CHAPTER

14

Bottled and Drinking Water

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WATER AND THE FOOD INDUSTRY

In the food industry, water can be an end product, such as bottled water, or an ingredient in a wide range of commodities. In addition, water may be used as a means to produce the food, such as irrigation water and shellfish growing waters, and in food processing, such as for washing produce and/or the materials for food production/processing. Also, water may be used as a transport mechanism. In each of these cases, the consumer is subjected to possible human health hazards from water. This chapter focuses on the different types of water used for the preparation of drinking water and potential hazards related to water intended for direct use by the consumer (bottled water, tap water, ice cubes), or indirectly as an ingredient of any food commodity that is consumed without further processing for safety. Practical cases are presented for the determination of safe water, processing for safety water treatment systems, water reuse in the food industry and bottled water safety.

DEFINITIONS FOR WATER

Terms used to designate types of water are diverse and diversely used. Here, we exemplify the different terms for water, their origin and their definition.

- **Bottled water (packaged)** addresses natural mineral water, spring water and all other drinking water, according to the European Union.
- **Packaged water:** Packaged drinking water means all water that is sealed in bottles, packages, or other containers and offered for sale for human consumption, including bottled mineral water, with no added ingredients (FDA, 2012).
- **Natural mineral waters** are waters derived from a natural mineral water spring, which:
  - have been extracted from the ground of a member state and are recognized by the responsible authority of that member state as satisfying the provisions of Schedule 1, Part 1 of S.I. No. 225 of 2007, or
  - have been extracted from the ground of a third country and imported into the Community, and have been recognized by the responsible authority of a member state pursuant to certification in the third country, and are intended to be placed on the market in a member state in bottles or containers, according to the EC.
- "**Other waters**" are those waters which are intended for human consumption, are not natural mineral waters as defined in S.I. No. 225 of 2007, are not spring waters as defined in S.I. No. 225 of 2007, and are intended to be placed on the market in a member state in bottles or containers, according to the European Union.
- **Drinking water:** Water that is intended for human consumption and suitable for all usual domestic uses, complying with the requirements of the WHO Guidelines for Drinking-water Quality or appropriate national standards established by the regulating authority (WHO, 2006). Water that meets or exceeds all applicable federal/provincial/local requirements concerning safety. Also known as **potable (drinkable) water** (Symons et al., 2000; WHO The Health and Environment Lexicon, 2012);
- **Tap water** (running water, city water, municipal water, etc.) is potable water supplied to a tap (valve) inside the household or workplace (Wikipedia).

- **Safe water:** see Drinking water.
- **Clean water:** Water that is clean and is acceptable to the consumer with respect to taste, odor and appearance (WHO, 2011).

LEGISLATION

Legally different categories of waters intended for human consumption supplied as bottled water or municipal drinking water are distinguished.

Bottled Water

Bottled water is covered by European Commission (EC) Regulation S.I. No. 225 of 2007 for natural mineral waters, spring waters and other waters in bottles or containers. This legislation covers the definition of natural mineral water, spring water and "other water," their exploitation, treatment, microbiological criteria, chemical contaminants, sales description, labeling and packaging. Spring waters and "other waters" must also comply with EC Regulation S.I. No. 278 of 2007 for drinking water.

Directive 2009/54/EC defines the provisions applicable to the marketing and exploitation of natural mineral waters. Commission Directive 2003/40/EC of 16 May 2003 establishes the list, concentration limits and labeling requirements for the constituents of natural mineral waters and the conditions for using ozone-enriched air for the treatment of natural mineral waters and spring waters. Natural mineral waters are subject to an authorization procedure carried out by the competent authorities of the EU member states or by European Economic Area (EEA) countries.

The lists of natural mineral waters officially recognized by the member states of the EU and of the EEA (Iceland) and (Norway) are published by the European Commission in the *Official Journal of the European Union*. These lists are regularly updated on http://ec.europa.eu/food/food/labellingnutrition/water/index_en.htm.

Natural mineral waters and spring waters may be treated at source to remove unstable elements and some undesirable constituents in compliance with the provisions laid down in Article 4 of Directive 2009/54/EC. Treatments other than filtration with possible oxygenation have to be assessed and authorized at EU level prior to their use by industry. Commission Regulation (EU) No. 115/2010 of 9 February 2010 lays down the conditions for use of activated alumina for the removal of fluoride from natural mineral waters and spring waters.

Municipal Drinking Water

The European Drinking-water Directive (DWD), Council Directive 98/83/EC as amended by Regulations 1882/2003/EC and 596/2009/EC, concerns the quality of water intended for human consumption and forms part of the regulation of water supply and sanitation in the European Union.

The Directive is intended to protect human health by laying down healthiness and purity requirements which must be met by drinking water within the Community. It applies to all water intended for human consumption apart from natural mineral waters (see §18.3.1) and waters which are medicinal products.

Member states shall ensure that such drinking water:

- does not contain any concentration of microorganisms, parasites or any other substance which constitutes a potential human health risk;
- meets the minimum requirements (microbiological and chemical parameters and those relating to radioactivity) laid down by the directive.

Member states will also take any other action needed in order to guarantee the healthiness and purity of water intended for human consumption.

On a global scale, the WHO provides guidelines for the safety of water, the so-called Guidelines for Drinking-water Quality (WHO, 2011). In these guidelines, the use of water safety plans (WSPs; see also "Risk Assessment and Risk Management," on page 366) is suggested as a comprehensive risk assessment and risk management approach that encompasses all steps in the water supply from catchment to consumer to be able to consistently ensure the safety of a drinking-water supply. The WSP approach draws on many of the principles and concepts from other risk management approaches, in particular the multiple-barrier approach and hazard analysis and critical control point (as used in the food industry).

For verification that the WSP has been put into place, minimum requirements for safe drinking water have been set as laid down in the WHO guidelines (Table 14.1). Microbiological testing shall always be regarded as a verification tool due to the retrospective nature of the methodology. Preferably microbial parameters are integrated with physical and chemical parameters such as temperature and disinfectant concentration, parameters that can be measured in real time and therefore are suitable for continuous monitoring.

SOURCES OF WATER

Earth harbors huge amounts of water, in total approximately 1.4 billion cubic kilometers (Table 14.2 and Figure 14.1). Only 3% of this volume consists of fresh water which is mainly employed for consumption. Increasingly, other sources such as brackish and saline waters are considered for the production of drinking water.

Drinking water may be produced from groundwater, surface water, rainwater and/or recycled water. Depending on the quality of such water and the required quality for its application, source waters may need to be treated prior to use.

Groundwater may originate from shallow and/or deep, (un)confined aquifers and is generally considered safe with respect to contamination with microbial, chemical and radiological hazards (discussed in detail in "Hazards Associated with Drinking Water," page 358). Natural mineral waters are characterized by their purity at source and their constant level of minerals.

Surface waters may include rivers, lakes, delta and groundwater areas with brackish water or a sea or ocean. If water is not fresh but brackish or salt then desalination processes are in order for the production of water suitable for consumption.

Alternatively, drinking water may be produced from rainwater and/or recycled water.

