Drinking Water Act. Studies by the US General Accounting Office (GAO, 1993) cited by Newman (1993) point to serious problems in the ability of states to fund Safe Drinking Water Act requirements. While the primary focus of the Safe Drinking Water Act reauthorization is the regulation of chemical contaminants, there is increasing recognition that microbial contaminants deserve at least equal attention because of their potential to cause widespread disease.

While in most instances groundwaters are free of pathogens of concern in drinking water (bacteria, viruses and protozoans), there have been numerous cases of enteric diseases' having been caused by groundwater water supplies; reasons have related to faulty well construction and maintenance, fractured rock and cavernous limestone aquifer systems, and inadequate separation of domestic wastewater introduction into the aquifers from the extraction of groundwater for use for domestic purposes. This situation is of sufficient concern to cause the US EPA to propose requiring chlorination and/or other treatment for groundwaters used for domestic water supplies.

The US EPA has found that the inability of current domestic water supply treatment processes to remove all human pathogens from treated waters is of sufficient concern to significantly strengthen domestic water treatment requirements. Macler (1993) reviewed the upcoming federal drinking water regulations and indicated that the US EPA will soon initiate a major information collection requirement (ICR) that will include intensive monitoring of microbial characteristics of domestic water supplies. According to Macler (1993), domestic water systems serving more than 100,000 people,

> *"must monitor monthly at intake of each plant: Giardia, Cryptosporidia, enteroviruses, total coliforms, fecal coliforms or E. coli"*

and

> *"with concentrations of 1 or more pathogens/liter in source water during first 12 months must begin monitoring finished water monthly for all five parameters* [pathogens or indicator organisms listed above]"

Also, according to him, systems serving between 10,000 and 100,000 people,

> *"must monitor every two months at intake of each plant Giardia, Cryptosporidia, total coliforms, fecal coliforms or E. coli."*

Macler indicated that the US EPA is also developing a groundwater disinfection requirement developed in an attempt to prevent waterborne disease caused by viruses. As noted above, bacterial and protozoan diseases are not typically associated with groundwater water supplies that incorporate properly constructed and maintained wells and not located in fractured rock or cavernous limestone aquifer systems. However, human enteroviruses are known to be transported for considerable distances in many aquifers. They are, therefore, a threat to domestic water supplies that draw from groundwater systems at locations fairly close to sources of domestic wastewaters that have not been fully disinfected/treated for control of enteroviruses. Powelson and Gerba (1993) investigated the persistence of viruses in domestic wastewaters recharged to groundwater systems through infiltration basins. From the information they provided, it appears that in a sandy alluvium aquifer at least a year's time should be provided between the time the wastewaters are recharged and the time water is removed for use for domestic purposes. According to Gerba (1993), a year's time in that type of aquifer should be adequate for viral deactivation.

Macler (1993) indicated that the US EPA's groundwater disinfection rule is scheduled to be proposed in August 1994 and will require the disinfection of each well to meet virus and fecal coliform levels. A water utility can avoid having to provide such disinfection if a water supply well is demonstrated not to be vulnerable to microbial contamination. The US EPA would still require the addition of a disinfectant to maintain a disinfectant residual in the distribution system, however. It also requires the groundwater-based water supply be under the control of a qualified operator.

Macler (1993) also discussed the coliform standard and the Surface Water Treatment Rules. He indicated that while the US EPA policy is to require that all water supply systems meet the coliform standard, the Agency acknowledges that meeting that standard does not indicate that the domestic water supply is free of human viruses and protozoan pathogens. According to the proposed Surface Water Treatment Rule, all surface supplies must be disinfected to achieve at least 99.9% and 99.99% removal/inactivation of *Giardia* and viruses. Further, treatment of surface water must include filtration unless source water quality criteria and watershed requirements are met.

Pontius (1993) also recently summarized the Surface Water Treatment Rule that sets disinfection standards for water systems that use filtration. He noted that the new requirements must ensure the total treatment process - filtration plus disinfection - achieves at least a 99.9% (3-log) removal or inactivation of *Giardia* cysts. That rule, however, does not address *Cryptosporidium* oocysts. Because of their public health importance and the difference in response to filtration and disinfection treatment processes as compared with *Giardia*, *Cryptosporidium* will have to be incorporated into the rule.

Adoption of the US EPA's proposed approaches for providing additional protection from waterborne pathogens in domestic water supplies will be a major step toward reducing the frequency and intensity of both the epidemic and endemic microbial diseases. It is clear, however, that it will still be necessary to develop a regulatory framework and associated funding at the state level to implement the improved public health protection provisions that would be afforded by US EPA's proposed Surface Water Treatment and Groundwater

Disinfection Rules. Further, state regulatory framework and funding will be needed for additional treatment/protection that may come to be recognized as needed to control microbial pathogens in domestic water supplies with a high degree of certainty so that those who use the water can be assured that there is little risk of acquiring a waterborne disease. It will be especially important to find mechanisms by which to assist small water utilities in implementing significantly improved control programs for microbial pathogens.

