Chapter 27

Recycled Water Treatment and Reuse

Channah Rock, Charles P. Gerba and Ian L. Pepper

27.1 RECYCLED WATER REUSE

Population increases in water-scant arid regions and inadequate supplies of water resources have led to the increased use of reclaimed (recycled) water for both potable and current nonpotable purposes. Recycled water is the liquid portion of municipal wastewater that has undergone a series of treatments usually involving a combination of physical, chemical and biological treatment technologies to remove suspended solids, dissolved solids, organic matter, nutrients, metals and pathogens (Jjemba *et al*., 2010). "Water reclamation" involves treatment of wastewater to make it reusable. "Water reuse" is the beneficial use of treated wastewater (Information Box 27.1). Recycled water is generally used for beneficial purposes including irrigation, industrial processes, toilet flushing or groundwater recharge of aquifers (WateReuse Association, 2011a). In addition, intentional reuse for the augmentation of potable supplies is also practiced.

The current extent of water reuse nationally in the U.S. is not precisely known, and in fact, a systematic analysis of the extent of effluent contributions to potable water supplies has not been made in the U.S. for over 30 years (NRC, 2012). However, in 2006 the U.S. EPA estimated that an average of at least 1.7 billion gallons of wastewater was reused daily (Brandhuber, 2006). Despite that, approximately 12 billion gallons of municipal wastewater effluent are still discharged each day into an ocean or estuary (NRC 2012). Currently, water recycling programs in Arizona, California, Florida and Texas account for about 90% of the water recycled in the U.S. However, new recycled water programs are emerging all over the country, including East Coast states such as Pennsylvania and Maryland (WateReuse Association, 2011b). As growth and population increase, sources of potable water become scarcer, and water recycling helps alleviate this need by replacing the use of potable water for applications that do not require water treated to such levels of quality. Thus, water recycling allows communities to become less reliant on ground and surface water sources.

Microorganisms play a critical role in the treatment of wastewater for reuse by transforming and removing

I.L. Pepper, C.P. Gerba, T.J. Gentry: Environmental Microbiology, Third edition. DOI: http://dx.doi.org/10.1016/B978-0-12-394626-3.00027-2

organic matter and chemical contaminants. In addition, most reuse applications require advanced treatment to further reduce exposure to waterborne pathogens. Finally, the growth and regrowth of water-based pathogens in the treated wastewater is also a potential concern.

27.2 TREATMENT TECHNOLOGIES TO PRODUCE RECYCLED WATER

Water utilities use a variety of well-tested and reliable treatment processes to treat effluent such that it can subsequently be reused. The four core stages of treatment are: preliminary treatment; primary treatment; secondary treatment; and tertiary or advanced treatment. The primary objective of conventional wastewater treatment is to reduce nutrient and contaminant loads to the environment, thereby maintaining the health of aquatic ecosystems. In recycled water applications, conventional wastewater treatment can be supplemented with additional processes to achieve a quality that is consistent with the intended use. At a minimum, recycled water will undergo some form of disinfection (WateReuse Association, 2011b). Examples of common treatment train processes are presented in Figure 27.1, while Table 27.1 outlines wastewater treatment processes. (See also Chapter 25).

Information Box 27.1 Terminology of Recycled Water

- Reclaimed water: Water that has been used more than one time before it is returned back into the natural water cycle.
- Recycled water: Synonymous with reclaimed water.
- Water reuse: The process of using water more than one time prior to environmental discharge. This term is frequently used with reference to potable uses.

27.3 RECYCLED WATER APPLICATION IN THE U.S.

Recycled water can be utilized as a resource in a variety of ways (Information Box 27.2), with the level of treatment being appropriate for specific end uses (see Figure 27.2).

