Viruses, Protists, and Other Organisms

Just as bacteria do, viruses, protists, and tiny multicellular organisms can also cause outbreaks of waterborne disease and taste-and-odor problems.

**VIRUSES**

Viruses are very simple, tiny life forms that do not multiply outside of living host cells. Their average size is $\frac{1}{10,000}$ millimeter in diameter. Viruses can survive in the environment for a few minutes to several hours. They are spread by hand-to-mouth transfer, by aerosol inhalation, or by ingestion.

Viruses are composed of protein packages of varying designs, all with the primary function of carrying the virus chromosome from one host cell to another. Upon attaching to the host cell, a virus injects its chromosome, which then incorporates into the host chromosome, reprogramming the cell to make viruses. Once the viruses reproduce, the cell ruptures, releasing the new viruses to scatter and infect new host cells.

These new viruses usually reinfect host cells of the same organism, but those infecting the respiratory tract may be released into the air with a sneeze or cough, or simply through speech. Hand-to-hand and fecal–oral transmissions are also possible, especially with intestinal viruses.

Viral infections are not treatable with antibiotics. They may be prevented by immunizations, careful hygiene, and effective water and sewage treatment. These methods address infection indirectly, but they have been highly successful in reducing disease, especially large-scale epidemics.

Disinfection with chlorine or ozone allows drinking water treatment facilities to easily remove most viruses from water. However, some indications suggest that viruses occasionally reactivate (become viable again) in the distribution system, despite apparently effective treatment. Utilities that practice lime softening reduce the likelihood of reactivation because
the high pH enhances the killing effect. Water treatment personnel who are unsure of their utility’s performance should check for viruses in water from mains distant from the point of disinfection.

Hepatitis A Virus

The hardy Hepatitis A virus causes the disease infectious hepatitis. It is most often transmitted by fecal–oral contact. Hepatitis A can be contracted from drinking water contaminated with sewage, or by eating food that has been handled by infected people who have not washed their hands well or who have not taken other precautions such as wearing clean food-handling gloves. Ingestion of contaminated shellfish is another common route of Hepatitis A contraction. Daycare centers occasionally are the source of outbreaks because children often exhibit poor hygiene practices.

The disease ranges from mild to severe, depending on the health and age of the host. Young patients often have mild cases of the disease, while those middle-aged and elderly suffer more severe symptoms.

Hepatitis viruses attack the host’s liver. Symptoms of this disease include fever, nausea, muscle aches, and vomiting; the liver may also swell and cause pain.

No effective cure for hepatitis is known, and the disease resolves itself in 4 to 8 weeks. Of the few who die from the disease, 70 percent are over 49 years old.

Enteroviruses (Poliovirus, Coxsackievirus, Echovirus, and Others)

The viruses of this group commonly cause intestinal disease in humans with a frequency equal to human respiratory afflictions. They may also cause generalized symptoms that affect many organs, including the brain.

A notable disease in this category is poliomyelitis, caused by the Poliovirus, which is now rare in the United States. An intensive nationwide immunization program has minimized the threat of transmission.

Waterborne transmission of the enteroviruses is possible, but person-to-person transmission is more common. However, as with other waterborne diseases, ineffective water treatment allows a potential for large-scale epidemics.
Gastroenteritis Viruses

This large group of viruses is responsible for a variety of stomach and intestinal flus. It includes the Norwalk virus, Rotavirus, and Adenovirus, along with many other genera. The adenoviruses are notable because they may cause either respiratory disease or gastrointestinal disease. They are very contagious, and both waterborne and person-to-person transmissions occur.

Protists

The world’s organisms, both large and small, often do not conform to the nomenclature that humans wish. Scientists sometimes debate the proper classification of large animals. When classification of the myriad microorganisms is attempted, the problem to find distinct lines of division increases greatly.

For decades, it has been understood that protozoa and algae have many common traits. Euglena is an example of a microbe that could easily be called a protozoan, because of its similarities to a Paramecium, but could also be called an alga, because of its similarities to Chlorella and many other photosynthetic microbes.

The taxonomic solution to this overlap of protozoan and algal characteristics was to place each group under one group called Protists. The terms protozoa and algae are still used in common communications and for general grouping of the organisms. They will also be used in this text.

Protozoan-Like Protists

The average size of protozoan-like protists is $\frac{1}{100}$ millimeter in diameter.

Most protozoan-like protists are larger than bacteria. They are single-celled organisms, as are viruses and bacteria, yet they possess more complex physiologies and life cycles. In particular, a protozoan cell incorporates a nucleus that contains its chromosomal DNA.