On behalf of the Natural Resources Defense Council, Olson (1993a) released a report entitled, *"Think Before You Drink: The Failure of the Nation's Drinking Water System to Protect Public Health."* That report summarized some of the literature pertinent to public health problems associated with chemical contaminants and pathogens in domestic water supplies. The Olson-NRDC report was based on two years of research, document review, and data analysis. According to Olson (1993a), review of US EPA records for 1991-1992 showed that the water purveyors of the US committed over 250,000 violations of the Safe Drinking Water Act; those water purveyors in violation supplied water to more than 100 million people. There were more than 25,000 violations for drinking water standards (MCL's) during that period. Olson (1993a) also reported on what he termed "Under-Reporting and Outright Deceit in Reporting Drinking Water Contamination." He claims that the General Accounting Office (GAO) and the US EPA have found widespread under-reporting of violations by water utilities. There is also widespread failure on the part of state and federal agencies to enforce the existing regulations. That failure relates to a lack of adequate funding to properly carry out the enforcement requirements of the Safe Drinking Water Act.

Olson (1993a) specifically singled out as water supply health risks the microbial pathogens, disinfection by-products, arsenic, lead, and radon. Olson (1993a) stated,

> *"Many state programs for protecting drinking water are in disarray due to inadequate funding, inability or unwillingness to adopt EPA's mandatory drinking water regulations in a timely fashion, and failure to enforce the Safe Drinking Water Act's rules requiring drinking water protection."*

Olson-NRDC was critical of water utilities and their professional organizations for their lobbying Congress to weaken the Safe Drinking Water Act in its reauthorization. Upon release of the Olson-NRDC report, US EPA Administrator C. Browner (1993) stated in a press release,

> *"The Clinton Administration has proposed a major overhaul of the Safe Drinking Water Act, one that agrees with most of the recommendations made today by the Natural Resources Defense Council in its report."*
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> * * *
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> *"We are proposing a package of reforms that will toughen enforcement, provide new funds to communities, and ensure the safety of the water supply and public health."*

There is widespread consensus in the technical community that there are significant problems in the approaches currently being used in treatment/management of domestic water supply water quality, especially as they relate to the protection of the public from waterborne microbial pathogens.

Coincident Concerns

One of the primary areas of concern in the more effective disinfection of municipal water supplies by chlorination is the increased formation of disinfection by-products, such as the trihalomethanes (THM's), chloroacetic acids, etc. There is no doubt that the effectiveness of chlorine disinfection of municipal water supplies has significantly decreased over the past 10 years or so, since the US EPA adopted limits for THM's in domestic water supplies. To meet the 100 μg/L total THM limit, many water utilities converted to disinfection by chloramination, in which ammonia is deliberately added to react with the chlorine to form chloramines. The chloramines are well-known to be far less-effective in disinfection for viruses and protozoans than free chlorine.

Miller (1993) summarized current information on disinfection by-products formed in the treatment of domestic water supplies. He noted that important changes will soon be made in regulating THM's and other disinfection by-products; the TTHM limit will be decreased and several additional disinfection by-products, such as chloroacetic acid, will be regulated. This situation could readily cause some water utilities no discontinue using the chloramination alternative to chlorination to meet THM limits since while chloramination reduces the amount THM's formed, it does not eliminate their formation.

Regli (1993) and Regli *et al.* (1993) offered a decision matrix for balancing the human health hazards of chemical disinfection by-products and the hazards of microbial pathogens. To reliably define that balance, however, there is need for additional research, especially on the disinfectant dose -- pathogen response (kill or inactivation) relationships for some of the microbial pathogens of greatest concern today, e.g., *Cryptosporidium*. The lack of a reliable dose--response relationship for *Cryptosporidium* is not justification for not including *Cryptosporidium* and other waterborne disease agents as significant factors in causing environmental-derived disease in humans. The fact that 370,000 people became ill last spring because of *Cryptosporidium* in the Milwaukee water supply that was considered to be "safe" but was in fact inadequately treated, points to the significance of this organism as a cause of human disease.

It is clear that there are significant public health risks associated with microbial pathogens in domestic water supplies that are not now being adequately addressed. The public health risk associated with microbial pathogens may be far greater than that associated with the residual unregulated chemicals in domestic water supplies today.

