FRI FOOD SAFETY REVIEWS

WATER SAFETY AND QUALITY

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Contents

Consumption of water is essential to human life, but, if it contains certain chemicals or pathogenic bacteria, viruses, or parasites, water can also cause serious illness. Epidemics of typhoid fever, cholera, and hepatitis A and E (*10;19;28;38*) plague developing countries without adequate water purification systems. Minerals, such as arsenic in groundwater from certain rock formations, may poison well water over a wide area, for example in Bangladesh (*36*). Pesticides and other chemicals in water may be long- or short-term health threats. While risks for waterborne illness in more developed countries are lower, outbreaks are still reported and are sometimes caused by unexpected pathogens.

Pathogens in water usually cause gastrointestinal symptoms after a variable incubation period that allows for growth. Some pathogens implicated in waterborne diseases are the same as those encountered in foodborne illness. But others, particularly some parasites with animal hosts including *Giardia*, are more commonly associated with waterborne outbreaks. Heavy metals and some chemicals, at high concentrations, may cause immediate symptoms, but at lower concentrations they may accumulate in the body over time to cause serious health issues. Controversy continues as to the real human health risk of some organic contaminants, such as bisphenol A, and of very low concentrations

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of certain chemicals that are known to be toxic to mammals at high concentrations.

Water may also harbor other types of pathogens, such as parasitic schistosomes that penetrate the skin and *Vibrio vulnificus* that causes wound infections. *Legionella* is a waterborne bacterium that causes respiratory infections when it is aerosolized. This brief review will primarily address issues related to water used for drinking and food processing and point out some current areas of concern and provide references for further information. Other hazards related to recreational use or contact with contaminated water will not be discussed in great detail.

Multinational food processing companies should be aware of the hazardous organisms and substances potentially present in water in the countries where they operate. Some waterborne pathogens are more commonly detected in warmer tropical areas or in countries without adequate wastewater treatment systems. As climate change progresses, temperature of surface waters will increase and may permit the growth of new bacteria and parasites (*34*). Managers also need to be alert to conditions in processing plants as well as to external conditions that may impact water quality.

Waterborne Illness Surveillance

Data on waterborne outbreaks in the U.S. are collected by WBDOSS (Waterborne Disease and Outbreak Surveillance System), a program that was started in 1971 by the Centers for Disease Control and Prevention (*4*). Surveillance summaries are published; the most recent one covers outbreaks in 2005–2006 (*45*). According to the CDC, the top five causes of drinking water outbreaks are: *Giardia*, *Shigella*, Norovirus, Hepatitis A, and Copper. A comprehensive review of WBDOSS data on drinking water outbreaks (1971–2006), that discussed information on 833 outbreaks affecting nearly 600,000 people, was published in July 2010 (*6*). About 82% of these outbreaks were associated with public drinking water supplies and 1.3% were traced to commercially bottled water. In 44% of the outbreaks, no etiological agent was detected. Parasites and non-*Legionella* bacteria were the most frequently identified outbreak causes, with viruses, chemicals, and *Legionella* accounting for most of the rest. CDC has also recently published surveillance data on Giardiasis (*48*) and Cryptosporidiosis (*47*).

In 2007, 32 waterborne outbreaks were reported to ENHIS (European Environment and Health Information System) from 8 countries in Europe but this is believed to be a significant underestimate and data were not reported for several large countries (*27*). A total of 354 outbreaks was reported for 2000–2007 in 14 European countries with routine surveillance systems. Reported etiological agents included bacteria (*Campylobacter*, *Aeromonas*, and *Shigella*), 45% of outbreaks; viruses (calicivirus, hepatitis A), 37.5% of outbreaks; protozoa (*Cryptosporidium*, *Giardia*), 5% of outbreaks. The European Centre for Disease Prevention and Control publishes an Annual Epidemiological Report on Communicable Diseases in Europe including information on food- and water-borne diseases. The most recent report, published in 2009, summarizes surveillance data from 2007 (*9*).

Waterborne outbreaks of gastroenteritis are not as commonly reported in Australia. From 2001–2007, a total of 54 outbreaks probably resulted from waterborne transmission of pathogens. Only ten of these outbreaks were associated with drinking water, with *Salmonella* and *Campylobacter* responsible for most of them. *Cryptosporidium* and *Giardia* each caused one outbreak. The remaining outbreaks were primarily ascribed to recreational exposure to contaminated water. *Cryptosporidium* was implicated in nearly all of those outbreaks (*7*).