TABLE 14.1 Microbiological Monitoring and Verification of Various Water Types within a Factory

Water	Target Organisms	Method	Guideline Value	Frequency of Monitoring
Potable, municipal drinking water at intake point.	Coliforms presence/absence test using membrane filtration	ISO 9308	ND[a] in 100 ml	As determined by HACCP
Water (municipal or well) after treatment	*Escherichia coli*	ISO 9308	ND in 100 ml	
	Enterococci	ISO 7899	ND in 100 ml	
	Total plate count 22°C	ISO 6222	≤100/ml	
	Total plate count 37°C	ISO 6222	≤10/ml	
Product make up water	Depended on processing	–	–	As determined by HACCP
Chilled water circuits (closed), unpreserved	Coliforms plate count	ISO 9308	≤1/ml	As determined by HACCP
	Total plate count 22°C	ISO 6222	≤1000/ml	
Chilled water circuits (closed), preserved	Coliforms plate count	ISO 9308	≤1/ml	As determined by HACCP. Check preservative concentration continuous or weekly
	Total plate count 22°C	ISO 6222	≤1000/ml	
Hot water circuits	None	–	–	Check temperature storage (60°C) and distribution (56°C) continuously
Final rinse water	Depended on processing	–	For aseptic processes sterility is required	As determined by HACCP
Cooling water for canning	Coliforms plate count.	ISO 9308	≤1/ml	As determined by HACCP. Check chlorine concentration continuous or daily
	Total plate count 22°C	ISO 6222	≤100/ml	
	Chlorination	ISO 7393	2–10 mg/l	
Bottled water	*Escherichia coli*	ISO 9308	ND in 250 ml	As determined by HACCP
	Enterococci	ISO 7899	ND in 250 ml	
	Pseudomonas aeruginosa	ISO 16266	ND in 250 ml	
	Total plate count 22°C	ISO 6222	≤100/ml	
	Total plate count 37°C	ISO 6222	≤20/ml	

Adapted from ILSI, 2008, WHO, 2011 and EC 2012
[a]*ND = Not detectable in the defined volumes.*

Groundwater

Groundwater is water contained beneath the surface in rocks and soil, and which accumulates underground in aquifers (WHO, 2006). Groundwater constitutes 30% of the global freshwater pool (Figure 14.1). In many parts of the world groundwater sources are the

TABLE 14.2 Estimation of the Global Water Distribution (Gleick, 1996)

Water Source	Water Volume, in Cubic Miles	Water Volume, in Cubic Kilometers	Fresh Water Percentage	Total Water Percentage
Oceans, seas, and bays	321,000,000	1,338,000,000	–	96.5
Ice caps, glaciers and permanent snow	5,773,000	24,064,000	68.7	1.74
Groundwater	5,614,000	23,400,000	–	1.7
Fresh	2,526,000	10,530,000	30.1	0.76
Saline	3,088,000	12,870,000	–	0.94
Soil moisture	3959	16,500	0.05	0.001
Ground ice and permafrost	71,970	300,000	0.86	0.022
Lakes	42,320	176,400	–	0.013
Fresh	21,830	91,000	0.26	0.007
Saline	20,490	85,400	–	0.006
Atmosphere	3095	12,900	0.04	0.001
Swamp water	2752	11,470	0.03	0.0008
Rivers	509	2120	0.006	0.0002
Biological water	269	1120	0.003	0.0001
Total	332,500,000	1,386,000,000	–	100

single most important supply for the production of drinking water, particularly in areas with limited or polluted surface water sources. Groundwater is typically of more stable quality and better microbial quality than surface waters. Groundwater quality from small suppliers suffers more from a lack of information, risk assessment and risk management. Groundwater often requires little or no treatment to be suitable for drinking. There are many examples of groundwater being distributed without treatment. However, groundwater quality may be corrupted by nearby sources of hazards if the groundwater well is insufficiently confined and/or well integrity is compromised. Viruses are considered to be the most critical pathogens for groundwater contamination, because of their ability to travel through the subsurface and their high infectivity (Schijven et al., 2010). Flooding of groundwater wells due to extreme precipitation and unnatural threats to its quality should be recognized (Schijven and de Roda Husman, 2005). It is vital therefore that the quality of groundwater is protected if public health is not to be compromised.

Surface Water

Surface water may consist of fresh or saline water, or a combination of semi-saline water called brackish water. Brackish and saline waters are present in our oceans, seas and river

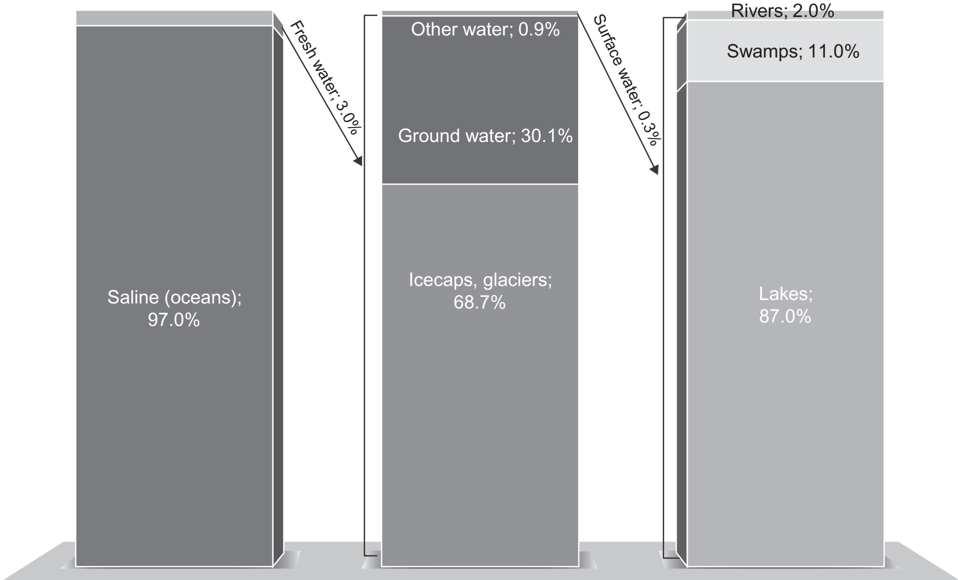

FIGURE 14.1 Freshwater sources.

delta areas. Fresh surface waters include rivers, lakes, swamps and groundwater (Figure 14.1). The larger part of fresh water (two-thirds) is, however, frozen and encapsulated in icecaps and glaciers. Groundwater also constitutes a large part: one-third. Of the remaining part, fresh water mostly includes lakes, swamps and rivers. Surface waters are largely under the influence of contamination from human and animal activities but also from the environment itself, which may compromise public health. The range of human activities in the catchment that may cause pollution of surface waters with microbiological, chemical and radiological hazards includes agricultural activities, sanitation practices, industry, mining, military sites, waste disposal and traffic. As compared with groundwater, surface waters generally need to be treated, often extensively.

Rainwater

Rainwater is initially free of contamination, except for air pollutants (Lye, 2009; Schets et al., 2010; WHO, 2011). However, the quality of rainwater may subsequently deteriorate during harvesting, storage and household use. When collected from rooftops or otherwise, it may become contaminated by animals and humans directly or indirectly from their waste or, alternatively, chemicals may dissolve from collecting and storage devices and human pathogens may grow in stored rainwater. Well-designed rainwater harvesting systems with clean catchments, covered cisterns and storage tanks, and treatment, as appropriate, supported by good hygiene at point of use, can offer drinking water with very low health risks. Rainwater can provide an important source of drinking water in some circumstances as well as be a useful source of water for blending with other sources to reduce the levels of contaminants that may cause health concerns, such as arsenic and fluoride.

Saline Water

In light of climate issues and population growth, it may be difficult to provide sufficient water supply to the world including meeting industry needs. In this respect, desalination of ocean and sea water has been explored. Desalination facilities exist all over the world, particularly in the eastern Mediterranean region, with use increasing on all continents. Desalination is used to remove salts from brackish or saline surface water and groundwater in order to render it acceptable for human consumption or other uses such as in the food industry. Some of the desalination processes used (especially distillation and reverse osmosis) are highly effective in removing microbial and chemical hazards facilitating the use of these processes as single-stage treatments.

Recycled Water

After use in the food industry (ILSI, 2012), water may be of sufficient quality for use in a similar process, e.g. washing. Depending on the contact, both in time and surface, between the water and food ingredient or end product, the recycled water needs to meet quality requirements. If these are not met, there is a range of available treatment options to improve water quality (WHO, 2011). See also "Water Reuse in Food Processing," on page 372.