Recent Information on Occurrence of Waterborne Pathogenic Protozoans

The Milwaukee Journal (1993) published a special reprint of series of articles that had been published during the week September 19-26, 1993, entitled, "Fatal Neglect - Milwaukee's Deadly Water Crisis Shows How Federal Inaction Has Endangered Our Health." That reprint report is highly critical of the US EPA's failure to develop policies to address the potential for outbreaks of *Cryptosporidium* such as had occurred in Milwaukee. The concern about *Cryptosporidium* in drinking water began nearly two decades ago; since the first reported case in 1974, major outbreaks have occurred in Carrollton, GA (where 13,000 people reportedly became ill), in Jackson County, OR (where 15,000 people reportedly became ill), and elsewhere in the US. Representatives of regulatory agencies were quoted by the Milwaukee Journal

(1993) as having stated that they were aware of the potential for public health problems to be caused by *Cryptosporidium* in drinking water although no action had taken to address it. The findings of the Milwaukee Journal (1993) review of this outbreak were

- *"• Government regulators knew Cryptosporidium lurked dangerously in drinking water but took no action*
- *Cryptosporidium is still causing long-term medical problems and deaths*
- *Milwaukee's epidemic has cost more than $54 million*
- *A leader in Congress who oversaw years of drinking water research cuts shipped $105 million in environmental money to his hometown*
- *Federal regulators for 20 years focused on chemicals in drinking water while ignoring more immediate health dangers from microorganisms*
- *Microorganisms in water may cause up to a third of all US diarrheal illness*
- *Current water treatment standards do not protect us from microorganisms".*

The scientific community recognized that *Cryptosporidium* was a significant danger long before the Milwaukee outbreak; the Milwaukee Journal (1993) review stated *"...that scientific knowledge evaded a flawed regulatory process that typifies the federal bureaucracy at its worst."* However, it is as much, if not more, the responsibility of the state regulatory community to address such issues. In the water quality management field, there is a chronic battle between the federal and state regulatory purviews. While it is not uncommon for states to feel that the federal agency (US EPA) tends to over-regulate, it often occurs that the US EPA is forced to regulate because of inaction by state and local agencies. It is the responsibility of state and local agencies to provide protection of water quality and public health. As long as federal and state agencies responsible for water quality are underfunded and understaffed to fulfill their regulatory obligations, problems of the type experienced with the outbreak of *Cryptosporidium* will be expected to occur. GAO (1993) discussed problems states are having in implementing the Safe Drinking Water Act with the resources available to them. GAO predicted that this situation will deteriorate further over the next few years because of increasingly diminishing resources available to states for these activities.

Leland *et al.* (1993) discussed an outbreak of cryptosporidiosis outbreak from a filtered-water supply in Jackson County, OR during January to June 1992. They reported that mechanical and operational difficulties at the water treatment plant and unusually poor water supply conditions associated with low stream flows that were not addressed with the treatment plant led to the outbreak. That situation was similar to that encountered in the spring of 1993 in Milwaukee, WI where inadequate filtration and elevated levels of raw water turbidity led to breakthrough of insufficiently filtered water that contained *Cryptosporidium*. As with the Milwaukee outbreak, cattle in the watershed were implicated as a source of the *Cryptosporidium* in the Jackson County, OR outbreak.

Rose *et al.* (1991) and LeChevallier *et al.* (1991) previously presented information on the occurrence of *Cryptosporidium* and *Giardia* in raw water supplies from 14 to 17 US states and 1 Canadian province. In a study of 257 surface water samples Rose *et al.* (1991) found that *Cryptosporidia* were found in 55% of the surface water samples, while *Giardia* were found in 16% of the samples. In a study of the raw water for 66 surface water treatment plants, LeChavellier *et al.* (1991) found that *Cryptosporidium* oocysts were present in 87% of the raw water locations and *Giardia* cysts were found in 81% of the raw water samples. Both groups

of investigators concluded that the cysts or oocysts are ubiquitous in many water supplies, and therefore pose a potentially significant threat of waterborne disease in situations where the treatment (filtration) practiced is not adequate.

In 1991-1992 MWD (1993) conducted a one-year pathogen monitoring program of its source and finished waters for enteric viruses, *Giardia*, *Cryptosporidium*, *Legionella*, as well as a number of indicator organisms. One hundred nine samples were collected for analysis. *Giardia* were found in about 14% of the samples of raw water evaluated; concentrations were as high 1.5 cysts per 100 liters. *Giardia* were not detected in any of the finished water samples analyzed. *Cryptosporidium* were found in 24% of the raw water samples in concentrations to 1.77 oocysts per 100 liters; 2 of the 34 finished water samples evaluated were positive for *Cryptosporidium* (0.21 and 0.28 oocysts per 100 liters). It was noted in the MWD study that the concentrations of *Giardia* and *Cryptosporidium* in the source waters investigated were 90% to 99.9% lower than concentrations observed in similar studies conducted in different geographical locations of the United States.