Many countries have not established routine national programs to collect and publish information on outbreaks of waterborne disease. Some information on food and waterborne diseases in developing countries is available on the Safe Food International web site. Many of the articles are short and do not contain much epidemiological information. However, they may be a useful alert to potential problems that should be considered in certain areas (*33*).

Routes of Water Contamination

Trends among the 833 waterborne outbreaks in the U.S. (1971–2006) included decreases in the importance of outbreaks in public water systems compared to private systems and a decrease in importance of outbreaks associated with surface water but continued importance of groundwater-associated outbreaks (*6*). **Table 1** lists some recently reported outbreaks traced to drinking water systems and factors contributing to the outbreaks. This is not meant to be a comprehensive list of all available data. Rather, it illustrates that water in all countries may contain pathogens and certain conditions enhance the likelihood of human illness. A review of waterborne outbreaks in developed counties reveals that they are a recurring problem even though we have the technology to prevent them (*16*). As Table 1 indicates, extreme weather events may cause flooding and excessive runoff, containing fecal material and pathogens from fields or overflowing septic systems, into shallow wells and surface waters. This excess water may also percolate more rapidly through the soil to groundwater. Turbidity also increases and pathogens often attach to particles. Bacterial and parasitic waterborne outbreaks often occur during the spring and summer when fecal material from animals is washed off fields and pathogens can survive in the warmer water. On the other hand, norovirus contamination of sewage was found to be greater during the winter in Norway, potentially increasing risk of contamination of water systems during cold weather. Viruses are known to persist longer in colder water, including groundwater aquifers (*20*).

Another recurring theme is inadequate disinfection. Usually there are multiple hygienic barriers to pathogens in drinking water facilities. There may be breakdowns in filtering systems caused by excessive inflow of turbid waters or lack of maintenance. Chlorination and other chemical disinfectants inactivate bacteria but are less effective against *Cryptosporidium, Giardia*, and some viruses. Their effectiveness is also decreased by the presence of other organic matter in the water. A great deal of information is available on design of water purification systems and will not be reviewed here. Rather, it should be emphasized that managers should be constantly alert to external conditions that may affect the quality of incoming water. Surface waters are usually more vulnerable to weather events but groundwater can also become contaminated. Deficiencies in disinfection accounted for about half the waterborne outbreaks analyzed in Norway (*20*).

Finally, plumbing problems, such as corrosion or inappropriate cross-connections, may allow mixing of sewage-contaminated water with clean water. A pressure drop in a Norwegian water distribution system allowed an influx of contaminated water causing more than 1000 cases of campylobacteriosis (*20*). Analyses of U.S. data indicate that there has also been an increase in the proportion of outbreaks associated with plumbing deficiencies outside the jurisdiction of public water utilities. Water distribution systems within buildings may not be carefully maintained and biofilms within these pipes can harbor pathogens (*6*).

Table 1. Selected recent waterborne outbreaks

Year	Location	Pathogen/Chemical	Cases	Contributing Factors	Reference
2007–2009	Uganda	Hepatitis E	10,196	Inadequate sanitary facilities and drinking water treatment	(*38*)
2007	US: NH	*Giardia*	31	Well placement near contaminated surface water	(*8*)
2007	Russia	*Legionella*	130	Breakdown in hot water supply to homes	(*18*)
2007	Ireland	*Crypytosporidium*	182	Recent heavy rainfall contaminating reservoir	(*35*)
2007	Finland	7 pathogens: most common *Campylobacter* and *Giardia*	8453	Cross-connection between sewage and drinking-water pipelines	(*21*)
2007	Australia	S. Saintpaul	24	Untreated bore water	(*7*)
2006	Republic of Georgia	*Francisella tularensis*	26	No chlorination of water supply	(*5*)
2005	Turkey	*Cyclospora*	35	Heavy rains; livestock or sewage contamination of public water source	(*1*)
2004	Norway	*Giardia*	2500	Leaking sewage pipes	(*30*)
2001	France	*Cryptosporidium*	563	Sewage contamination of tap water	(*35*)
2000	Canada (Walkerton)	*E. coli* O157:H7	2300	Livestock contamination of wells	(*17*)
1995	Canada	*Toxoplasma*	100	Heavy rainfall; lack of filtration system and chloramination	(*3*)
1993	US: WI (Milwaukee)	*Cryptosporidium*	>400,000	Inadequate coagulation of particulates in source water and filtration failure; severe spring storms causing runoff	(*13*)