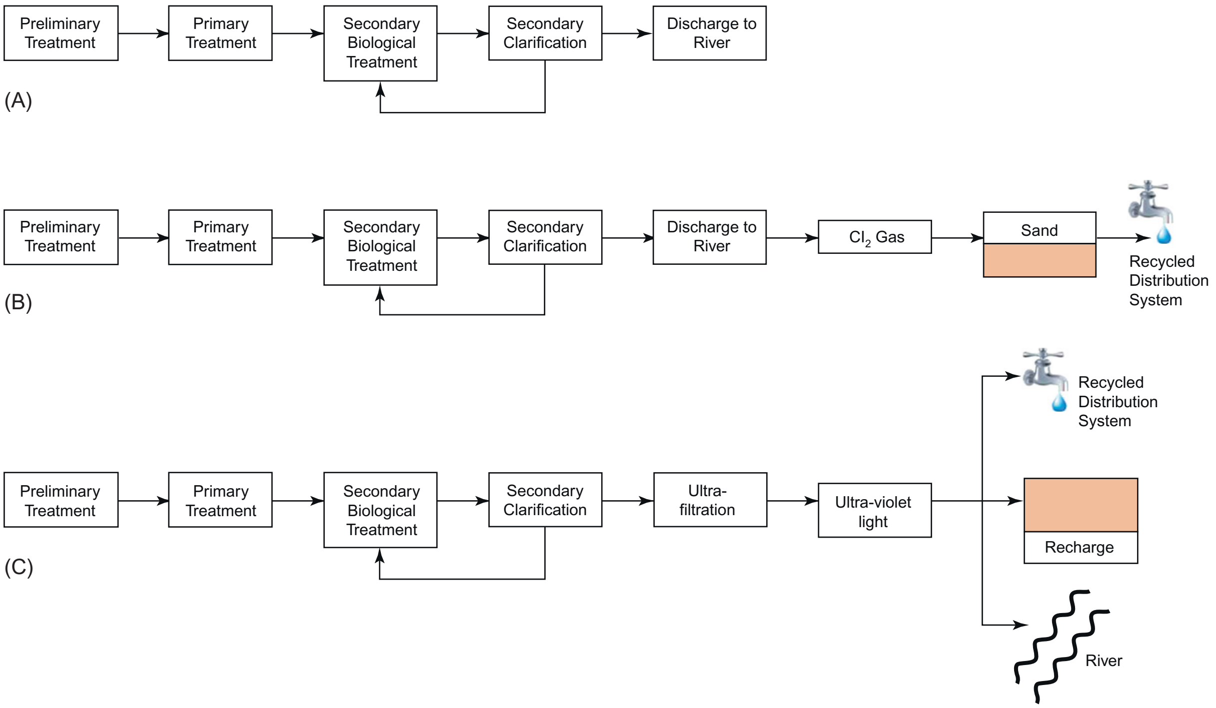


FIGURE 27.1 Wastewater treatment trains. (A) Preliminary treatment: screening of debris. Primary treatment: physical treatment in which solids settle out and are removed as primary sludge; fats, oils and greases (FDG) are skimmed off the surface. Secondary treatment: biological treatment via aerobic microbial degradation of organic matter which produces biological biomass on floc. Secondary clarification: biological floc settles out as secondary sludge. Discharge: secondary effluent is discharged to river. (B) Similar to treatment train (A) but with the addition of disinfection via chlorine gas, and sand filtration to remove particulates prior to distribution for irrigation. (C) Advanced treatment: utilizes ultrafiltration to remove particulates and ultraviolet light for water disinfection prior to discharge for irrigation, groundwater recharge or a surface water.

TABLE 27.1 **Wastewater Treatment Processes: Purpose and Example Technologies**

Treatment stage	Purpose	Technologies
Preliminary	Removal of large solids and grit particles	Screening; settling
Primary	Removal of suspended solids and some organic matter	Screening; sedimentation
Secondary	Biological treatment and removal of common biodegradable organic pollutants as well as inactivation of some microorganisms	Percolating or trickling filter; activated sludge; anaerobic treatment; waste stabilization ponds (oxidation ponds)
Tertiary (or advanced)	Removal of suspended particles and specific pollutants such as phosphorus, and removal/inactivation of bacteria, parasites and some viruses	Sand filtration; membrane bioreactor; microfiltration; ultrafiltration; reverse osmosis; chemical coagulation; UV; activated carbon

Modified from Wu et al. (2009).

Information Box 27.2 Recycled Water Applications in the U.S.

- Urban reuse
- Agricultural irrigation
- Industrial reuse
- Recreational reuse
- Groundwater recharge

27.3.1 Urban Reuse

Urban reuse is a term used to categorize a wide variety of different applications. Some of these applications have been utilized for many decades, especially golf course irrigation. The regulations and water quality standards required for any given application vary according to the potential for human contact with the recycled water. A large amount of recycled water is utilized for golf course and landscape irrigation. For example, in Arizona, the use of "secondary effluent," as it was then designated, was evaluated as a means for turf irrigation back in 1981 (Anderson *et al.*, 1981). Today, any new golf course brought into production in Arizona must use recycled water as a primary irrigation source. In addition, recycled water is now used extensively for irrigation of parks and playgrounds. A further benefit of such extensive reuse is that the practice is now widely accepted by the general public, and not subjected to the "yuck factor" (Information Box 27.3) associated with the "toilet-to-tap" perception. Other urban reuse applications include: fire protection; dust control; car washing; and toilet flushing. Generally, toilet flushing is restricted to commercial or industrial facilities, as in the case of Florida, where toilet flushing with recycled water is not permitted in residential homes.

FIGURE 27.2 The Santa Cruz River for much of the year has flow that is sustained by treated effluent discharge, south of Tucson, Arizona. Photo courtesy C. Rock.

27.3.2 Agricultural Irrigation

Agricultural irrigation is the oldest practice of recycled water use, and the largest end use by volume in the world. Depending on the type of crop, agricultural irrigation may be either unrestricted or restricted. Restricted irrigation applies to nonfood crops (e.g., cotton, switch grass) and requires less stringent treatment, whereas unrestricted irrigation for food crops (e.g., vegetables that are eaten raw) requires a very high level of treatment to produce appropriate water quality.