Stewart (1993) recently reported on the findings of MWD's State Project/Delta Water Pathogens Monitoring Project during the period April 1992 to April 1993. Forty-eight samples were collected at several locations in the State Water Project source system and the MWD water treatment system, and analyzed for *Giardia*, *Cryptosporidium*, enteric viruses, and fecal and total coliforms. He reported that 42% of the samples of Sacramento River water collected at Greene's Landing (about 10 miles below the city of Sacramento's domestic wastewater discharge) contained *Giardia* cysts. At the Banks Pumping Plant, the location from which water is taken from the Delta System for the State Project, no *Giardia* cysts were found in the samples collected. *Cryptosporidium* oocysts were found in 50% of the samples collected at Greene's Landing and in 25% of the samples collected at the Banks Pumping Plant. Enteric viruses were found in three of the 48 samples collected in this study; two of the samples positive for enteric viruses were collected at Greene's Landing and one at the Banks Pumping Plant. Stewart pointed out that while concentrations of *Giardia* and *Cryptosporidium* in State Project/Delta Water were about six-times lower than those reported in surface waters in nationwide surveys, they were 200 to 600 times higher than those found in MWD's survey of reservoirs in Southern California that receive State Project Water and Colorado River water. Stewart warned that consideration of these findings should take into consideration the limitations of the methodology and analytical interference encountered. Without further substantiation, the data should not be interpreted to mean that the passage of water through the Delta region affected the microbial character of the water.

It is important to point out that there are significant problems in the methodology for quantifying *Cryptosporidium* and *Giardia* in water supplies that affect their reliability; the methods used tend to underestimate the occurrence of these organisms compared with the actual numbers present. Stewart (1993) indicated that there is need for significant improvement in the methodology for recovery of *Cryptosporidium* and other waterborne pathogens, especially in turbid waters.

Rose's (1993) reporting of the widespread occurrence of *Giardia* and *Cryptosporidium* in raw water supplies throughout the United States and the significant contamination of finished drinking waters with low levels of oocysts and cysts that can lead to both epidemic and endemic disease, points to the importance of developing significantly more reliable methods of detection as well as of improving domestic water supply protection and treatment. MWD's finding of these organisms in the major water supply system of the state of California points to the need for enhanced protection of domestic water supplies in California from waterborne pathogens.

Recent Information on Waterborne Enteroviruses

Payment (1993) recently reviewed the prevalence of waterborne viral disease, the occurrence of pathogenic viruses in water supplies, and the sources of enteric viruses. He reported that there are more than 100 known enteric viruses, all of which are pathogenic to man, and concluded that the human health risks of waterborne viruses are generally underestimated. In addition to causing gastroenteritis, enteric viral infections can also result in meningitis, respiratory disease, and encephalitis. Payment pointed out that children less than 10 years of age are particularly susceptible because of their low levels of immunity.

Payment (1993) also reported that viruses have been found in a small number of drinking waters that meet current microbiological water quality criteria, supporting that, as has been recognized, the fecal coliform test is not reliable for the detection of contamination by enteric viruses. He concluded that enteric viruses are a major health risk for consumers because enteric viruses are ubiquitous in domestic water supplies, they are extremely resistant to water treatment processes, and the immunity of US and Canadian populations to enteric viral infection is low.

Payment (1993) also discussed the societal costs of the so-called "mild illnesses" that do not necessarily result in hospitalization or consultation with a physician. Because of the wide range of symptoms associated with enteroviruses and because enteroviruses may be acquired through routes other than water, it is impossible to estimate the societal costs of mild illnesses caused by waterborne enteroviruses. However, those costs are expected to be very high, ranging in the order of hundreds of millions of dollars per year for the USA.

MWD (1993) reported that enteric viruses were detected in 9% (5 of 58) of raw water samples and in 3% (1 of 34) of finished water samples evaluated. Gene probe analyses on the concentrates revealed that the predominate viruses were of the human enterovirus group (poliovirus, coxsackieviruses, and echoviruses); no Hepatitis A virus was detected.

Recent Information on Waterborne Bacterial Diseases

Olson (1993b) recently reviewed the occurrence of bacterial pathogens in domestic water supplies. She pointed out that outbreaks of waterborne bacterial disease from such organisms as *Legionella, E. coli, Shigella, Vibrio cholerae,* and *Yersinia* occasionally occur where those organisms are found in the environment in relatively high concentrations. According to Olson (1993b) the conditions that lead to these outbreaks are poorly understood.

One of the more common diseases associated with drinking water is legionellosis (Legionnaires' Disease and Pontiac Fever). According to Cal/EPA (1993), approximately 50 to 100 cases of Legionnaires' Disease are reported in California every year. However, due to reporting procedures, it is difficult to differentiate the number of morbidities from mortalities. In a recent study conducted by the CDC, Marston *et al.* (1993) estimated that community-acquired legionellosis is under-reported by a factor of ten.

Not all cases of legionellosis are fatal; in fact, the majority of cases fit the symptomatology of Pontiac Fever, a flu-like disease. Legionnaires' Disease occurs sporadically among immuno-compromised populations, but on rare occasion can occur in an outbreak situation, infecting normally healthy individuals. Bacteria of the genus *Legionella* can survive drinking water treatment and can be disbursed in small numbers throughout a water distribution system.