DRINKING-WATER APPLICATIONS IN THE FOOD INDUSTRY

Water is used widely in the food industry. It is used to move products, to produce and/or wash vegetables, fruits, fish and poultry, and to clean and refresh raw vegetables after harvesting and during distribution. Water, or steam made from it, is used for cleaning, disinfection and heating purposes. Finally, water can be a consumer end product and/or an ingredient in food. Virtually all frozen foods carry a glaze of ice which is often derived from process water, and for certain frozen foods (such as fish and shellfish) a glaze is added as a protective measure.

The amount of water used to produce food commodities is sometimes impressive. The so-called water footprint is defined as the total volume of fresh water that is used to produce the goods and services consumed by an individual or community or produced by a business. The production of 1 kilogram of beef requires 15,415 liters of water, an average of 1,600 liters are needed for 1 kg of bread and 27 liters are needed for a cup of tea (250 ml). (www.waterfootprint.org, accessed June 2013).

Water as End Product

Water is delivered to the consumer either as tap water from a piped distribution system or packaged in bottles, cartons or other containers. The food industry delivers packaged water only.

The following types of water are produced as an end product, packaged in plastic or glass bottles, cartons, water coolers, water dispensers and so on. Sizes range from small single serving PET bottles to large carboys for water coolers.

- **Spring water:** Bottled water derived from an underground formation from which water flows naturally to the surface of the earth. Spring water must be collected only at the spring or through a borehole tapping the underground formation feeding the spring.
- **Purified water:** Water that has been produced by distillation, deionization, reverse osmosis or other suitable processes while meeting the definition of purified water in the United States Pharmacopoeia.
- **Mineral water:** Bottled water containing not less than 250 parts per million total dissolved solids.
- **Sparkling bottled water:** Water that, after treatment and possible replacement with carbon dioxide, contains the same amount of carbon dioxide that it had as it emerged from the source.
- **Artesian water/Artesian well water:** Bottled water from a well that taps a confined aquifer (a water-bearing underground layer of rock or sand) in which the water level stands at some height above the top of the aquifer.
- **Well water:** Bottled water from a hole bored, drilled or otherwise constructed in the ground, which taps the water aquifer.

The amount of bottled water consumed per year was estimated in 2011 to be 262 billion liters worldwide. This represents an average of 37 liters per capita. (http://www.zenithinternational.com/accessed june 2013). However, some countries show extremely higher figures. Table 14.3 shows the 20 countries where most bottled water is consumed, compared to the average global consumption.

The market is forecasted to grow to over 400 billion liters in 2020.

Bottled water has come under criticism in recent years for the environmental impacts of groundwater extraction, the energy and environmental costs of the plastic packaging and transportation costs and concerns about water quality and the validity of some marketing claims. One criticism of bottled water concerns the packaging. Bottled water commonly is packaged in polyethylene terephthalate (PET), which requires a significant amount of energy to produce. While PET is recyclable, only a fraction of plastic bottles made from PET are actually recycled. For example, in the United States, according to a NAPCOR (National Association for PET Container Resources) study, water bottles account for 50% of all the PET bottles and containers collected by curb side recycling, and the recycling rate for water bottles was 28% in 2009. However, bales of PET collected for recycling often contain materials such as polypropylene caps, labels and glue, and other contaminants, which are then weighed and included in the PET recycling rate. The percentage of "clean PET flake" yielded once the contaminants have been removed was 21% in 2009 and is a more accurate depiction of how much PET actually gets recycled. European recycling rates tend to be somewhat higher. In the United States, plastic used to create bottles uses an estimated 15 million barrels of oil annually (data on recycling from http://www.container-recycling.org, accessed September 2012).

TABLE 14.3 Per Capita Bottled Water Consumption by Top Countries 2000 to 2010

	Per Capita Bottled Water Consumption (liters)		
Countries	**2000**	**2005**	**2010**
Mexico	124	179	243
Italy	160	191	187
United Arab Emirates	114	181	153
Belgium–Luxembourg	118	160	148
Germany	102	128	134
France	126	139	132
Spain	105	146	124
Lebanon	77	107	121
Thailand	70	76	114
Hungary	39	70	111
Switzerland	90	104	108
United States	67	99	107
Slovenia	56	81	107
Croatia	47	78	101
Cyprus	72	98	98
Qatar	–	79	95
Saudi Arabia	80	93	95
China, Hong Kong SAR	–	68	95
Czech Republic	68	90	92
Austria	75	81	91

Data from Beverage Marketing Corporation and http://www.worldwater.org – accessed September 2012.

Water as Ingredient

The importance of water quality cannot be underestimated by food manufacturers. It plays a vital role, both as a critical ingredient in ensuring food quality and as a key to efficient production. It provides appropriate water content in the final product. For example, canned soups and vegetables contain a high percentage of added water once they have been cooked and packaged. Another important function of water is to dissolve ingredients. Especially when used as ingredient, it is important that the water produces no hazards, flavors or smells which might affect the quality or consistency of the final product. "Determination of Water

Safety," on page 367, presents a simple safety classification of water "fit for purpose" and an easy-to-use decision tree for assessing the suitability of water for its intended use.

Producers of food products that need to be rehydrated before consumption should be aware of the safety of water used for this purpose. In particular products that will not, or will not sufficiently, be reheated need attention from both the water supplier as well as the supplier of the dried food. The water supplier obviously needs to provide safe water, either bottled or tap. The food supplier is responsible for pathogen-free products, maximal intrinsic security (like water content or capacity, acidity, temperature, packaging) and shall instruct customers in how to safely rehydrate the product – in particular if they sell their products to areas where safe water is not commonly available.

Dried foods intended for babies, such as infant formula, require specifically safe water as infants' immune system is not fully developed and they are particularly vulnerable. Of course, the product itself shall be free from any harmful chemical, microbiological or physical hazards; however, consumers should be alerted that dried foods are not sterile. Risks associated with the rehydration of products and their final preparation for consumption, including recontamination during storage, should be considered in the products' HACCP plan, and validated safety instructions should be provided to consumers. The Codex Guidelines on Validation of Control Measures provide guidance on the validation process for preparation of consumer information (see Codex Alimentarius. Guidelines for the Validation of Control Measures).

The World Health Organization has issued guidelines for safe preparation, storage and handling of powdered infant formula (WHO, 2007b). These guidelines are valuable for consumers and producers of infant formula. A few relevant subjects for producers of infant formula are summarized:

- **Formula preparation:** In most cases, it is safe to mix formula using ordinary cold tap water that has been brought to boil and then boiled for 1 minute and cooled. According to the World Health Organization, recent studies suggest that mixing powdered formula with water at a temperature of at least 70°C (158°F) will eliminate the bacterium *Cronobacter sakazakii* (previously *Enterobacter sakazakii*) and other pathogenic (micro) organisms. Remember that formula made with hot water needs to be cooled quickly to body temperature if it is being fed to the baby immediately. If the formula is not being fed immediately, refrigerate it right away and keep refrigerated until feeding.
- **Water:** Use the exact amount of water recommended on the label. Under-diluted formula can cause problems related to dehydration. Over-diluted formula will not provide adequate nutrition, and, if fed for an extended period of time, may result in slower growth.
- **Bottled water:** If consumers use non-sterile bottled water for formula preparation, they should follow the same directions as described for tap water above. If the water is marketed by the manufacturer as sterile and for infants, it must meet general requirements for commercial sterility.
- **"Use by" or "expiry" date:** This is the date after which a package or container of infant formula should not be fed to infants.
- **Storage:** Manufacturers must include instructions on infant formula packaging for before and after the container is opened. They must also include information on the storage and disposal of prepared formula.