27.3.3 Industrial Reuse

Industrial reuse of water is increasing due to increased population growth and water conservation. For example,

Information Box 27.3 Recycled Water and the "Yuck Factor"

The concept of reusing water for potable purposes has for many people induced a fear and repugnance now colloquially known as the "yuck factor." The yuck factor was coined by University of Pennsylvania bioethicist Arthur Caplan to describe the instinctive adverse response to the concept of converting wastewater into drinking water (Schmidt, 2008). The yuck factor creates such strong feelings that it is difficult to overcome. In fact, the yuck factor creates feelings similar to the fear of eating genetically modified food crops, where opponents of such modified food exploited the gut reaction by calling it "Frankenfood" (Schmidt, 2008). Hence, even when presented with scientific facts that document the safety of recycled water, changing the opinions of the public is hard to do. Overall, many studies and projects have evaluated the safety of utilizing recycled water to augment potable sources, but there is no scientific documented adverse effect of such practices on human health.

the Curtis Stanton Energy Center in Orlando, Florida, uses 8 mgd (million gallons per day) of recycled water to cool the plant's boilers. Recycled water is also used as boiler feedwater to generate steam or hot water for thermal power stations. Such feedwater must be of very high quality to prevent boiler corrosion, scale and sediment deposits. Finally, recycled water is commonly used with flue-gas scrubbers found in waste incineration plants.

27.3.4 Environmental Enhancement

Recycled water can also be used for stream augmentation or the creation of artificial wetlands to serve as wildlife habitats and refuges. Use of recycled water for artificial wetlands is particularly attractive to municipalities since they serve several missions concurrently including: water treatment; creation of an urban wildlife habitat; and additional use as an outdoor classroom. At the Sweetwater Wetlands in Tucson, Arizona, secondarily treated effluent from a wastewater treatment plant enters recharge basins, filters through sediments beneath the basins and replenishes the local aquifer. This recycled wastewater is recovered by extraction wells during periods of high water demand and subsequently distributed and utilized for irrigation of golf courses, parks and other recreational areas (Case Study 27.1).

27.3.5 Recreational Reuse

An additional use of recycled water recreationally involves the creation of artificial lakes. These can be as simple as small water retention basins or ponds on golf courses; water-based recreational reservoirs with incidental human contact through fishing and boating; or full body contact involving swimming or wading. The recreational reuse can be restricted or unrestricted depending on the potential for public access, and the degree of body contact. Generally, higher degrees of treatment are utilized to provide better water quality when warranted. One of the primary issues with human-made lakes that utilize recycled water is the high inputs of nitrogen and phosphorus that can stimulate algal growth, turning the lake in question green. Controlling algal growth can involve application of chemicals such as copper sulfate, or aluminum phosphate, which sorb waterborne phosphate making it unavailable for algal growth. Advanced treatment in addition to aeration can also be used to reduce the amount of phosphate released from lake sediments.

Case Study 27.1 Tucson, Arizona, Recycled Water System

- Established in 1985
- In summer months daily deliveries of recycled water can exceed 30 mgd
- The recycled water distribution system consists of 160 miles of pipe
- Irrigation with recycled water serves 18 golf courses, 39 parks and 52 schools including the University of Arizona, with golf courses using about 60% of the recycled water annually
- Recycled water saves over a 6 billion gallons of drinking water annually, enough to serve 60,000 families for a year

27.3.6 Groundwater Recharge

In addition to utilizing recycled water for irrigation as a means to save potable water, recycled water can also be used to replenish aquifer water reserves. Multiple terms have been coined to describe groundwater replenishment with recycled water (Information Box 27.4). The process of using a shallow aquifer to treat recycled water is termed soil aquifer treatment (SAT) or aquifer recharge and recovery (ARR) (Missimer *et al.*, 2012). In contrast, aquifer storage and recovery (ASR) refers to the process of storing water during periods of abundance, and allowing for subsequent withdrawal and use in times of need. Groundwater recharge can also be used to prevent ground subsidence that can occur after large-scale groundwater withdrawals.

Regardless of the purpose, artificial groundwater recharge relies on the presence of gravels, sands and sites to remove contaminants. These include nutrients and trace

Information Box 27.4 Terminology Used to Describe Recycled Water Purification via Recharge Processes

- Aquifer recharge: The process of water movement from the land surface or unsaturated zone into the saturated zone or aquifer
- Soil aquifer treatment (SAT): The process of using a shallow aquifer to treat recycled water
- Aquifer recharge and recovery (ARR): Synonymous with SAT
- Managed aquifer recharge (MAR): Synonymous with SAT
- Aquifer storage and recovery (ASR): Injection of water into an aquifer for storage purpose prior to later withdrawal in times of need

organic chemicals, as well as pathogens, all of which can survive wastewater treatment (Missimer *et al.*, 2012). However, soils and vadose zone material can only adsorb finite amounts of phosphate, and due to the high phosphate content of most recycled waters, this increases the potential for phosphate contamination of groundwaters following long-term recycled water applications (20—25 years) (Moura *et al.*, 2011). Other compounds of concern that may be subject to leaching due to nonsorption include the pharmaceuticals diclofenac and ibuprofen, which also have relatively long half-lives of greater than 50 days due to low rates of microbial degradation (Lin and Gan, 2011). Other pharmaceuticals such as naproxen and trimethoprim demonstrate strong sorption to soil (Lin and Gan, 2011). If pharmaceuticals are sorbed, they generally do not degrade. Those that do not adsorb can be readily degraded by bacteria.

