Why the Concern About Pathogens in Water?

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More than 100 years have passed since modern water treatment was first utilized in the United States. In major U.S. cities, the introduction of filtration followed by disinfection led to a dramatic reduction in typhoid, cholera, amoebic dysentery, and other diseases associated with fecally contaminated water. This ended the age of waterborne epidemics in the United States – at least so it was thought. But suddenly in 1993 the largest such outbreak ever documented in the United States occurred in Milwaukee, Wisconsin. More than 400,000 people developed gastroenteritis and 100 individuals died.

Investigations revealed that the protozoan parasite *Cryptosporidium parvum* was responsible (Mackenzie et al., 1994). After a period of heavy rains allowed some of the organisms to penetrate the filtration barrier of the

DEFINITIONS

Enteric
related to the intestinal tract

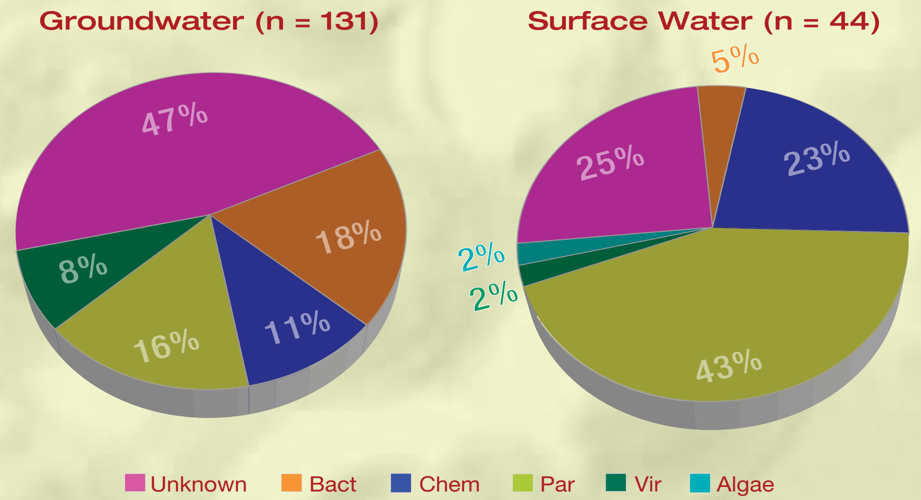
Etiologic
related to the cause of disease

Outbreak
generally two or more people experiencing similar illness that can be traced to a single source

Pathogen
disease-causing microorganism

The annual number of drinking water-borne disease outbreaks reported in the United States has more than doubled in the last few years and the number of outbreaks associated with recreational water use has more than tripled.

Etiologic agents associated with drinking water outbreaks, by water type - United States, 1989-2000

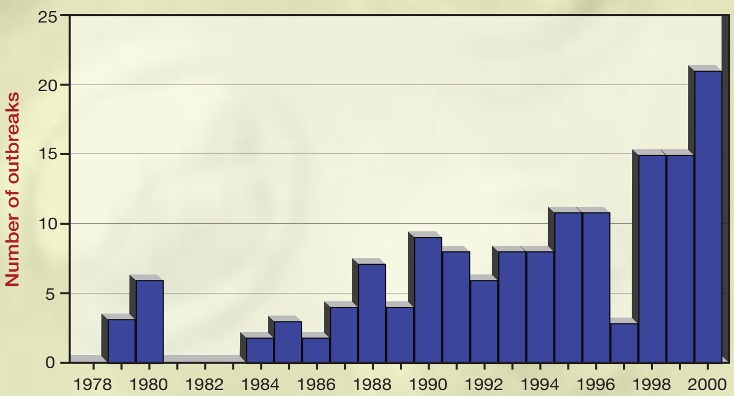


Cause of outbreaks in groundwater and surface water. Unknown = acute gastrointestinal illness of unknown cause (etiology); Bact = bacteria; Chem = chemicals; Par = parasites; Vir = viruses. n = number of outbreaks traceable to either a groundwater or surface water source. An outbreak is generally defined as two or more people experiencing similar illness traceable to a common drinking water source. From the Centers for Disease Control and Prevention.