Water for Processing

During food production, water is widely used as a processing aid without the aim of serving it as an ingredient. Examples of demands for water during food processing are (not exhaustive):

- Washing or cleaning of (raw) products.
- Transport of products.
- Treatment of the product (e.g. alteration, separation).
- Cooling processes: for example, fish is typically shipped in ice; poultry may be cooled in water and slush ice and transported in ice.
- Steam generation for heating, directly or indirectly.
- Cleaning or rinsing of equipment.
- Abnormal incidents (like fire protection).
- Sanitation.

Increasingly process water is recycled. This subject is discussed in "Water Treatment Technologies for Safe Water Production," on page 367.

Water at Household Level

To obtain and maintain safe water at the household level, integrated planning, combined with effective monitoring and evaluation, is critical. An estimated 780 million people drink water from unimproved sources, and millions more drink contaminated water from improved sources (WHO and Unicef, 2012). Until safe, reliable, piped-in water is available to every household, interim measures, such as household water treatment and safe storage (HWTS) to prevent contamination during collection, transport and use in the home, are needed to reduce the burden of diarrheal disease. While a growing body of evidence demonstrates that the use of HWTS methods improves the microbial quality of household drinking water and reduces the burden of diarrheal disease in users, there is also increasing evidence that inconsistent and/or incorrect use may be a major challenge in realizing the full potential from HWTS. In order to develop effective mechanisms to encourage and sustain correct use of HWTS, there is a need to monitor and evaluate uptake. Recently, WHO (2012) has provided a toolkit including process monitoring to assess program implementation and quantitative analysis through surveys, direct observation and water quality monitoring. As part of this toolkit, a set of indicators pays attention to reported and observed use; correct, consistent use and storage; knowledge and behavior; other environmental health interventions; and water quality.

HAZARDS ASSOCIATED WITH DRINKING WATER

Microbial, chemical and radiological hazards may compromise water quality and confer public health risks by human consumption of food and water. The great majority of evident water-related health problems are the result of microbial (bacterial, viral, protozoan or other biological) contamination.

An appreciable number of serious health concerns may occur as a result of the chemical contamination of drinking water. Adverse health effects due to exposure to microbial hazards will be acute and may be chronic as opposed to exposure to most chemical hazards that are rarely acute.

Microbial Hazards

Bacteria, viruses, protozoan parasites, algae, amoebae and helminths are known microbial hazards associated with drinking water. Some of these organisms, such as a few bacterial species, algae and helminths, can multiply independently in the aquatic environment whereas other, so-called enteric pathogens are completely dependent on their warm-blooded host, animals and/or humans, for their multiplication (Table 14.4). In case the enteric bacteria, viruses or parasites can be transmitted from animals to humans, whether or not waterborne, these are called zoonotic. Examples are the protozoan parasite *Cryptosporidium*, the hepatitis E virus and the bacterium *Campylobacter*. Viruses (20–300 nm) in general are much smaller than bacteria (approx. 1 μm) which are turn smaller than protozoan parasites (10 μm or larger). The different sizes affect their fate and transport in the aquatic environment as well as their removal and inactivation efficacy by treatment.

Infection with waterborne pathogens may pass without symptoms, or lead to mild disease, severe disease or death. Young children are especially vulnerable for contracting water-related infections and diseases mainly involving diarrhea, and if not properly treated these could be life threatening. On a global level, the UN and partners estimate that child mortality has declined by 41% since 1990, from 12 million deaths per year to 6.9 million in 2011 (data from WHO, accessed November 2012). However, many countries, especially in sub-Saharan Africa, are still far off-target in reducing child deaths. Contaminated water is an important cause of the catastrophe (see also Motarjemi et al., 1993, 2012): worldwide, an estimated 780 million people lacked safe drinking water in 2010 involving 1.8 million diarrheal disease deaths, mostly children, every year (WHO, 2011).

In low income regions exposure to *Vibrio* bacteria causes large cholera outbreaks with many thousands becoming ill, resulting in countless deaths (Mandal et al., 2011). These outbreaks may follow natural disasters such as floods, as in Haiti in 2010. However, outbreaks are ongoing in sub-Saharan Africa. Hepatitis E virus has caused numerous outbreaks among displaced people in Chad and Sudan in 2004 resulting in more than 45 deaths, mostly pregnant women (Boccia et al., 2006). In 2007, in northern Uganda, the virus demanded 160 deaths with more than 10,196 persons diseased (Teshale et al., 2010). Although the problem with unsafe drinking water is strongly related to low income countries, high income countries may also suffer from major outbreaks. One of the largest recorded outbreaks of waterborne disease took place in Milwaukee (USA) in 1993. Over 400,000 people were infected with *Cryptosporidium parvum*. This outbreak was probably caused by polluted water from Lake Michigan, the source of the drinking water. In May 2000 approximately 2300 people became seriously ill and seven died from exposure to contaminated drinking water in the town of Walkerton, Ontario (Canada). A combination of extreme weather, lack of appropriate control systems and human failure resulted in water being contaminated with *E. coli* O157:H7 and *Campylobacter jejuni*. These cases illustrate that the complexity of (tap)water systems in developed countries may be alive to technical and/or human failure.

TABLE 14.4 Sources of Water-related Pathogens

	Source		
Pathogen	**Human**	**Animal**	**Environmental**
Acanthamoeba	−	−	+
Adenoviruses	+	+	−
Aeromonas	+	+	+
Campylobacter	+	+	−
Cryptosporidium	+	+	−
Cyanobacteria	−	−	+
Pathogenic *E. coli*	+	+	−
Enteroviruses	+	+	−
Giardia	+	+	−
Hepatitis A virus	+	−	−
Hepatitis E virus	+	+	−
Legionella	−	−	+
Leptospira	−	+	−
Mycobacterium (nontuberculous mycobacteria)	−	−	+
Naegleria fowleri	−	−	+
Noroviruses	+	−	−
Pseudomonas aeruginosa	−	−	+
Rotavirus	+	−	−
Salmonella (para)typhi	+	−	−
Salmonella nontyphi	+	+	−
Shigella	+	+	−
Staphylococcus aureus	+	−	−
Toxoplasma	+	+	+
Vibrio	+	+	+

(Updated from Schets et al., 2010)

Disease outbreaks may be directly associated with drinking-water consumption but also to more indirect exposure. After heavy rainfall, 60% of cruise participants reported gastroenteritis with stools positive for *Shigella sonnei*, *Giardia* and *Cryptosporidium* after consumption of ice produced from potable water contaminated with lake water (Serdarevic et al., 2012).

Chemical Hazards

Water may contain many different chemicals, usually in low to very low concentrations; however, spills may be extensive. An example is the Minamata disease in Japan (1956). It was caused by the release of methyl mercury in the industrial wastewater from the Chisso Corporation's chemical factory, which continued from 1932 to 1968 (Wikipedia, accessed December 2012). In Bangladesh it is estimated that a major part of the population is at risk of poisoning because groundwater used for drinking has been contaminated with naturally occurring inorganic arsenic (Smith et al., 2000). Due to labor and technical limitations only part of these chemicals are monitored; beyond this the focus is addressed to well-known substances or groups of chemicals (and not the individual elements). The main sources of chemical hazards are (WHO, 2011):

- Naturally occurring: rocks, soils and the effects of the geological setting and climate.
- Industrial sources and human dwellings: mining (extractive industries) and manufacturing and processing industries, sewage, solid wastes, urban runoff, fuel leakages, pharmaceuticals, hormones, personal care products.
- Agricultural activities: manures, fertilizers, intensive animal practices and pesticides.
- Water treatment or materials in contact with drinking water: coagulants, DBPs, piping materials.
- Pesticides used in water for public health: larvicides used in the control of insect vectors of disease.
- Cyanobacteria producing unwanted metabolites: eutrophic water bodies.