Microbial contamination of groundwater is also a concern since pathogenic organisms have been detected in groundwaters receiving wastewater (Levantesi *et al.*, 2010). This has posed the question of whether additional advanced tertiary treatment technology is needed prior to SAT. Despite these concerns, SAT, ARR and ASR have become more widely practiced in the twenty-first century in the U.S., Europe and Australia (Dillon *et al.*, 2008).

27.3.7 Potable Reuse

Potable reuse refers to the process of augmenting surface or groundwaters with recycled water to aid in water supply sustainability. This is practiced in many parts of the world including the U.S., Singapore, Australia, Saudi Arabia and the United Kingdom. Unplanned or incidental potable reuse occurs when wastewater is discharged from a wastewater treatment plant into a river, and is subsequently used as a drinking water source for a downstream community. Such is the case for downstream communities on the Mississippi and Ohio rivers in the United States. In contrast to this, "planned" potable reuse can be direct or indirect.

27.3.8 Indirect Potable Reuse (IPR)

Planned indirect potable reuse (IPR) involves the intentional discharge of treated wastewater into bodies of water used as potable sources. Normally, this discharge occurs upstream of the drinking water treatment plant. Planned reuse indicates that there is an intention to reuse the water for potable use. The point of return could be into either a major water supply reservoir, a stream feeding a reservoir or a water supply aquifer (managed aquifer recharge or MAR). In the case of MAR, natural processes of filtration and dilution of the water with natural flows aim to reduce any real or perceived risks associated with eventual potable reuse. Locations of large planned indirect potable reuse facilities in the U.S. include San Diego, Tampa, Denver and the Orange County Water District. Abroad, examples include Australia, Singapore, Namibia and other water-scant areas. Many of these projects are large scale such as the Orange County Sanitation District IPR system known as the Groundwater Replenishment System (GWRS) (Case Study 27.2).

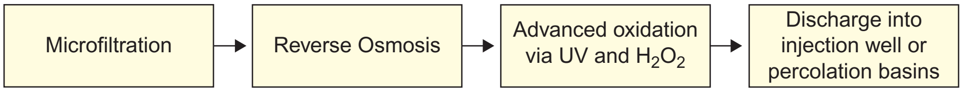
Following purification in the Orange County GWRS, approximately half of the high quality water (35 mgd) is pumped into injection wells to create a seawater intrusion barrier. The other half (35 mgd) is pumped into Orange County Water District's percolation basins in the city of Anaheim, where it flows through sand and gravel to deep underground aquifers, ultimately meeting the potable water needs of 600,000 residents. Upon withdrawal, the water is subjected to additional advanced treatment, then injected directly into the potable water distribution system without any recharge via SAT, or interaction with surface water.

27.3.9 Direct Potable Reuse

This is the so called toilet-to-tap perception, which has generally caused adverse public reaction known as the "yuck factor" (Information Box 27.3). A strict definition of direct potable reuse (DPR) is reclaimed water that is treated to potable water standards, and supplied pipe-to-pipe to consumers without an environmental buffer. In some countries, including Australia, the definition of DPR has been expanded to include: injection of recycled water directly into the potable water supply distribution system downstream of the water treatment plant, or into the raw water supply immediately upstream of the water treatment plant. Thus, injection could be either into a service reservoir or directly into a water pipeline. Therefore, the water used by consumers could be either undiluted or slightly diluted recycled water. In this definition, the key distinction with indirect potable reuse is that there is no temporal or spatial separation between the recycled water introduction and its distribution to consumers. Public perception of what extent of separation is required for reuse to become indirect may ultimately dictate the definition adopted. While most states in the U.S. consider DPR as a last resort scenario, there are a few examples where direct potable reuse has been practical. These locations include Windhoek, Namibia, in South Africa (duPisani, 2006), and the use of NEWater in Singapore (Case Study 27.3). Both of these locations were under such severe water stress that the communities had little choice but accept DPR as an alternative water supply. In these cases, adverse public perception issues were not readily apparent, illustrating that when potable water supplies are extremely scarce, the public is more accepting of toilet-to-tap.

Case Study 27.2 The Orange County Groundwater Replenishment System (GWRS)

Wastewater is conventionally treated at the Orange County Sanitation District before it flows to the GWRS, where it undergoes advanced state-of-the-art purification process consisting of three technologies.



Case Study 27.3 NEWater in Singapore

Singapore is comprised of 63 small islands, and faced with water shortages. In 1974 the city-state began a water recycling program. By 1998 the Public Utilities Board (PUB) and the Ministry of the Environment and Water Resources in Singapore had instituted a water reclamation study which resulted in NEWater. NEWater is the result of advanced water treatment of municipal effluent using membrane filtration reverse osmosis and oxidative (UV) technologies. Today treated wastewater comprises 30% of Singapore's water supply. Much of the water is used for industrial purposes including wafer fabrication processes for the semiconductor industry and water for cooling towers, freeing up potable sources of water. However, some NEWater is added directly to potable water reservoirs. As a pioneer in indirect and direct potable reuse, the country is constantly evaluating new technologies to enhance the water quality of recycled water (Qin *et al.*, 2009).