A recent survey of the occurrence of legionellae in municipal drinking water supplies in California revealed that more than 50% of samples of source waters analyzed in MWD's Pathogen Monitoring Program were positive for *Legionella* spp. (Paszko-Kovla *et al.*, 1993; MWD, 1993). Further, it was found that 30% of finished drinking water samples tested were positive for *Legionella* spp.; 25% were positive for *Legionella pneumophila*. Concentrations of *Legionellae* in positive raw water samples were reported to be as high as 400 cells/mL; concentrations in positive finished drinking water samples were reported to be as high as 120 cells/mL. Those concentrations were similar to those reported from other studies of waters in the United States. Joly (1993) stated that, worldwide, water in up to 75% of hospitals, 50% of hotels, and 30% of private houses have tested positive for legionellae. Humidifiers and heat exchange systems (e.g., cooling towers), have been linked to outbreaks of legionellosis. Shelton *et al.* (1993) suggested a rating system for risk of legionellosis from cooling towers based upon the concentration of legionella (CFU/mL) in the water.

Risks of Microbiological Disease Associated with Water Contact

It is difficult to estimate risk of acquiring a disease through water contact recreation since there is little dose-response data; organisms responsible for those diseases are, with a few exceptions, not routinely measured; the methods for measuring some of the more pathogenic organisms (e.g., encephalitic amoeba) are not robust; and reporting is rare unless associated with a large outbreak (e.g., associated with a swimming pool or bathing beach).

In ocean waters, the US EPA and California State Water Resources Control Board (SWRCB) employ standards for microbial "quality" based on indicator organisms (coliforms and enterococci) (SWRCB, 1990). In some studies, the concentrations of enterococci have been linked to the rate of swimming-associated gastroenteritis (Cabelli *et al.*, 1983). The Santa Monica Bay Restoration Project (SMBRP) has compiled data on the concentrations of enterococci from several locations along the extent of Santa Monica Bay and has calculated the relative risk of contracting swimming-associated gastroenteritis (SMBRP, 1992). Based on SMBRP enterococci data and a US EPA model for predicting gastroenteritis using that indicator, in dry weather, the average number of persons expected to contract acute gastrointestinal illness (AGI) should be between 0 and 12 per 1,000 persons exposed. The 90th percentile would be 10 to 22 persons with AGI per 1,000 persons exposed. In wet weather, the number of persons that would be expected to contract AGI increases to an average of 12 to 17 expected AGI per 1,000 persons, with a 90th percentile of 20 to 30 expected AGI per 1,000 persons. However, in practice, there are usually fewer people using the beaches during wet periods and the County Health Departments routinely close beaches that fail to meet microbiological water quality standards.

In the mid-1980's, numerous claims were being made by various environmental groups that a significant number of people were contracting diseases from body contact with New Jersey coastal waters. Those claims led the state Medical Society to undertake a review of this issue; it appointed an advisory committee to review the information available on the incidence of disease arising from contact recreation with New Jersey coastal waters; the senior author of this report (G. F. Lee) was a member of that advisory committee. The state Medical Society concluded that there was no evidence of an increase in disease as a result of contact recreation in New Jersey coastal waters. It also reported, however, that the data base upon which its conclusion was developed may not be adequate to detect a low-level disease incident that may occur from body contact with coastal waters of the State. This led the New Jersey Department

of Health (NJDOH) to conduct one of the most comprehensive studies of the public health risks associated with contact recreation in coastal marine waters (NJDOH, 1990).

The NJDOH study, initiated in the spring of 1987, had as its specific objective the determination of whether microbial contamination of ocean nearshore areas by municipal wastewater discharges or stormwater runoff was causing an increased risk of infectious disease by primary contact recreation. The study included investigation of beach water quality and health effects on beach-goers at nine beaches along the New Jersey shore and at two inland lakes. The study included analysis of hundreds of water samples and interviews of more than 16,000 beach-goers during the summers of 1987 and 1988. Four microbial indicators of contamination were used in these studies, fecal coliforms, enterococci, F2 male-specific bacteriophage, and *Clostridium perfringens*. The 1988 study included examination of Highly Credible Gastrointestinal Illness (HCGI), also known as "stomach virus." Other infectious illnesses included in the study were ear infections, eye irritations, skin rashes, and sore throats.

In 1987 and 1988 the levels of all four microbial indicators were low at nearly all beaches on almost all weekends. Findings from follow up interviews of swimmers were that swimmers at all beaches had higher rates of symptoms than did non-swimmers, but there was no increased illness associated with sewage or stormwater runoff at any of the study beaches. These results were consistent with previous studies conducted in the US and Canada. It is well-documented that the activity of swimming carries with it an inherent risk of these common health complaints. The overall conclusions from those studies was that during the summers of 1987 and 1988 when the overall beach water quality was good based on the indicators used, there was no discernible increase in illness that could be attributed to body contact with particular bathing waters.