The effect of chemical contaminants may be categorized as follows:

- Toxic to live stock.
- Toxic to fish, shellfish or crustaceans, in particular in aquaculture.
- Toxic to crops (phytotoxic).
- Accumulation in fish, livestock, plants and products derived from them.
- Toxic to humans, either directly or indirectly.

Chemical hazards are usually not related to acute toxicity while concentrations are usually very low. Of concern, however, is exposure to very low concentrations with effects that are only evident after a very long period of time.

An extensive overview of chemical hazards has been described by the WHO. Without being complete this list includes the following categories.

Inorganic

This group of potential hazards includes metals and metalloids (like lead, iron, nickel, zinc, mercury, arsenic, boron, cadmium and molybdenum), salts (sodium, chloride, potassium, calcium, manganese and magnesium), nitrate and nitrite and the parameter total hardness.

Some of the inorganic substances are derived from soil and/or rocks, but some metals are potentially released from pipeline systems. An epidemiological study on the extent of lead exposure via tap water in Hamburg (Germany) showed that people with lead in tap water above 5 mg/L showed significantly higher blood lead levels compared to those with no detectable lead in the tap water. Elevated levels of lead (and other metals) may cause adverse health effects after prolonged periods of exposure (Cidu, 2011).

In the UK an incident affecting five children attending a summer camp was related to consumption of "blue colored" drinking water. The contamination occurred in an old building which was being used for the first time after a few months. Because the stored water had been left standing for many months it had become blue tinged due to the copper pipes and tanks. The children's symptoms were consistent with excessive copper ingestion. After the system had been completely flushed through, the water returned to its natural colorless state and the levels of copper were confirmed to be below the (UK) guideline values (Paranthaman, 2010).

These examples elucidate the urge to analyze risks associated with the tap water distribution system.

Nitrate toxicosis can occur through metabolism of nitrate to nitrite, which in turn oxidizes the iron atoms in hemoglobin from ferrous iron (2+) to ferric iron (3+), rendering it unable to carry oxygen. This process can lead to generalized lack of oxygen in organ tissue and a dangerous condition called methemoglobinemia. Methemoglobinemia in infants is known as blue baby syndrome. Although nitrates in drinking water were once thought to be a contributing factor, there are now significant scientific doubts as to whether there is a causal link to disease (Wikipedia, accessed 29 August 2012).

Although salts are necessary for the human body and physiology, excessive salt concentrations may be hazardous. Fresh water normally has a salt concentration <0.05%. Drinking water with elevated amounts of salt can have unfavorable effects on blood pressure and heart rate, and produce physiological changes (headache, dizziness, nausea, blood-stained stools, vomiting). In extreme cases, the increased salt content of drinking water may cause severe illness and even death.

In conclusion, inorganic hazards may cause severe illness in humans. However, the chance that the threshold concentrations end up in tap or bottled drinking water can be controlled relatively easy with an appropriate HACCP system.

Organic

Organic pollutants are a comprehensive group of chemicals that include (Wikipedia, accessed August 2012; WHO, 2011):

- Detergents.
- Disinfection by-products found in chemically disinfected drinking water, such as chloroform.
- Food processing waste, which can include oxygen-demanding substances, fats and grease.
- Insecticides and herbicides, a wide range of organohalides and other chemical compounds.
- Petroleum hydrocarbons, including fuels (gasoline, diesel fuel, jet fuels and fuel oil), lubricants (motor oil) and fuel combustion by-products from storm water runoff.
- Tree and bush debris from logging operations.
- Volatile organic compounds (VOCs), such as industrial solvents, from improper storage.
- Chlorinated solvents that may fall to the bottom of reservoirs, since they do not mix well with water and are denser.

- Polychlorinated biphenyl (PCBs).
- Trichloroethylene.
- Perchlorate (both a naturally occurring and man-made chemical that is used to produce rocket fuel, fireworks, flares and explosives). Perchlorate can also be present in bleach and in some fertilizers (http://water.epa.gov, accessed December 2012).
- Various chemical compounds found in personal hygiene and cosmetic products.

The WHO guideline for drinking-water quality provides detailed information on many of the organic hazards and proposes methods to prevent and control them (WHO, 2011).

Disinfectants

Disinfectants commonly used in the food, drink and catering industries include the following:

- Surface active agents (surfactants). These include the amphoterics (based on amyl alkyl glycines), the cationics (quaternary ammonium compounds – known as QACs or quats) and biguanides/diguanides. Many of the amphoterics and cationics are classified as skin, eye and respiratory irritants. Biguanides/diguanides are of low toxicity and irritancy and are useful skin disinfectants.
- Alcohols. These are used as skin cleaners as well as a transport medium for other active ingredients, but nevertheless are irritating to eyes, nose and throat at high airborne concentrations and can be a fire risk.
- Aldehydes. Glutaraldehyde is classified as a skin and respiratory sensitizer. Formaldehyde is a strong respiratory irritant and is also classified as a category 3 carcinogen.
- Peracetic acid is a powerful oxidizing agent used in the food and drink industries and is also extremely corrosive.
- Hypochlorite and organic chlorine-releasing compounds are corrosive in their concentrated form and are classified as eye and skin irritants in their dilute form (5–10%).

Most disinfectants are used to disinfect equipment or the premises. But drinking water used for food production may also contain disinfectants which are added by water suppliers to control pathogens (see "Water Treatment Technologies for Safe Water Production," on page 367). Disinfectants themselves can react with naturally-occurring materials in the drinking water to form by-products, such as trihalomethanes and haloacetic acids, which may pose health risks. The challenge for water suppliers is to control and limit the risks from pathogens and disinfection by-products as well as health risks to customers from disinfection by-products. For actual information on allowed disinfectants and maximum residual disinfectant levels, food companies shall address to local suppliers and legislation.

The food industry may also be at risk directly because chemicals are used for cleaning and disinfection. Residues may come in contact with the product(s) causing hazards, e.g. as with the supplied drinking water, and HACCP plans should cover these risks appropriately.

Pharmaceuticals, Hormones and Drugs

As a consequence of strong increases in human (and animal) healthcare more and more pharmaceuticals, hormones and drugs are prescribed. Part of the substances themselves or their metabolites are excreted and may reach water sources. In particular substances that are designed to be active in the human body at low levels are of concern. For other substances small quantities mean that effects are only evident after a long period of time. Therefore most standards for drinking water are based on risk assessments for long-term exposure.

A study in 2010 reviewed various QPhRA (quantitative pharmaceutical risk assessment) studies to identify potential threads (Kumar, 2010). In general, for low concentrations of APIs (active pharmaceutical ingredients), none of the QPhRA studies has identified any human health risks via exposure to drinking water, but uncertainties related to the QPhRA still exist and warrant consideration. In particular, knowledge about chronic effects and mixture effects of pharmaceuticals is very limited and requires further study.

Radiological Hazards

Radiation may originate from a number of naturally-occurring and human-made sources. Natural materials like uranium, thorium and potassium-40 can be found in diverse environments. Radioactive constituents of drinking water can result from:

- Naturally-occurring radioactive substances.
- Technological processes from which radioactive materials are released (like mining, processing of mineral sands or phosphate fertilizer production).
- Radionuclides discharged from nuclear fuel recycle facilities.
- Manufactured radionuclides (e.g. for medical and industrial use) that are not properly discharged.
- Past releases of radionuclides into the environment, including water sources (nuclear research programs and tests).

Radiation risks are limited, in particular when water is supplied by reliable suppliers. Food companies using natural sources should analyze the possible radiological risks by assessing the environment and if necessary testing for contaminants.

Greater concerns are related to nuclear disasters.