27.4 RECYCLED WATER REGULATIONS

Of major concern in water reclamation is the removal of waterborne pathogens. Conventional sewage treatment (activated sludge) still contains significant concentrations of viruses and protozoan parasites. Treatment performance measures and fecal indicator organisms are both used to monitor the microbial quality of reclaimed waters. The greater the exposure to the public, the greater the needed treatment to reduce pathogens present in the wastewater. Usually, multiple barriers (e.g., disinfection and ultrafiltration) are employed as a redundancy plan to further reduce the risk, especially in indirect and direct potable reuse applications. Bacterial indicators are usually employed as treatment performance indicators, because of the lower cost and speed with which they can be detected compared to actual pathogen detection. Assessment of treatment processes for enteric viruses and protozoan parasites are sometimes required, depending upon local regulations.

Several states consider recycled water to be viable as a water source alternative, and have developed regulations with specific water quality requirements and/or treatment processes for a variety of reuse applications. In other states, water reuse regulations have been developed with the primary intent of providing a disposal alternative to surface water discharge. A few states have no specific regulations or guidelines on water reclamation and reuse, although programs may still be permitted with approval on a case-by-case basis.

27.4.1 Recycled Water Regulations and Water Quality Standards

To date, no federal regulations exist that govern water recycling in the U.S.; rather, such standards have been developed and implemented at the state government level. The lack of federal regulations and coordination between states has resulted in diverse standards for recycled water across the country. Despite the differing standards, the process of recycling water always involves a multi-barrier approach (i.e., physical, chemical and biological treatment processes). The U.S. EPA has developed *Guidelines for Water Reuse*, a comprehensive, technical document to encourage states to develop their own regulations (U.S. EPA, 2004).

The fundamental precondition for water recycling is that applications will not cause unacceptable public health risks (UNEP, 2004). Therefore, microbiological parameters have historically received the most attention in water reuse regulations and guidelines. Recently, the focus on microbiological parameters has shifted slightly to address contaminants of emerging concern, including pharmaceuticals and potential endocrine disrupting compounds (EDCs). However, microbial pathogens still pose the greater demonstrated risk in water recycling applications. Since monitoring for all pathogens is not practical, specific indicator organisms are monitored to minimize health risks (U.S. EPA, 2004). Indicator organisms (e.g., total coliforms, fecal coliforms) are generally not pathogenic, but their presence in a water sample signals the possible presence of fecal contamination, though recycled water guidelines may also mandate screening for disease-causing organisms (e.g., enteric viruses) (Table 27.2).

Updated in 2006, the World Health Organization (WHO) introduced guidance for the safe use of wastewater in 1971. The WHO guidelines are relatively less restrictive than water reuse regulations and guidelines adopted by the various states in the U.S. (Metcalf and Eddy 2007). The main intent of the WHO guidelines is to introduce some level of treatment of wastewater, and interrupt transmission of diseases, prior to food crop irrigation.

Since the U.S. EPA views it as a regional issue, regulations for water recycling have been developed and implemented at the state government level. According to U.S. EPA's 2004 *Guidelines for Water Reuse*, 26 states have adopted water recycling regulations, 15 states have guidelines or design standards and nine states have no regulations or guidelines.

The lack of federal regulations has resulted in varying regulations and guidelines. Among the states, Arizona, California, Colorado, Florida, Hawaii, Nevada, Oregon, Texas, Utah and Washington have developed regulations or guidelines specifying recycled water quality and treatment requirements. This allows for the full spectrum of reuse applications that allows for water reuse as a sustainable water conservation and management strategy.

27.5 MICROBIAL WATER QUALITY ASPECTS OF RECYCLED WATER

Recycled water is the end product of conventional wastewater treatment that receives additional advanced treatment prior to use. The level of treatment received varies depending on the targeted end use, and specific regulations that vary from state to state within the U.S. All classes of microorganisms can be found in wastewater including bacteria, virus, fungi, protozoa and helminths, but most studies have focused on bacteria. Here we describe relevant features of microbes found in recycled water. The types of organisms found in recycled water depend on the degree of treatment.

27.5.1 Bacteria

Recycled water normally contains large populations of bacteria that include heterotrophic plate count bacteria (HPC), but bacterial pathogens are generally reduced or eliminated. HPC concentrations within recycled water vary depending on the level of treatment but can be as high as 10^8 colony forming units (CFU) per 100 ml of water (Ajibode *et al.*, 2013). Standards require very low levels of indicator bacteria, which indicate the absence of waterborne bacterial pathogens in the treated water. However, regrowth of indicator bacteria may occur after treatment, and, in addition, *E. coli* has been detected in recycled water including O157:H7 (Jjemba *et al.*, 2009). Water-based pathogens including *Legionella* and *Mycobacterium* can also be found in recycled water

TABLE 27.2 **Summary of Microbial Water Quality Parameters of Concern for Water Reuse**

Parameter	Range in Secondary Effluents	Treatment Goal in Recycled Water	U.S. EPA Guideline
Total coliform	<10 CFU/100 ml–10^7 CFU/100 ml	<1 CFU/100 ml–200 CFU/100 ml	–
Fecal coliform	<1–10^6 CFU/100 ml	<1 CFU/100 ml–10^3 CFU/100 ml	14/100 ml for any one sample; 0/100 for 90% of samples
Helminth eggs	<1/L–10/L	<0.1/L–5/L	–
Viruses	<1/L–100/L	<1/50 L	–

Source: U.S. EPA (2004). Guidelines for Water Reuse.