It is important to point out that the New Jersey coastal water studies did not include examination of the incidence of disease associated with swimming or other body-contact in waters determined to be grossly polluted based on fecal coliform or enterococcus standards that are used today to assess whether beaches should be closed because of pollution. There have, however, been numerous studies over the years on the incidence of illness to swimmers and others who had contact with grossly polluted waters as determined by total coliform and fecal coliform standards. It has been repeatedly found that there is no relationship between the incidence of disease and the concentrations of total coliform or fecal coliform concentrations in bathing waters. It was for this reason that the US EPA (1986) concluded the fecal coliform standard for beach contact recreation is not a reliable indication of risk associated with body contact recreation. NAS/NAE (1973) had cautioned about use of coliform indicators of bacterial quality of bathing waters since many of the diseases that seem to be causally related to swimming in polluted water are not enteric diseases or are not caused by enteric organisms.

A group of organisms of concern are the non-cholera vibrios that can cause wound infections that can lead to sepsis. That group of organisms is almost impossible to control since they are native to ocean and estuarine waters. The most effective way to avoid contact with those organisms is to avoid contact with those waters. Tackett *et al.* (1984) estimated the relative risk of developing wound infections from *Vibrio* spp. This type of analysis has not been conducted for infections caused by other relatively common bacterial genera such as *Aeromonas, Staphylococcus*, or *Pseudomonas*. Those organisms are generally responsible for folliculitis and wound infections associated with fresh water, estuaries, swimming pools, hot tubs, whirlpools, etc. In some cases, *Pseudomonas* spp. and toxigenic *Aeromonas* spp. can proceed to septicemia if wounds are sufficiently deep. There have been studies that have shown that 70% to 90% of *Aeromonas* isolates are pathogenic in animal models (Morgan *et al.*, 1985).

Mortalities can occur with these bacterial organisms, but generally they occur sporadically and in the form of a secondary infection. The number of these types of infections, directly linked to water, and leading to death, annually has not been reported.

Although rare, primary amoebic meningoencephalitis (PAM) is a rapidly fatal, human water-contact disease caused by protozoans of the genera *Acanthameoba* and *Naegleria*. Those organisms are associated with fresh water; *Naegleria* is most commonly associated with warm waters and thermal pools. In animal models, 10,000 of these organisms introduced intranasally (common route of transmission) can produced up to 100% mortality. PAM are not reportable diseases unless they are linked to an outbreak.

Risks Associated with Reclaimed Water

Industrial and population growth coupled with years of drought has made Californians more conscious of the value and importance of water. Even though the most-recent drought has officially passed, many communities continue control measures for water consumption and search for alternate sources of water. To that end, some communities have established wastewater reclamation facilities to provide water for such uses as agriculture, landscaping, recreation, and groundwater recharge. The use of "reclaimed" (treated) domestic wastewaters is being encouraged and is increasing in California. The state of California has a goal of recycling 700,000 acre-feet of wastewater by the year 2000, and 1,000,000 acre-feet by the year 2010. While much of that reclaimed wastewater would be used ways that represent a limited threat to groundwater quality, some land-surface uses, such as lawn and shrubbery irrigation, could lead to groundwater pollution by contaminants in the reclaimed wastewater since the reclaimed wastewater is not necessarily treated adequately to prevent groundwater pollution by residual contaminants in the reclaimed wastewater. Much of the reclaimed wastewater that is used today for irrigation of shrubbery, golf courses, and other areas has not been adequately treated to remove human pathogens. Of particular concern are the cyst-forming protozoans such as *Cryptosporidium* and *Giardia*, and those that cause amoebic dysentery. Further, some of the treatment provided for reclaimed wastewater is not effective for killing (inactivating) enteric viruses that can cause human disease.

The degree of treatment of wastewaters before groundwater recharge depends on whether the recharge takes place at the surface by recharge from river-beds or infiltration ponds, or by injection into the aquifer through wells. Less treatment beyond conventional wastewater treatment is typically required when the recharge is accomplished by infiltration. Some water districts are actively involved in enhanced river-bed recharge of groundwaters with treated domestic wastewaters that have not received additional treatment beyond conventional wastewater treatment.

The infiltration of reclaimed wastewaters from river-beds and ponds makes use of the unsaturated zone of the aquifer for removal of some contaminants before the recharge water reaches the watertable. Use of the unsaturated zone for that additional treatment causes localized pollution of the unsaturated zone by the contaminants that remain in it, such as inorganics (e.g., heavy metals and salts) and certain organics their transformation products. During the period of recharge, that area may become fully saturated which affects the reactions/transformations that take place in that area. As discussed by Lee and Jones-Lee (1993a) there can be significant differences in the transport and transformation of chemicals and in the persistence of microorganisms including pathogens in unsaturated and saturated systems.