Background: Cryptosporidium *oocysts, typically 3-7 µm in size. Image courtesy of CH Diagnostic and Consulting Services, Inc., Loveland, Colorado.*

city's water source, the organism appeared in high concentrations. Because *Cryptosporidium* is extremely resistant to chlorine disinfection, these infectious organisms were able to reach household taps. Surveys from a decade ago showed that *Cryptosporidium* was common in surface waters and in 60 percent of the treated drinking water supplies in the United States (Rose et al., 1991; LeChevallier and Norton, 1995). It became obvious that *Cryptosporidium* was causing a low level of endemic illness via the drinking water. Since that time, new rules for protecting, treating, and monitoring surface water supplies have been put into place in the United States and the United Kingdom. Later this year, the U. S. Environmental Protection Agency is expected to release a final version of the Groundwater Treatment Rule designed to protect drinking water from disease-causing microorganisms, known as pathogens.

Recreational Water-Related Outbreaks



Number of outbreaks involving gastoenteritis associated with recreational water, by year in the United States, 1978-2000 (n=146). Source: Centers for Disease Control and Prevention.

Primary Pathogens Transmitted by Water

Although humans are continually exposed to a vast array of microorganisms in the environment, only a small portion of these microbes are pathogens. The three primary groups of pathogens are viruses, bacteria, and protozoa (see box below). Pathogenic viruses transmitted by water usually are of human origin. Disease-causing enteric bacteria require food and do not survive in the environment as long as do viruses and protozoa. The parasitic protozoans, such as *Giardia* and *Cryptosporidium*, are very resistant to disinfectants and can survive for weeks in water. Pathogenic viruses and protozoa are more resistant to drinking water treatment and common disinfectants than bacteria; viruses are also small enough to pass through the filters used in drinking water treatment. Bacteria and protozoa infect animals as well as humans; therefore their presence can always be expected in surface waters.

Water-associated illnesses can be classified into three groups: waterborne, water-based, and water-related. *Waterborne* diseases are transmitted by drinking fecally contaminated water. Microorganisms transmitted by this route are referred to as enteric pathogens since they grow in the intestinal tract and are excreted in the feces. *Water-based* pathogens grow in the water. Some of these, like *Legionella* and *Mycobacterium*, grow in biofilms on the walls of pipes in drinking water distribution systems. *Water-related*

See Pathogens, page 27

The Three Primary Categories of Pathogens

BACTERIA

Bacteria are unicellular organisms that reproduce by binary fission and vary widely in size, with diameters ranging from 0.5 micrometer (μm) to 1.5 μm and length ranging from 1 μm to 6 μm. Infectious gastroenteritis may be caused by a variety of bacterial pathogens, including *E. coli* O157:H7, *Legionella* (Legionnaire's disease) *Salmonella typhi* (typhoid fever), *Campylobacter jejuni* (Campylobacteriosis), *Shigella* (shigellosis), and *Vibrio cholerae* (cholera). The most common clinical symptom of bacterial gastroenteritis includes cramps, abdominal distress, diarrhea, nausea, and vomiting with occasional chills, headache and mild fever. Bacterial pathogens require food, are relatively less resistant in the environment than viral or parasitic pathogens, and can effectively be inactivated in drinking water by chlorination.

VIRUSES

Viruses are the smallest (0.02-0.07 μm in diameter) and most basic of known life forms. They are composed only of nucleic acid and a protein shell (or capsid). Their simple genetic system consists of single-stranded or double-stranded DNA or RNA. They take over living cells and utilize the cells' reproductive mechanisms to replicate and continue their parasitic life. After the subsequent death of the host cell, viral particles are spread to neighboring cells, resulting in the infection of the individual.

More than 140 different enteric viruses are known to infect man. These are excreted in high numbers in the feces of infected individuals (up to 1,000 per gram of feces) and may directly or indirectly contaminate drinking water. They are commonly found in domestic wastewater, even after disinfection. Once in the environment, they can survive for months under the right conditions. The enteric viruses include the enteroviruses, rotaviruses, hepatitis A and E, noroviruses, adenoviruses, reoviruses, and others. They are transmitted by the fecal-oral route, infect the gastrointestinal or respiratory tracts, and are capable of causing a wide range of illnesses including diarrhea, fever, hepatitis, paralysis, meningitis, and heart disease. Ground and surface waters may become fecally contaminated from a variety of sources, including sewage treatment plant effluents, on-site septic waste treatment discharges, land runoff from urban, agricultural, and natural areas, and leachates from sanitary landfills.

PROTOZOA

Waterborne parasites have played a major role in shaping the history of mankind and continue to challenge human civilizations. Because of their relatively larger size and visibility, they have been known since ancient times. *Dracunculus medinensis* (guinea worm), the "fiery serpent of Moses", is mentioned in the Bible. Of nearly 20,000 protozoan parasites, about 20 genera are known to cause diseases in humans. Water utilities continue to face challenges posed by centuries-old and newly emerging parasites.