Case Study 27.4 Influence of Residence Time in Water Distribution Systems on Recycled Water Quality

The distribution systems of two wastewater reclamation systems located in southwest Arizona were monitored over a 15-month period for microbial recycled water quality. The two plants' utilities produced recycled water of similar water quality except for nitrogen. Specifically, Utility A produced Class A+ water with a total nitrogen concentration of less than 10 mg/L, whereas Utility B produced Class A water with no nitrogen limitation. The two utilities also differed in their means of disinfection with Utility A utilizing chlorine and Utility B using ultraviolet light. Both distribution systems were monitored with increasing distance from the point of entry. Traditional waterborne indicators such as *E. coli* and *enterococci* were rarely detected and only at

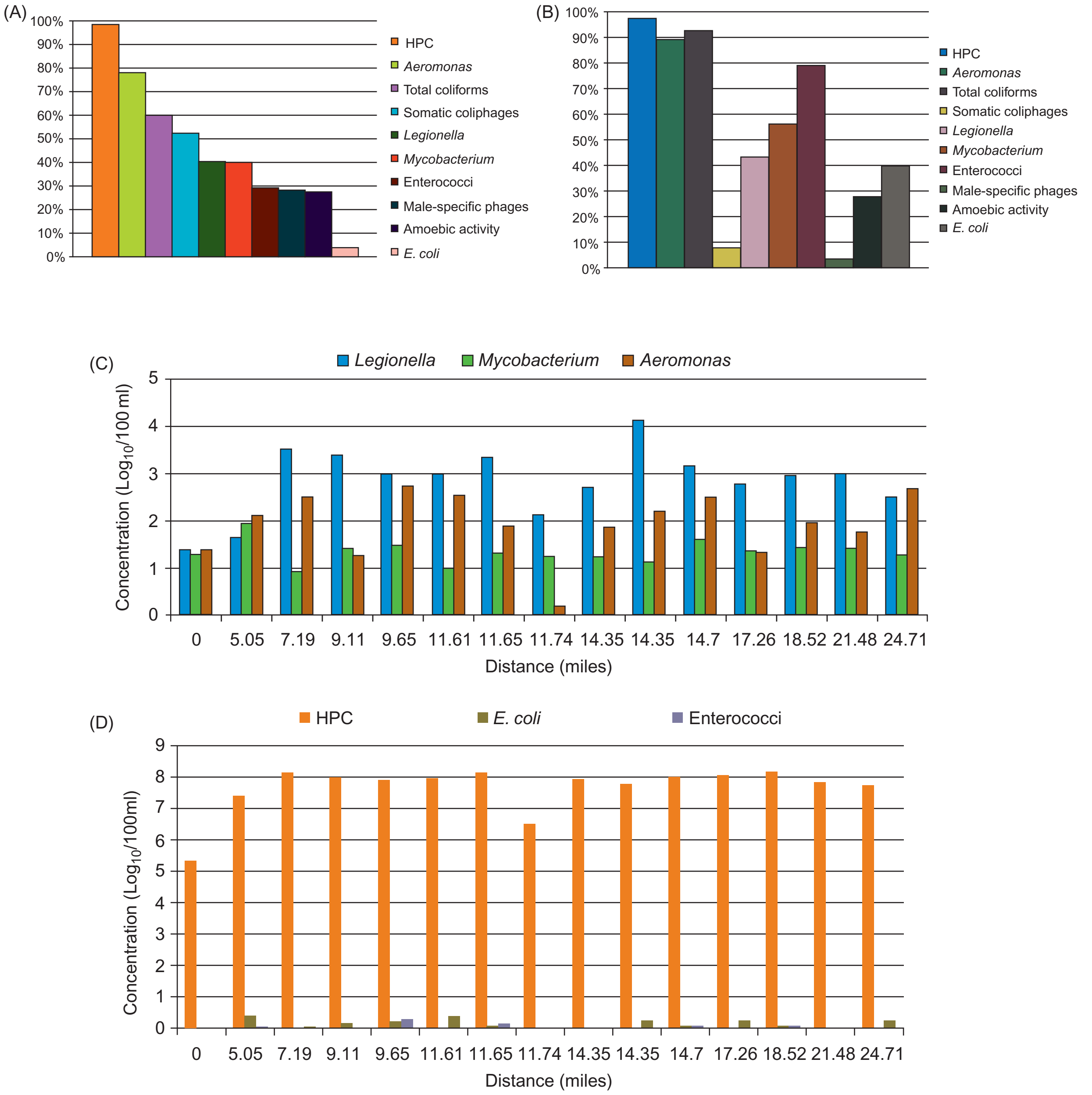


FIGURE 27.3 (A) Frequency of occurrence of opportunistic pathogens, indicator bacteria and phages in chlorinated recycled water at Utility A. (B) Frequency of occurrence of opportunistic pathogens and indicator bacteria and phages in UV disinfected recycled water at Utility B. (C) Influence of residence time on concentrations of water-based pathogens in recycled water distribution systems of Utility A. (D) Influence of residence time on microbial indicators in recycled water distribution systems of Utility A. *Source*: Ajibode *et al*. (2013).

low concentrations. In contrast, water-based pathogens such as *Legionella* or *Mycobacterium* were frequently detected (Figure 27.3A and B). Overall, waterborne indictor organisms such as *E. coli* were less prevalent in the chlorinated system (Utility A) than the UV system (Utility B). The impact of residence time on waterborne and water-based pathogens for plant A is shown in Figure 27.3C and D. Overall, there are numerous instances where significant concentrations of water-based pathogens were found, despite the absence of waterborne indicator organisms (*E. coli*). In fact, waterborne fecal indicators were not correlated with water-based pathogen incidence or concentration.