At this time there is no consistent pattern of regulating the type or amount of treatment, or characteristics, of wastewaters prior to their incidental or enhanced recharge into groundwaters. The California Department of Health Services (DHS) has developed revised, updated Title 22 regulations governing some aspects of enhanced groundwater recharge, such as direct injection and specifically constructed infiltration basins. These have been available for informal professional review (information) and are expected to published soon for public review. Those regulations, however, do not address the enhanced groundwater recharge of domestic and industrial wastewaters that occurs in natural river-beds. The NPDES permits issued to some wastewater dischargers by some regional boards consider the potential for chemical contaminants in the wastewaters to cause groundwater pollution by enhanced river-bed and incidental groundwater recharge. There is however no consistent policy or approach in effect in this area at this time. Further, and most importantly, many enhanced and incidental recharge situations that are occurring in the State are not being adequately monitored to detect incipient groundwater pollution before widespread pollution occurs.

The draft revised DHS Title 22 treatment requirements for certain types of enhanced domestic wastewater recharge that are soon to be released by DHS are based largely on the experience gained at several locations in the State where enhanced groundwater recharge has been practiced for a number of years. It appears that high degrees of additional treatment can render domestic wastewaters apparently "safe" for enhanced groundwater recharge considering known, potentially hazardous or otherwise deleterious chemicals and pathogens. The major area of concern, however, is that the known, regulated chemicals being considered in projects recharging groundwater with reclaimed wastewater represent only a small number of the potentially hazardous or otherwise deleterious chemicals that are present in domestic and other wastewaters that could be detrimental to the quality of the recovered groundwaters. While on the order of 100 to 200 chemicals may be examined (regulated) in a reclaimed wastewater groundwater recharge project, there are on the order of 60,000 chemicals in use in the US today.

The DHS draft regulations focus on the total organic carbon (TOC) content of recharge waters as an approach to reduce the "hazard" of unknown chemical contaminants in domestic wastewaters. The DHS approach is to reduce the TOC in the enhanced recharged domestic wastewaters to an arbitrarily established level of a few mg/L based on the method of enhanced recharge that takes place outside of river-beds, i.e., in infiltration ponds and by direct injection. However, a large proportion of the organic chemicals remaining in reclaimed wastewater after treatment to the degrees proposed by DHS, are unidentified and unknown, and therefore uncharacterized. These unidentified, uncharacterized organic components are commonly referred to as "non-conventional" pollutants and account for most of the compounds measured as "total organic carbon" in domestic wastewaters. It is well-established that there is a major discrepancy between the TOC present in treated domestic wastewaters that have been judged suitable for groundwater recharge and the sum of the identified, known organic chemicals in those waters. Thus, while the approach proposed by DHS is a step in the right direction toward protecting groundwater quality from adverse impact from recharge waters, it is not necessarily adequate to address the key issue of unidentified hazardous/deleterious chemicals (non-conventional pollutants) remaining in treated reclaimed wastewaters that meet the TOC limitation, that will be a significant threat to public health and/or groundwater quality in association with an enhanced reclaimed wastewater recharge project.

It is important to understand that the amount of groundwater recharge that occurs from enhanced recharge projects with reclaimed wastewaters that have typically received additional treatment is small compared to the incidental groundwater recharge of less-well-treated domestic and other wastewaters, and of untreated stormwater runoff from urban and rural areas that has occurred and continues to occur in the State. If there are highly hazardous, yet-to-be-

identified chemicals in treated domestic wastewaters that are a threat to groundwater quality, the threat from the incidental or unregulated enhanced recharge that occurs in river-beds would, in most areas, be a greater threat than that from recharge projects regulated under DHS Title 22. Further, DHS has not yet focused its regulatory program for reclaimed wastewaters on the control of the cyst-forming and oocyst-forming pathogenic protozoans that are known to cause significant disease in humans. For wastewater reclamation regulated by and meeting the California Department of Health Services requirements there appears to be a very small to insignificant public health risk. There are, however, significant gaps in the regulation of reclaimed wastewaters that could lead to increased health risks for some members of the public, to pathogenic agents in inadequately treated reclaimed wastewaters. With the State's emphasis on increasing the amount of reclaimed wastewaters used in California it is important that the regulatory framework be developed and most importantly adequately funded to be reliably implemented to provide a high degree of protection of public health from pathogenic agents in reclaimed wastewaters directly or indirectly reused. The increased use of household gray water for landscaping irrigation represents a small potential increased risk of waterborne pathogen transmission to the public for those systems in which the public comes in contact with the gray water.

Current California regulations prohibit the use of reclaimed wastewater for direct reuse for drinking (DHS, 1993). However, depending on the level of treatment, reclaimed water may be used for unrestricted and restricted recreational use, and for restricted and unrestricted irrigation of crops.