Numerous waterborne outbreaks of giardiasis and cryptosporidiosis have been documented. Low numbers of *Giardia* cysts and *Cryptosporidium* oocysts are usually found in water supplies. These cysts and oocysts are environmentally resistant and are the infectious units of the microorganisms. After ingestion, they reside in the human gut and cause infection. In healthy people, *Cryptosporidium parvum* causes subclinical infections and self-limiting diarrhea. Infections in immunocompromised people, or those with underlying illnesses, can be persistent and fatal. Duration of infection can range from seven to 14 days in healthy individuals and from 23 to 32 days in the immunocompromised. As few as one to 10 viable cysts or oocysts can cause human infection.

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Pathogens, continued from page 15

diseases are associated with transmission by insects, such as mosquitos, that breed in water. A familiar example is the West Nile virus, which has plagued central Arizona this year.

How Common is Waterborne Illness?

Over the last 20 years, microorganisms have caused 75 percent of all waterborne illnesses associated with drinking water. The annual number of drinking water-borne disease outbreaks reported in the United States has more than doubled in the last few years and the number of outbreaks associated with recreational water use has more than tripled (CDC, 2002). Data from 448 wells in groundwater production aquifers in 36 states showed that viral contamination of U.S. groundwater is common, with eight to 21 percent of samples testing positive (Abbaszadegan et al., 2003). Viruses are believed to be more of a problem than enteric bacteria and parasites in groundwater because they can travel further distances through soil and survive longer. Sources of viral contamination in groundwater are believed to be on-site disposal systems, leaking sewer lines, and animal wastes.

These outbreaks and the recent identification of new microbial agents that could be transmitted by water have resulted in several new treatment rules for their control. Amendments to the Safe Drinking Water Act in 1996 required EPA to review and publish a list of unregulated contaminants that are known or expected to occur in public water systems and that may pose a risk in drinking water. In 1998, the first of these lists, known as the Drinking Water Contaminant Candidate List, or the CCL, was produced. The CCL contains 10 microorganisms selected for their potential for transmission by drinking water (see upper table above).

Microorganisms in the EPA's Contaminant Candidate List

Pathogen	Associated ailments
Acantamoeba	Eye infection
Adenoviruses	Diarrhea; eye, nose and throat infections
Aeromonas hydrophila	Diarrhea
Caliciviruses (Norwalk virus)	Diarrhea; vomiting
Coxsackieviruses	Meningitis; heart disease, fever, rash, diabetes
Cyanobacteria (blue-green algae)	Diarrhea
Echoviruses	Meningitis; rash; vertigo
Helicobacter pylori	Common ulcer; stomach cancer
Microsporidia	Diarrhea
Mycobacterium avium	Lung infection

Why Waterborne Pathogens Continue to Emerge

- Increase in sensitive populations (elderly, immuno-compromised; cancer patients)
- Globalization of commerce and travel
- Development of molecular methods for detection and source tracking
- Changes in drinking water treatment technology
- Changes in food supply production
- Evolution (genetic re-assortment)

Waterborne pathogens have continued to emerge for several reasons (see lower table above). Over the last 10 years, one new potential waterborne pathogen has been identified almost every year. The application of the polymerase chain reaction (see page 35) to pathogen detection in water was a major breakthrough. This technique allows the detection of microorganisms that cannot be grown in the laboratory. It also provides a method to demonstrate whether a pathogen in water is identical to one causing illness in the exposed population. The development of molecular source tracking has led to the new field of identifying sources of waterborne agents in water.

What or Who is to Blame?

Application of these tracking methods has demonstrated how globalization of world trade and travel has resulted in the introduction into industrialized nations of pathogens that were previously limited to the developing world. Changes in the way we produce food also have increased risks from pathogens. The rapid development of confined feeding operations allows more animals to be concentrated at one location. Wastes from these operations now impact our groundwater and surface water supplies. Attempts to improve drinking water quality through new technologies may solve some water treatment issues but also generate new ones. For example, the application of ultraviolet light as a means to disinfect water without causing the production of harmful chloramines removes many pathogens, but simultaneously makes it more difficult to control the viruses that affect the upper respiratory tract, which are especially resistant to UV light. Finally, controlling the growth and distribution of water-based pathogens such as *Legionella* is a continuing challenge because of their resistance to disinfectants.

Water-related diseases will always present a serious challenge to those responsible for managing and treating our water resources. Even during periods when outbreaks of water-related diseases are rare, water managers and health professionals must remain vigilant to new problems that are likely to be introduced through increased globalization, new technologies, and the genetic evolution of pathogens, humans, and animals.

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