Regardless of the organism monitored, all opportunistic water-based pathogen concentrations increased fairly rapidly upon entry into the distribution system of either utility, perhaps due to rapid dissipation of residual chlorine. This in turn was followed by reasonably constant concentrations of all organisms despite further increases in residence time. This is in contrast to the conventional view that microbial water quality decreases consistently as water age increases. The maintenance level of organisms may be due to assimilable organic carbon concentrations becoming constant as some organisms continued to grow, while others died and were lysed. Note that rechlorination of the distribution system at the 11.7 mile booster station in Utility A only reduced the concentrations of bacteria temporarily, resulting in the survival and regrowth of organisms including pathogens and indicators. Finally, amoebic activity was detected in approximately one-third of all samples from both systems, corroborating other studies with distribution systems cited by Thomas and Ashbolt (2011).

(Ajibode *et al*., 2013). In contrast to bacteria, fungi have not been as well studied. However, *Aspergillus* spp. have been detected (Smit *et al*., 2005).

27.5.2 Viruses

Viruses are more resistant to disinfection than bacteria, and are also more difficult to remove by filtration due to their small (nm) size. To reduce the level of viruses, extended chlorination or a combination of chlorine and UV light is routinely practiced. Soil aquifer treatment, ultra-filtration and membrane reverse osmosis also cause significant reductions in viruses.

27.5.3 Protozoa

Protozoa including *Cryptosporidium* and *Giardia* have been detected in recycled water despite prior filtration and disinfection (Jjemba *et al*., 2009). Free-living amoebae can also be found in recycled water after treatment, particularly within biofilms found in distribution systems (Ajibode *et al*., 2013). They are very resistant to chlorine in the biofilms, and live off of the bacteria in the biofilm. Of particular interest are *Acanthamoeba* spp., which act as a host for *Legionella*, and *Naegleria fowleri* and *Balamuthia mandrillaris*, which are known to cause brain encephalitis (see also Section 2.3.2.2).

27.5.4 Algae

Algae are photosynthetic microorganisms that can cause esthetic problems (taste and odor) and anoxic conditions in both open and closed reservoirs. However, they can also be found within recycled water distribution systems, where they can contribute to biodegradable carbon in the distribution system, and create amoxic conditions that subsequently result in hydrogen sulfide production, creating foul odors (Jjemba *et al*., 2010). Overall, blue−green algae or cyanobacteria are the most prevalent algae found in recycled water. Many of the cyanobacteria can produce anatoxins or endotoxins that cause flu-like symptoms following exposure via aerosols (Annadotter *et al*., 2005).

27.6 INFLUENCE OF RESIDENCE TIME IN DISTRIBUTION SYSTEMS ON MICROBIAL WATER QUALITY

The chemical and microbial quality of recycled water is routinely monitored as it leaves the treatment plant, since this is frequently the point of compliance, where regulations require the water to be tested. However, due to the fact that the water must travel extensive distances through the distribution system to the point of use, there is potential for the quality of water to deteriorate within the distribution system, with residence time or water age being a key factor. Residence time will normally be a function of water demand and system operation and design. As residence time increases, both chemical and microbial water quality can be diminished (Weinrich *et al*., 2010). The influence of residence time on microbial recycled water quality was recently evaluated in a study in Arizona. Specifically, two wastewater reclamation facilities were studied that utilized different treatment methods and different methods of disinfection. Recycled water from both facilities was monitored for an extended period of time and water quality was evaluated and compared (Case Study 27.4).

With increased residence time, concentrations of bacteria within distribution systems generally increased perhaps due mainly to two factors; the maintenance level of assimilable organic carbon; and the lack of residual chlorine in the distribution system. Since some of these bacteria are opportunistic pathogens they may be of concern and warrant additional evaluation.

QUESTIONS AND PROBLEMS

1. What is the largest use of recycled water?
2. What is the difference between indirect and direct potable reuse?
3. What is unplanned or incidental potable reuse?
4. What are the differences between water-based and waterborne pathogens?
5. Why do we use multiple barriers for the treatment of reclaimed waters for potable reuse? Look up the latest standards for water reuse in your state or country. Do they include bacterial standards? What are the microbial testing requirements? Is direct potable reuse allowed?
6. Why should water-based pathogens be of concern in recycled wastewater?

REFERENCES AND RECOMMENDED READING

Ajibode, O. M., Rock, C., Bright, K., McLain, J. E. T., Gerba, C. P., and Pepper, I. L. (2013) Influence of residence time of reclaimed water within distribution systems on reclaimed water quality. *J. Wat. Reuse & Desalination* **3**, 185–196.