There are a variety of forms of protozoa. In fact, they are developed to the point that generalizations about their shape and nature are difficult to make.
Paramecium species are present throughout nature and are one of the many protists important for ecology. They are classic examples of protists that commonly live in natural waters (Figure 3-1).

Many students encounter Paramecium while microscopically examining pond water. The pear-shaped cells of this genus are covered with tiny hairs called cilia that beat rhythmically to propel the organism through the water environment. Protozoa with cilia are called ciliates.

These ever-active microbes spin and cruise through the water like so many bumper cars, proliferating when nutrients and bacterial numbers are high. They and other related microbes consequently help control the balance of the ecosystem.
**Giardia lamblia**

*G. lamblia* has profound importance for the water industry. It is a common intestinal parasite of humans and other mammals. It exists in two stages: the active trophozoite stage and an inactive cyst stage during which it is resistant to conditions in its environment (Figure 3-2).

Beavers are notorious for passing *Giardia*, which they harbor in their intestines, via their feces into apparently clean mountain streams. People lured by visions of nature’s beauty and purity drink from the cold mountain streams and find themselves suffering from giardiasis (camper’s diarrhea). This disease creates severe diarrhea, cramping, and fatigue. It is treatable with antibiotics when correctly diagnosed; however, untreated giardiasis often continues for weeks before self-resolving.

*Giardia* cysts are also transmitted from person to person via the fecal-oral route, an especially common problem in daycare centers where young children do not practice good hygiene.

The inactive cysts are resistant to chlorine, so they might survive treatment if they pass through a facility’s filtration system and if disinfectant contact time is not sufficient to overcome resistance.

Ingested *Giardia* cysts mature into trophozoites, which then multiply. Millions of organisms attach to the wall of the small intestine and cover so much of it that they interfere with nutrient absorption. Diarrhea accompanies the limited nutrient absorption, creating great fatigue and weight loss if the disease is prolonged.

*Figure 3-2  Giardia cysts*
Cryptosporidium parvum

C. parvum is a species of protozoa quite different from free-living organisms, such as Paramecia. It is active only inside a mammalian host’s small intestine where it develops into small rod-shaped sporozoites, ultimately invading the intestinal lining. The microbe develops further to the reproductive stage when it produces oocysts, each containing up to four more sporozoites. Sporozoites with thin oocyst walls are immediately released to reinfect the same host’s intestinal lining. Other sporozoites with thick oocyst walls are defecated into the environment or wastewater system (Figure 3-3).

The disease of cryptosporidiosis involves severe diarrhea accompanied by intestinal cramps and fatigue. The infection lasts from a few days to a few months, depending on the strength of the host’s immune system. Serological studies have found antibodies to Cryptosporidium in many people, indicating past infections that had not been medically attributed to cryptosporidiosis. This incidence of immunity likely accounts for the relatively mild cases that occur during epidemics.

People with compromised immune systems, such as leukemia patients, transplant recipients, infants, the elderly, and individuals with AIDS, are endangered most by the disease. This group might add up to one-fourth of the population. Antimicrobial treatment is available for treatment of cryptosporidiosis for patients with adequately strong immune systems. Person-to-person transmission is possible when proper hand washing is ignored. Also, ingestion of oocysts from lakes, streams, swimming pools, or poorly treated drinking water can cause cryptosporidiosis. Many mammals, including cattle (especially calves), hogs, and humans, are susceptible to cryptosporidiosis, allowing them to transmit the disease.

The largest waterborne epidemic of the disease in the United States occurred in Milwaukee, Wis., in 1993. Investigators believe that huge numbers of Cryptosporidium oocysts flowed into Lake Michigan in runoff from cattle stockyards or other flows of sanitary sewers following heavy rains. The plume of oocyst-laden water was apparently drawn into the city’s drinking water facility, which uses lake water as its source.

High numbers of Cryptosporidium oocysts can escape coagulation with conventional treatment chemicals. A portion can then pass through
granular filtration systems. The oocysts are also very resistant to the killing effects of chlorine. In Milwaukee, the infective oocysts reached the distribution system and were ingested by most of the utility’s 600,000 customers. Initially, an estimated 400,000 people became ill with gastro-enteritis, likely caused by *C. parvum*. This estimate has been lowered after extensive epidemiological analyses, but the significance of the incident is still profound. Up to 100 deaths occurred during the outbreak, primarily involving individuals with weakened immune systems.