Asano *et al.* (1992) used a risk model for virus infection to estimate the relative risks associated with different applications of reclaimed municipal wastewater in California. Based on exposure to chlorinated effluent with 1 viral unit per 100 liters, the following predictions were made:

Application	Annual Risk
Recreational (Swimming or Golfing)	10^{-2} to 10^{-7}
Food Crop Irrigation/Groundwater Recharge	10^{-5} to 10^{-11}

There have been several studies conducted by utilities in California on the microbiological quality of wastewater reclamation. The Sanitary Districts of the County of Los Angeles experimented with the tertiary treatment of wastewater (Parkhurst, 1977). That project employed methods of advanced wastewater treatment from Title 22 California Health and Safety Code; it was reported that no enteric viruses were detected in the effluent samples. Similar studies involving domestic wastewater reuse and groundwater recharge were undertaken by Orange County Sanitary District (Water Factory 21) and Los Angeles County at its Whitter Narrows site. A health effects committee determined that the effluents from those two systems did not produce significant health effects, and reported the risks to be similar to those risks estimated for commonly used surface water (Hrudey and Hrudey, 1988).

The Monterey Wastewater Reclamation Study for Agriculture (Cort *et al.*, 1988) investigated the impacts of the same Title 22 methods of advanced wastewater treatment on the removal of enteric viruses from the wastewater, and on the survivability of enteric viruses on a variety of crops. No viruses were detected on the vegetation of any of the plants receiving the advanced-treated wastewater.

More recently, the city of San Diego completed a Health Effects Study (SDHES) of its tertiary treatment wastewater pilot plant (Cooper *et al.*, 1993). Following three years of intensive monitoring of tens of thousands of gallons of non-chlorinated effluent, no enteric pathogens (enteric viruses, *Giardia, Cryptosporidium, Salmonella, Shigella, Campylobacter*, and other intestinal parasites) were detected in the final effluents. Virus spiking studies showed >99.99999% removal of poliovirus by that treatment system. Given that the virus concentrations in the wastewater were 100 to 10,000 pfu per liter, the concentration of viruses in the final effluent would theoretically be expected to be 0.01 pfu per 100 liters. Concentrations of *Giardia* were found to be 100 to 1000 cysts per liter in the wastewater; their concentrations would be expected to be 0.0001 cysts per 100 liters in the finished water. However, if the finished water were subject to further treatment (chlorination), the concentrations of those agents could be reduced by another 100 to 1000 fold. The number of virus would be about 0.000001 pfu per liter and *Giardia* concentrations would be about 0.000001 cysts per liter, thus further reducing the risk of infection.

In addition to the three years of microbiological monitoring, the SDHES conducted an epidemiological study of women of child-bearing age and collected data on reproductive outcomes of more than 1500 women. The object of that part of the study was to determine the baseline of vital statistics and prevalence rates of genetic disease in the exposed population so that comparisons could be made with the characteristics of future generations exposed to the product water from the full-scale plant. A full-scale plant that will produce 5 million gallons of reclaimed water per day is scheduled to begin in 1994. During the first two years of operation (1994-1995) the same level of scrutiny will be applied to the scale plant as was used for the pilot plant.

The reliability of risk assessments for wastewater reuse depend on the reliability of the treatment plant to perform as expected. The US EPA has established criteria that treatment plants can follow to identify the sub-system most likely to fail (US EPA, 1982). That information is vital for identifying where redundant systems are necessary in order to maintain the quality of effluent. While some California wastewater reclamation efforts have reportedly been able to produce water that meets current drinking water standards for those parameters for which standards exist, the State Health and Safety Code prohibits the direct reuse of domestic wastewater for drinking water.

The recent drought has stimulated interest in the development of individual gray-water reuse systems in which homeowners reuse waters from some parts of their home systems for example to irrigate shrubbery. Lee and Jones-Lee (1993b) discussed the potential for gray water systems to lead to surface and groundwater pollution. Rose *et al.* (1991) investigated the health effects of domestic gray water usage. They reported that pathogenic enteric viruses can survive up to one week in stored gray water. Therefore, there are increased risks associated with gray water reuse when shedding hosts are contributing to the gray water reservoir.

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QUALIFICATIONS OF THE AUTHORS

The senior author, G. F. Lee, has had more than 35 years of experience in domestic water supply water quality issues. He has frequently served as an advisor to regulatory agencies and has conducted extensive research on water supply water quality, water and wastewater treatment, and water pollution control. He and Dr. Jones-Lee have worked together as a team on these issues since the mid-1970's.

Dr. Lee has a bachelor degree and a Master of Science in Public Health degree with emphasis on the environmental sciences/water quality. His PhD degree is in environmental engineering with emphasis on aquatic chemistry and public health microbiology. He taught graduate-level water quality courses in university environmental engineering programs for 30 years. In 1989 he relinquished his Distinguished Professorship in Civil and Environmental Engineering to expanded the part-time consulting he had been doing while a university professor into a full time endeavor. During his university career he conducted more than $5 million in research in a variety of areas of water quality evaluation and management; he has published more than 600 professional papers and reports on his work.

Dr. Jones-Lee has an undergraduate degree in biology and masters and PhD degrees in environmental sciences with emphasis on biological and chemical aspects of water quality. She held university and teaching research positions for 11 years. In 1989 she left her tenured Associate Professorship in Civil and Environmental Engineering to work with Dr. G. F. Lee in full-time consulting activities through G. Fred Lee & Associates.