Anderson, E. L., Pepper, I. L., and Kneebone, W. R. (1981) Reclamation of wastewater by means of a soil-turf filter. I. Nitrogen removal. *J. Wat. Pollut. Control Fed.* **53**, 1402–1407.

Annadotter, H., Cronberg, G., Nystrand, R., and Rylander, R. (2005) Endotoxins from cyanobacteria and Gram-negative bacteria as the cause of an acute influenza-like reaction after inhalation of aerosols. *Econ. Health* **2**, 209–221.

Brandhuber, P. (2006) EPA releases updated version of guidelines for water reuse. *Wat. Wastes Dig.* **46**, 1.

Dillon, P., Page, D., Vanderzalm, J., Pavelic, P., Toze, S., Bekele, E., *et al.* (2008) A critical evaluation of combined engineered and aquifer treatment systems in water recycling. *Wat. Sci. Technol.* **57**, 753–762.

duPisani, P. L. (2006) Direct reclamation of potable water at Windhoek's Goreangab reclamation plant. *Desalinization* **188**, 79–88.

Jjemba, P. K., Weinrich, L., Cheng, W., Givaldo, E., and LeChevallier, M. W. (2009) "Guidance Document on the Microbiological Quality and Biostability of Reclaimed Water Following Storage and Distribution," WateReuse Foundation Report WRF-05-002 WRF, Alexandria, VA.

Jjemba, P. K., Weinrich, L. A., Cheng, W., Giraldo, E., and LeChevallier, M. W. (2010) Regrowth of opportunistic pathogens and algae in reclaimed water distribution systems. *Appl. Environ. Microbiol.* **76**, 4169–4178.

Levantesi, C., Mantia, R. L., Masciopinto, C., Böckelmann, U., Ayuso-Gabella, M. N., Salgot, M., *et al.* (2010) Quantification of pathogenic microorganisms and microbial indicators in three wastewater reclamation and managed aquifer recharge facilities in Europe. *Sci. Total Environ.* **408**, 4923–4930.

Lin, K., and Gan, J. (2011) Sorption and degradation of wastewater-associated non-steroidal anti-inflammatory drugs and antibiotics in soils. *Chemosphere* **83**, 240–246.

Metcalf and Eddy (2007) "Water Reuse: Issues, Technologies, and Applications." McGraw-Hill, New York.

Missimer, T. M., Dreses, J. E., Amy, G., Maliva, R. G., and Keller, S. (2012) Restoration of Wadi aquifers by artificial recharge with treated wastewater. *Ground Water* **50**, 514–527.

Moura, D. R., Silveira, M. L., O'Connor, G. A., and Wise, W. R. (2011) Long-term reclaimed water application effects on phosphorus leaching potential in rapid infiltration basins. *J. Environ. Monit.* **13**, 2457–2462.

National Research Council (NRC) (2012) "WateReuse: Potential for Expanding the Nation's Water Supply through Reuse of Municipal Wastewater," National Academy Press, Washington DC.

Qin, J. J., Kekre, K. A., Oo, M. H., and Seah, H. (2009) Pilot study for reclamation of the secondary effluent at Changi Water Reclamation Plant. *Desalin. Wat. Treat.* **11**, 215–223.

Schmidt, C. W. (2008) The yuck factor when disgust meets discovery. *Environ. Health Perspect.* **116**, A524–A527.

Smit, L. A. M., Spaan, S., and Heederik, D. (2005) Endotoxin exposure and symptoms in wastewater treatment works. *Am. J. Indust. Med.* **48**, 30–39.

Thomas, J. M., and Ashbolt, N. J. (2011) Do free-living amoebae in treated drinking water systems present an emerging health risk? *Environ. Sci. Technol.* **45**, 860–869.

UNEP (2004) Water and wastewater reuse: an environmentally sound approach for sustainable urban water management. URL: <http://www.unep.or.jp/ietc/Publications/Water_Sanitation/wastewater_reuse/Booklet-Wastewater_Reuse.pdf>.

U.S. EPA (2004) *Guidelines for Water Reuse*. EPA/625/R-04/108. URL: <http://www.epa.gov/nrmrl/pubs/625r04108/625r04108.pdf>.

WateReuse Association (2011a) Sustainable solutions for a thirsty planet (Website). <http://watereuse.org/information-resources/about-water-reuse/faqs-o>; (accessed October 2011).

WateReuse Association (2011b) Sustainable solutions for a thirsty planet (Website). <http://athirstyplanet.com/be_informed/what_is_water_resuse/who-is-reusing>; (accessed August 2011).

Weinrich, L. A., Jjemba, P. K., Giraldo, E., and LeChevallier, M. S. (2010) Implications of organic carbon in the deterioration of water quality in reclaimed water distribution systems. *Wat. Res.* **18**, 5367–5375.

Wu, L., Weiping, C., French, C., and Chang, A. (2009) Safe Application of Reclaimed Water Reuse in the Southwestern United States. University of California Extension Publication #8357. URL: <http://anrcatalog.ucdavis.edu/>.