In 1986 the Chernobyl accident contaminated 125,000 square miles of land in Belarus, Russia and Ukraine with radio nucleotides including cesium-137, strontium-90 and plutonium-239. It is interesting that the water supply is not nearly as contaminated as the soil. Levels in water bodies fell rapidly during the weeks after fallout through dilution, physical decay and absorption of radionuclides to catchment soils. Bed sediments are an important long-term sink for radioactivity. Aquatic habitats also tend to be more tolerant of radioactive contamination (http://environmentalchemistry.com, accessed August 2012 + Chernobyl's Legacy: Health, Environmental and Socio-economic Impacts and Recommendations to the Governments of Belarus, the Russian Federation and Ukraine. The Chernobyl Forum: 2003–2005).

The Fukushima-Daiichi nuclear plant disaster after the earthquake and tsunami that struck Japan on 11 March 2011 again illustrated the risk of radiological contamination of water. Most of the radioactive material ended up in the sea and will be strongly diluted and therefore will not cause concern for the drinking water, as illustrated by Yasuhiro Sonoda (MP) drinking a glass of decontaminated water taken from puddles inside the housing of the reactors. However, some scientists fear that deep water fish, fish at the top of the food chain, mollusks and other filtrating sea life are most sensitive to nuclear contamination/concentration.

For the food industry radiological hazards from (drinking) water may be relevant only if the company is located near a disaster area or when water is imported from these areas. A thorough risk analysis and monitoring program is required under these conditions.

Organoleptic (Taste, Odor, Appearance) Hazards

Taste and odor in drinking water are two of the most widespread causes of customer complaints. Although there are in general no associated health effects, the importance for the food industry is significant while organoleptic problems may influence product quality.

Since taste and odor work together it is often difficult to distinguish the two. Common organoleptic deviations include (http://extoxnet.orst.edu, accessed September 2012):

- **Strong chlorine taste or smell:** Generally this occurs when the water is treated at the water treatment plant by disinfection (see "Chemical Hazards Associated with Drinking Water," above).
- **Metallic taste:** Some water systems have a high mineral concentration causing a salty or soda taste. In the case of iron and manganese, a strong metallic taste is readily detected.
- **Rotten egg odor:** This is usually a result of decaying organic deposits underground. As water flows through these areas, hydrogen sulfide gas is picked up, and when this water reaches the surface or comes out of the tap, the gas is released into the air. Hydrogen sulfide gas produces the rotten egg odor, can be corrosive to plumbing at high concentrations and can tarnish silver rapidly. As little as 0.5 ppm (parts per million) can be tasted in drinking water.
- **Musty or unnatural smells:** These smells are normally a result of, even low amounts of, organic matter or even some pesticides in the water supply.
- **Turpentine taste or odor:** This smell can be a result of methyl tert-butyl ether (MTBE) contamination. MTBE is a gasoline additive, used as an oxygenate to raise the octane number. The odor threshold of MTBE is fairly low, so many people can smell it.
- **Red or brown color:** A red, brown or rusty color is generally indicative of iron or manganese in the water. It may cause stains in sinks, or discolored laundry.
- **Yellow color:** This coloration occurs in regions where the water has passed through marshlands and then moved through peat soils. It is more commonly found in surface water supplies and shallow wells. Although the yellow color may be displeasing, it presents no health hazard, as it is only small particles suspended in the water.
- **Blue or green color:** A green or blue color is generally a result of copper in the water supply, or copper pipes and corrosive water. Copper has a taste threshold of around 5 ppm. Copper can become a problem if the concentration is higher than 30 ppm. Effects at this dose are vomiting, diarrhea and general gastrointestinal distress.
- **Cloudy white or foamy water:** Cloudy water is usually due to turbidity. Turbidity is caused by finely divided particles in the water. When light hits the water, it is scattered, giving a cloudy look to the water. The particles may be of either organic or inorganic nature. Neither one causes any harmful effects to the body, although they can cause abrasions to pipes, or possible staining of sinks.

When water is used for food production, or may be in contact with food, organoleptic hazards are part of the HACCP plan. If necessary, appropriate measures shall be taken to mitigate aberrant characteristics of the water.

Miscellaneous Hazards

To ensure the safety of water in the food industry, apart from environmental and processing care to produce safe water, the role of the staff in the food industry also needs to be considered. The workers need to be aware that they may be asymptomatic carriers of pathogens and therefore need to exercise optimal (hand) hygiene after defecation. For instance, cruise ships are regularly involved in large-scale gastroenteritis outbreaks associated with norovirus often due to insufficient hygiene of kitchen workers. Water has been epidemiologically identified as one of the risk factors (Verhoef et al., 2008). Prerequisite programs on ship sanitation such as by the WHO and CDC should cover this. In 2011 the WHO launched the third edition of the guide to ship sanitation with global reference on health requirements for ship construction and operation. And the Vessel Sanitation Program (VSP) at the CDC assists the cruise ship industry to prevent and control the introduction, transmission and spread of gastrointestinal illnesses on cruise ships.

The design and maintenance of the entire water distribution system (tanks, boilers, piping) shall be as optimal as possible. Dead ends shall be removed and long setting times must be followed by adequate flushing with hot water (or disinfectant). In particular care should be taken to avoid growth of *Legionella*. The WHO has issued an extensive document on *Legionella* and the prevention of legionellosis (WHO, 2007a). This WHO document has separate chapters on potable water and in-building distribution systems and on cooling towers and evaporative condensers.

Drinking water is also a potential vehicle for the deliberate use of microbial pathogens, microbe-derived products or chemicals that cause harm to humans, livestock or agricultural crops. Food companies shall conduct assessments of their vulnerabilities to terrorist attack or sabotage and set up preventive programs or systems to provide a safe and reliable supply of drinking water (for further information see Chapter 35).

RISK ASSESSMENT AND RISK MANAGEMENT

The most effective means of consistently ensuring the safety of a drinking-water supply is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in the water supply from catchment to consumer. The WHO has proposed such a water safety framework and the implementation of comprehensive water safety plans (WSPs) to consistently ensure drinking-water safety and thereby protect public health (WHO, 2011). Failure to ensure drinking-water safety may expose the community to the risk of outbreaks of intestinal and other infectious diseases. Outbreaks of waterborne disease are particularly to be avoided because of their capacity to result in the simultaneous infection of a large number of persons and potentially a high proportion of the community.

Water safety plans (WHO, 2009, 2011) are suggested to comprise of:

- A system assessment to determine whether the drinking-water supply (from source through treatment to the point of consumption) as a whole can deliver water of a quality that meets the health-based targets.
- Operational monitoring of the control measures in the drinking-water supply that are of particular importance in securing drinking-water safety.
- Management plans documenting the system assessment and monitoring plans and describing actions to be taken in normal operation and incident conditions, including upgrade and improvement, documentation and communication.

HACCP CASE STUDIES

Determination of Water Safety

As with any hazard, radiological, chemical and (micro)biological hazards in drinking water should be assessed using principles of HACCP (see Chapter 31).

The first step is to establish the intended use of the water. Questions that should be answered: does the water come in contact with the product and, if so, at what stages? Are consumers exposed to the water and, if so, in what form (drinking water, adherent water, ice, steam)? A simple classification for the "fit for purpose" is (adapted from ILSI, 2008):

	Chemically potable	**Chemically non-potable**
(Micro)biologically potable	Class 1	Class 3
(Micro)biologically non-potable	Class 2	Class 4

For each application the right category shall be chosen. For products with little or no further processing for safety, class 1 water shall be used as ingredient. If only class 2 water is available, an appropriate pretreatment shall be applied, or the processing itself contains appropriate steps to eliminate microbiological risks. Classes 3 and 4 will normally not be suitable for water as ingredient, but may be used as processing water that will not be in direct contact with the product itself.

Treatment of the water may change the class. Heat treatment may change class 2 water to class 1 water. Ultrafiltration and additional chemical treatment may even change class 4 water to class 1 water.

To establish whether the water is safe for the intended use, a decision tree was published by ILSI (adapted from ILSI, 2008 – see Figure 14.2).