*Cyclospora cayetanensis*

*C. cayetanensis* is a protist that is similar to *Cryptosporidium* in its structure and in the disease it causes. Diarrhea from the disease can last for several weeks without treatment. It has been implicated in a few waterborne disease outbreaks. It also has caused foodborne epidemics when people ingested contaminated raspberries imported to the United States from Central America. In 2013, an epidemic thought to be foodborne occurred in Iowa, where more than 70 people became ill. Ingestion of raw vegetables or fruit was the likely source. The common antibiotic Trimethoprim/Sulfamethoxazole is effective for treatment.

*Microsporidia Group*

This group of protozoa—primarily the genera *Encephalitozoon, Nosema, Vittaforma, Pleistophora, Enterocytozoon*, and *Microsporidium*—infests both animals and humans. These parasites invade the intestinal lining where they proliferate into high numbers, causing the host to experience intestinal illness.
Microsporidia produce thick-walled spores that are resistant to environmental stresses. This resistance allows them to pass from infected individuals to new, distant hosts, via water or soil. Host-to-host transmission is also likely.

The significance of Microsporidia for the water industry is still not fully defined. The prevalence, treatment-resistance, and pathogenicity of these genera are presently under study.

Detection of the tiny spores (2–3 µm in diameter) is relatively difficult. Microsporidiosis is a disease with no present antibiotic treatment.

Amoebae

Effective water treatment removes many soil and water amoebae. The most notorious are Acanthamoeba, Balamuthia, Entamoeba, and Naegleria. The flexible cell walls of these organisms allow them to “ooze” in one direction or another by sending out projections called pseudopodia. The rest of the cell’s cytoplasm follows into the pseudopodia until the entire cell has been transported. Amoebae make cysts that are resistant to environmental stresses such as drying. This helps the species survive and reach new niches (Figure 3-4).

Entamoeba histolytica is an intestinal pathogen. This invasive amoeba is contracted by person-to-person contact or by ingestion of water contaminated with feces or foods irrigated with contaminated water. When treated wastewater is used to irrigate vegetable crops, such as lettuce, cysts become trapped in the plants’ crevasses. If the vegetables are not washed well, the cysts are ingested and continue their life cycle.

E. histolytica invades and multiplies in the host’s intestinal tissue. If the disease is protracted, the amoebae travel to the liver or brain causing development of amoebic abscesses. Antimicrobial treatment becomes difficult once the infection has reached this stage.

Acanthamoeba, Naegleria fowleri, and Balamuthia are free-living amoebae that inhabit soil, ponds, and rivers. They do not require an animal or human host to survive. Acanthamoeba and Balamuthia are rare yet particularly notorious pathogens. Each can
cause severe encephalitis, a brain infection that can progress rapidly, usually with fatal results. Swimmers in ponds and lakes harboring these organisms contract them through the nasal passages. The amoebae progress to the nasal olfactory lobes and eventually to the brain.

More commonly, *Acanthamoeba* causes infections of the ears, maxillary sinuses, lungs, and especially keratitis of the eyes. Keratitis occurs when *Acanthamoeba* invades the cornea, often after contact lenses are exposed to contaminated water and then worn for an extended time. Extended exposure gives the amoeba an opportunity to create a corneal ulcer. People that prepare their own saline washes for contact lenses and those who swim while wearing their lenses have the greatest risk of infection. Corneal ulcers are painful and must be aggressively treated to prevent complete destruction of the eye.

The amoeba *N. fowleri* is a free-living soil and water organism. It can invade the human nasal chamber and eventually the brain, causing severe meningoencephalitis.

Figure 3-4  Amoeba on filamentous algae strands
Algal-Like Protists

The average size of algal-like protists is $\frac{1}{100}$ millimeter in diameter.

The surface waters of the world are filled with algal-like protists. Numerous species are included in several groups of green, yellow-green, golden-brown, Euglenoid, and Cryptomonad algae.

Numerous excellent color figures of algal groups can be found in *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA, and WEF 2012) and in AWWA Manual of Practice M57, *Algae: Source to Treatment*.

Apart from their photosynthetic process, many algae are very much like protozoa. Some exist individually as unicellular organisms (Figures 3-5 through 3-8), perhaps even with flagella for motility. Others grow in groups as colonial organisms (Figures 3-9 and 3-10), some have unique forms like the drumlike *Cyclo-tella* (Figure 3-11), and yet others exhibit filamentous structures (Figure 3-12 and 3-13).

Algae that remain freely suspended in water are called *planktonic algae* (Figure 3-14). Those that attach to surfaces are called *sessile algae*.

Diatoms are algae with cell walls of hard silica. They may be loosely viewed as the “glass seashells” of the microscopic world.

Dinoflagellates may threaten fish or cause “red tide” conditions that affect fishing and recreational activities. One such organism, *Pfiesteria*, produces neurotoxins that cause lesions and death in fish. Humans may also develop skin lesions, respiratory problems, and central nervous system problems if they come into significant contact with the toxins.