Agents of Waterborne Disease

The U.S. Environmental Protection Agency provides a great deal of information on potential contaminants in drinking water and strategies to produce and maintain a safe water supply. Current drinking water rules and regulations under consideration are also described (*39*). Another source of information is the publication by the World Health Organization "Guidelines for Drinking Water Quality in 2008" (*43*). These sources contain a large volume of information on pathogenic and toxic microbes (bacteria, viruses, cyanobacteria, protozoan parasites, and parasitic worms) and chemicals (including metals, radioisotopes, pesticides, solvents, chlorinated compounds and other industrial chemicals) that have been detected in water. Design and management of treatment facilities is also discussed.

Pathogens. In addition to the more common bacteria that have been associated with waterborne outbreaks (*Vibrio cholerae, Shigella sonnei, Campylobacter, E. coli*, and *Salmonella* spp.), *Legionella* is emerging as an important cause of some outbreaks (*6;29*). *Cyclospora* (*15;31*), *Giardia* (*30;48*), and *Cryptosporidium* (*26;35;46*) have become important protozoan parasites. Cyanobacteria and their toxins are prevalent in surface waters experiencing blue-green algal blooms. Some toxins, including microcystin, have killed dogs, other animals and 76 dialysis patients in Brazil who received contaminated water. Chlorination generally oxidizes

and inactivates microcystins but is not as effective against other toxins (*12;41;49*).

Chemical contaminants. Recent large surveys in the U.S. and Europe have documented the presence of numerous organic pollutants in groundwater and untreated drinking water. Of 47 U.S. groundwater samples tested in 2000, 81% contained detectable levels of at least one of the 65 contaminants analyzed. Most common compounds were DEET (insect repellant), bisphenol A (plasticizer), tri(2-chloroethyl) phosphate (fire retardant), sulfamethoxazole (human and veterinary antibiotic), and 4-octylphenol monoethoxylate (detergent metabolite) (*2*). In the European groundwater survey, 164 sites were sampled and tested for 59 compounds. The most relevant compounds detected included DEET, caffeine, perfluooctanoic acid (PFOA, a surfactant), and atrazine. Bisphenol A and sulfamethoxazole were also detected in 24–40% of samples. Some chemicals were present at levels above the European standards (*25*). Untreated drinking water sources (25 ground-, 49 surface-waters) in the U.S. were also tested for 100 chemicals. A median of 4 compounds was detected per site. Most common compounds in the groundwater were: tetrachloroethylene (solvent), carbamazepine (pharmaceutical), bisphenol A, tri(2-chloroethyl) phosphate, and 1,7-dimethylxanthine (caffeine metabolite). Most common surface water contaminants were: cholesterol, metolachlor (herbicide), cotinine (nicotine metabolite), β-sitosterol (natural plant sterol), and 1,7-dimethylxanthine (*11*). While some of the pesticide levels reported exceed standards, the toxicological significance of relatively low concentrations of some of the other chemicals is still unknown. The fate of all these compounds as they pass through water treatment systems is also not well understood.

Strategies for monitoring and controlling chemical contaminants, particularly some "emerging" chemicals of recent interest, during drinking water production were discussed as a HACCP approach (*40*). The presence of human and veterinary drug residues and various compounds associated with plastics (phthalates, bisphenol A, polybrominated compounds) that may act as endocrine disrupters are currently of concern (*14;22;24;32;44*) while heavy metals, aluminum, and pesticides continue to be important (*23;37;42*).

Summary

Ensuring drinking water quality is a complex process requiring attention to external weather-related factors in the environment, effectiveness of public water treatment systems and in-plant water use and distribution systems. Multiple species of bacteria, protozoan parasites, and viruses as well as biological toxins from cyanobacteria may contaminate water, and filtration and disinfection systems may or may not effectively inactivate them. There is also a wide variety of chemicals used in industry, medicine, agriculture, and personal care that are known to be present in source waters. The toxicological significance of many of these compounds is presently unknown. However, it may be important to consider the effects of these chemicals in the aggregate as some may exert additive or synergistic effects. Metals and radionuclides are also naturally present at potentially toxic levels in some source waters. In addition, intentional contamination of foods and water by disgruntled employees does occasionally occur and managers should consider this possibility.

Water is an important component of food production and processing systems. Some outbreaks listed as foodborne infections are likely due to the use of contaminated water during washing or other processing steps or even as an ingredient. Therefore, it is essential to maintain good water quality in processing plants.

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