Water Treatment Technologies for Safe Water Production

An increasing number of technologies are developed to process water for safety. Typical industrial wastewater treatment consists of a combination of physical, biological and chemical processes to remove solids and organic matter, and, if necessary, pathogens, metals and

1. Is the water potentially contaminated with either radiological, chemical or (micro)biological hazards at concentrations which are significant for human health? The fit for purpose classification.	→ NO (Class 1 water)	"SAFE" WATER
→ YES (Class 2, 3 or 4 water)		
2. Will the water be consumed without further treatment or come into contact with products that will be consumed without further treatment?	→ NO (Class 2, 3 or 4 water)	
→ YES (Class 2, 3 or 4 water)		
3. Is the water treated to eliminate potential hazards before consumption or contact with the product that will be consumed?	→ YES (Class 1 water)	
→ NO (Class 2, 3 or 4 water)		
4. Will subsequent treatment of the product for consumption, either in the factory or at home by consumers, eliminate the hazard?	→ YES (Class 1 water)	
→ NO (Class 2, 3 or 4 water)		
UNSAFE WATER		

Question 1 defines the fit for purpose class and refers to knowledge of the potential hazards and criteria set in water guidelines and (inter)national regulations. If no criteria are available a full risk analysis is necessary to establish potential hazards and judgment of chance and impact/severity.

Question 2 refers to the intended use of the water and whether a potential hazard may be in contact with the consumer either directly or indirectly. Therefore this question involves an evaluation of exposure and risk. Is exposure of the hazard to the product or consumer likely (the chance)? If so, how much and how long and what will be the potential consequence (severity)? Interestingly water not fit for use (Classes 2, 3 and 4) can be considered safe when not used for indirect or direct consumption.

Question 3 refers to existing steps in the process that will (un)intentionally act as mitigation step(s) to potential hazards and risks? Steps can involve, for example, heating, filtration, chemical treatment, UV treatment, ozone treatment.

Question 4 addresses the additional mitigation steps, either at the consumers' home or at the producers' factory. In the latter case this usually involves process steps that are not intended to reduce the risks but as side effect do so.

FIGURE 14.2 Water safety decision tree. *Adapted from ILSI, 2008*.

nutrients from wastewater. Table 14.5 summarizes some water treatment alternatives for given challenges.

The goal in designing a processing system to obtain safe water is to develop an integrated cost-effective scheme that is capable of reliably meeting water quality and safety objectives. The degree of treatment required in individual water treatment facilities varies according to the specific (re)use application and associated water quality requirements

Filtration

Filtration involves porous material (filter) to separate (suspended) solids from the water. Most applied systems are granular filtration and require the use of filter cartridges (EHEDG, 2004). Granular filtration uses a filter bed consisting of one or more layers of sand and anthracite. Factors that influence effectiveness are the size, form and nature of the particles, the strength, the porosity, the filtration rate and the bed height. Filter cartridges are usually placed in a pressure vessel. Effectiveness is determined by the right pore size and fouling. Pressure drop over the filter indicates saturation with solids. In time, replacement of the

TABLE 14.5 Water Treatment Alternatives

Challenge	Treatment Option	Advantage	Concern
Microbiological hazards (bacteria, viruses, protozoa)	Chlorination	Easy to handle, effective to most bacteria	Most protozoa are resistant and some viruses are not eliminated. Chemical by-products. Elevated turbidity reduces effectiveness
	Ozone	Very effective against most bacteria and viruses. Viruses generally more resistant than bacteria, effective to *Cryptosporidium*	Complex technology, bromate formation, some viruses are not eliminated
	UV	Easy to handle, effective to *Cryptosporidium*	TSS, turbidity and color may render it inefficient
	Membranes (ultra-filtration, nano-filtration)	No by-products, no smell, no taste	Costs, fouling
	Heating (sterilization)	Very effective, no smell, no taste	Costs (energy)
Suspended solids	Granular media, filters	Low cost, readily available, simple and effective. Large volume, low pressure	Require regular maintenance
	Screen filters	Widely available in specialized materials	Relatively coarse separation. Not suited to heavy loads, clogging
	Tubular screen filters	Robust and offer repeated use	Selection of screen material must match process conditions
	Membrane (micro-filtration, ultra-filtration)	No by-products, no smell, no taste	Higher operating costs, fouling
Organic matter	Advanced biological treatment (e.g. bio-filtration).	Low cost	Only for biodegradable substances
	Adsorption (PAC, GAC)	Very effective for non-polar substances	Costly, residuals (spent carbon)
	AOP (advanced oxidation processes)	No residuals produced	Formation of unknown (biodegradable) compounds
Inorganic compounds: heavy metals	Flocculation/precipitation		Chemicals used increase salinity
Inorganic compounds: salinity	Ion-exchange	Effective	Cost, salt increase
	Reverse osmosis	Effective	Residuals to be disposed may need to be treated to reduce corrosivity

(Adapted from ILSI, 2008 and WHO, 2011).

TABLE 14.6 Types of Membrane Filtration (EHEDG 2004)

Type of Membrane Technology	Pressure Applied (bar)	Porosity (cut-off value)	Retention
Micro-filtration (MF)	1–2	20–1000 nm	Solid particles, bacteria, yeasts, protozoa, colloids
Ultra-filtration (UF)	1–5	20–200 nm	Above + polysaccharides, proteins
Nano-filtration (NF)	5	1–10 nm	Above + sugars, amino acids, hardness (calcium salts), multiple charged ions (e.g. sulfates, phosphates), viruses
Reversed osmosis	15–50	<2 nm	Above + salts

filters or back-washing (water flow in the opposite direction) is necessary. Drawbacks are long running times, insufficient frequency of back-washing or filter replacement and installation of non-compliant cartridges in pressure vessels. For filtration of small solids, soluble materials and microorganisms, membrane filtration is necessary.

Membrane Filtration

Membrane filtration is a pressure-driven technology. Depending on the pore sizes particles are retained (Table 14.6).

The choice of a filtration system is complex and requires specific knowledge of available materials (organic polymers, ceramic and stainless steel), membrane geometry (spiral, tubular, capillary, hollow fiber) and the application involved (temperature, pH, particles in the fluid, cleaning methods/chemicals). Like any filtration technology, membrane filtration is susceptible for fouling and systematic cleaning (or replacement) is required. Leakage of membranes due to chemical and mechanical damage induces risk of post-filtration contamination. Reversed osmosis water may have corrosive properties due to removal of minerals. Remineralization may be required in certain applications.

Chlorination

Chlorination is one of the most used disinfection systems for potable and utility water.

Sodium hypochlorite (N_aOCl) is the predominant chemical used for chlorination. The main reasons are availability, simplicity of the application, cost effectiveness and, if properly used, reliability. Chlorine is effective at inactivating bacteria and viruses, and under certain circumstances parasites like *Giardia*. However, chlorine has little impact on the parasite *Cryptosporidium* at typical water treatment concentrations (up to 5 mg/l). Chlorine's general disinfection capability with respect to microorganisms can be illustrated in the following way from most effective to least effective: bacteria > viruses > *Giardia* cysts > *Cryptosporidium* oocysts (USPHC, 2006).

Even higher numbers of bacteria are generally killed in minutes. This is particularly true for Gram-negative bacteria like *E. coli* and *Salmonella*. Gram-positive bacteria, especially spore-forming species like *Bacillus* and *Clostridium*, tend to be less sensitive but can still be eliminated at appropriate concentrations of chlorine and contact times.