Dinoflagellates are common, normally harmless inhabitants of most rivers, lakes, and oceans. However, their role may change when excessive nutrients such as nitrates, phosphates, and sewage enter the water. The change in environmental conditions apparently allows dramatic proliferation of *Pfiesteria*, creating conditions for disease in fish and humans that contact the water. The Menhaden fish is the primary host of *Pfiesteria*. This fish is harvested for its oil, which is then used in cattle feed and in cosmetics.

Presently, *Pfiesteria* is no threat to drinking water facilities. Nevertheless, potential for emergence as a powerful source of disease demonstrates how environmental changes can alter an organism’s role in nature in surprising and worrisome ways.
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Figure 3-5  Unicellular alga

Figure 3-6  Unicellular algae

Figure 3-7  Dinoflagellate

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Algae flourish during warm, sunny months when nutrients are high and ample light is available to fuel photosynthetic processes. Finished water regulations make little mention of algae, but operators at surface-water facilities usually are well aware of the potential impact of these organisms on plant operations and finished water quality. Algal blooms in source waters may create taste-and-odor problems; filters may clog, requiring significantly more frequent backwashing; and finished water color problems may arise from chlorophyll that is dispersed in the water from ruptured algae cells. Whole cells and remnants of cells that pass through treatment and into distribution systems add to the organic material that transforms into disinfection by-products. These potentially carcinogenic compounds are regulated by USEPA. Excessive amounts will cause a water utility to violate the minimum contaminant level set through regulation and require that a public notice bulletin be posted.

Furthermore, strain on initial steps in multistage systems might allow increases of organic compounds derived from algae, even at the clearwell. Consequently, chlorine demand might rise.

Algae do play a beneficial ecological role. They help oxygenate water and remove numerous chemical contaminants such as phosphorus, ammonium, and nitrate compounds. They are an essential part of complex food chains, giving them a vital role in maintaining the overall health of a lake or river (Figures 3-5, 3-6, 3-14, and 3-15).

Algal blooms in a reservoir can be controlled by dispersing copper sulfate in the water. When properly administered, this practice is effective, but planning must account for the toxic effect of copper sulfate on snails and other water animals and plants that are important in maintaining a healthy reservoir. The chemical should be used at acceptable dosages.

“Blue-green” algae are actually photosynthetic bacteria called cyanobacteria. When people speak of “algal” toxins, they usually mean cyano-toxins. (See chapter 2, Bacteria).
Figure 3-8  Pennate diatom

Figure 3-9  Colonial algae *Pediastrum*

Figure 3-10  Colonial algae *Astrionella*
Figure 3-11  *Cyclotella* diatomaceous alga

Figure 3-12  Filamentous algae
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**Figure 3-13** Filamentous alga *Spirogyra*

**Figure 3-14** Planktonic algae

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MULTICELLULAR ORGANISMS

Water treatment facilities must also contend with small multicellular organisms. These organisms are not pathogenic for humans, but they might interfere with treatment processes.

_Nematodes_ are microscopic round worms that are common in soil and water (Figure 3-16). Ideal habitats for these organisms are in the sludge blanket of a treatment basin, or in the mixed media matrix of a rapid filter. Nematodes might multiply to the point that they clog the filter. Because of their impressive resistance to chlorination, they might also reach finished water. Customers with acute vision may spot the worms in their drinking glasses, compromising water aesthetics. If nematodes from source water survive treatment and pass into the finished water, they might carry along viable pathogenic bacteria that they have ingested.

Des Moines Water Works personnel have discovered that rubber lines leading to freezer ice making machines can colonize with high numbers of nematodes. This usually results in complaints about stale tasting ice.

_ROTIFERS_ are microscopic creatures that flourish in water high in nutrients (Figure 3-17). They are distinguished by circles of cilia around their mouths. The movement of the cilia, resembling revolving wheels, directs

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**Figure 3-15  *Euglena***

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food particles into their mouths. Like tiny vacuum cleaners, rotifers can rapidly draw in thousands of bacteria for consumption, thus they play a large role along with protists in keeping the ecosystem balanced. The water industry seldom has a problem with rotifers. Small crustaceans and insect larvae might survive treatment to reach finished water at some facilities (Figure 3-18). This possibility is especially likely when water is unfiltered or when mains and filters become colonized with the organisms. These tiny organisms do not cause disease; however, their presence in drinking water is clearly undesirable. They also can disrupt filter operation, which might increase finished water turbidity.
Figure 3-17  Rotifer

Figure 3-18  Water flea with eggs