TABLE 14.7 The Various Forms of Chlorine (CAWST, 2012)

Product	Strength	Remarks
High test hypochlorite (HTH) (calcium hypochlorite)	65% – 70%	Usually in granular form. Stable (approximately 2% active chlorine loss per year)
Chlorinated lime, aka bleaching powder	30%	Usually in powder form. Not stable.
Household bleach (sodium hypochlorite)	2.5–10%	Liquid form. Not stable; only use if manufactured recently (<3 months) and stored away from heat and light
Sodium dichloro-isocyanurate (NaDCC), used in products such as "Aquatabs"	50–60% as granules. 5 mg to >5 g active chlorine per tablet	Usually in tablet form, also available in granular form. Tablets pre-dosed for water treatment. Very stable (shelf-life approximately 5 years)

Chlorine has been shown to be a highly effective viricide. Most viruses are killed very effectively after exposure to chlorine within minutes. The most resistant virus was a poliovirus, requiring more than 60 minutes for 4-log removal.

Chlorine has been shown to have limited success inactivating protozoa. An important indicator, *Giardia lamblia*, requires prolonged contact times (30–60 minutes) at chlorine residual concentration (2–3 mg/l) to achieve 99.9% (3-log) inactivation.

The parasite *Cryptosporidium*, however, is very resistant and requires high chlorine concentrations and extreme long exposure times to eliminate cells and oocysts. One *Cryptosporidium* study reported that 80 mg/l of free chlorine required 90 minutes to achieve only a 1-log (90%) inactivation of oocysts! These exposure times and concentrations are generally not feasible and therefore chlorination is not an option to control protozoa.

Chlorine kills bacteria and viruses by interfering with chemical bonds and in particular inactivation of enzymes.

Chlorination for the control of microbiological contamination of drinking and processing water involves the following parameters (WHO, 2011):

- Residual concentration of free chlorine minimal 0.5 mg/l, typical 2–3 mg/l and maximum 5 mg/l.
- Contact time at least 30 min at pH <8.0 (optimum pH 5.5–pH 7.5).
- The contact time is valid at 18–20°C and above. For every 10°C drop in temperature the efficiency of disinfection reduces by 50–60% (at close to 0°C disinfection efficiency is very poor).

Chlorine is available in several forms (see Table 14.7).

Despite the benefits, some disadvantages must be addressed (EHEDG, 2005):

- Reduced effectiveness at pH >8.0 and lower temperatures.
- Reacts with nitrogenous compounds forming chloramines (unpleasant odors and health concerns). Also reactive with several organic materials forming compounds with possible health impacts.

- Easily quenched by organic matter and turbidity in the water.
- Highly corrosive.

An alternative to chlorine is the use of chlorine dioxide, a highly reactive compound that cannot be stored in its active form. Therefore it is generated on site, close to the point of use. Compared to chlorine it mitigates most of the disadvantages; however, the costs and the necessity to generate it at the point of use makes it a less interesting option for smaller companies.

Filtration and Chlorination

While chlorination alone is not (always) effective against protozoa, a dual approach may be applied. Several (household) water treatment systems incorporate both a physical filtration step for particle removal and a chlorination step for disinfection. Alternatively particles, including protozoa, may be removed by flocculation prior to chlorination, using coagulants. Aluminum coagulants include aluminum sulfate, aluminum chloride and sodium aluminate. Iron coagulants include ferric sulfate, ferrous sulfate, ferric chloride and ferric chloride sulfate. Other chemicals used as coagulants include hydrated lime and magnesium carbonate. Overall *Giardia* and *Cryptosporidium* removals after coagulation and filtration may be approximately 5-log (for further reading: www.iwawaterwiki.org, assessed January 2013).

Water Reuse in Food Processing

Fresh water resources are globally subjected to increasing pressure in the form of consumptive water use and pollution. On national and international levels awareness is growing that water resources should be protected both qualitatively and quantitatively. The food industry is in general regarded as a major water consumer resulting in relatively high water footprints. Apart from increased efficiency, reuse of water is a way to reduce fresh water exploitation. When applying reused water it is necessary to identify whether the reused water will be in contact with the product(s) or not. Typical applications of reused water are indirect cooling or the generation of steam that will not be in contact with the product. Direct contact applications may include washing and/or transport of raw products (like fruit or vegetables that will be processed) or cleaning of equipment.

Any food industry considering the application of reused water should ask the following questions (ILSI, 2008)[1] :

- What is the proposed reuse? Will the water come into contact with food or will it be used as a noncontact processing aid (e.g. coolant)?
- What are the regulatory, consumer safety and technical requirements for the water in the proposed reuse application?
- What is the starting quality of the intended reuse criteria and what treatments or controls can be applied so that it meets the criteria defined in the previous question?

[1] ILSI is working on a Water Recovery Guideline which is expected to be released in 2013 (www.ilsi.org).

- What monitoring procedures need to be put in place to adequately monitor the performance of the treatments and/or controls?
- What procedures need to be put in place to overcome existing technical difficulties, such as chemical or biological fouling (e.g. biofilms)?
- What measures need to be taken if a deviation from the required quality is detected?
- What changes to availability or cost are likely in the future and may alter the current situation (e.g. proposals in Brazil to charge industry for water abstracted from either groundwater or rivers)?
- What changes to water supply quality are likely in the future (e.g. salination of groundwater)?
- What treatments will be required to ensure that the water meets the necessary standards?
- What modifications could be incorporated into either existing or new equipment (e.g. appropriate filters on bottle washers) or existing or new process lines to maximize the opportunities for water reuse?
- What regulatory conditions encourage (or discourage) optimized water use?

Example: Recycled Hot Water as a Decontamination Technique for Meat Carcasses

The European Food Safety Authority has delivered a scientific opinion on safety and efficacy of using recycled hot water as a decontamination technique for meat carcasses (EFSA, 2012). At the moment (2013) only the use of potable water is allowed in the EU for carcass decontamination purposes. However, recycled water (i.e. reusing water after reheating) is used for carcass decontamination in some countries (e.g. Canada, Denmark). Environmental care and energy-preserving motives are driving forces for recycling. The EFSA study has considered potential microbiological and abiotic risks for carcasses associated with recycled hot water decontamination and related control options.

From the study it is concluded that the decontamination efficacy of recycled hot water does not differ significantly from that of hot potable water.

By ensuring proper heating regimes of recycled water, vegetative bacterial cells and protozoan parasites are controlled. Microbial toxins are not significantly inactivated in the recycling process, but production of these toxins during the first round of carcass decontamination and prior to heating is not relevant.

According to the EFSA study, only microbiological risks associated with heat-resistant bacterial spores (*C. botulinum*, *C. perfringens*, *C. difficile* and *B. cereus*) are relevant for recycled hot water. These risks can be controlled by ensuring that recycled hot water is verifiably subjected to appropriate reheating and frequency of renewal regimes. These regimes shall ensure that the microbiological risk in recycled water is not higher than in hot potable water. For abiotic risks, the only concern with recycled hot water derives from the potential presence and accumulation of residues of veterinary drugs and other chemical contaminants in the water for decontamination of poultry carcasses.

As with any process recycling of water for decontamination of carcasses shall be subjected to HACCP. Important criteria for efficacy and control of possible risks include minimal heating temperature, time regime and frequency of renewal of recycled water. These criteria shall ensure compliance with existing microbiological criteria for potable water and prevent accumulation of heat-resistant spores. Recycling procedures shall be microbiologically validated, continuously monitored by instrumental measurements, verified periodically by microbiological testing of water and documented. Compliance with the chemical criteria for potable water needs to be verified for recycled hot water by periodic chemical analysis of the water and documented. The absence of residues of veterinary medicinal products in recycled hot water used for decontamination of poultry carcasses has to be verified by periodical testing and be documented.

Finally, the application of recycled hot water applied on carcasses (temperatures, application techniques and related parameters) shall be subject to risk analysis in the same way as with hot potable water decontamination.

Bottled Water Safety

Aside from adhering to the various industry regulations, the best way to minimize the risk of contaminated bottled water is to have a good HACCP system in place. The seven principles of a HACCP system (see Chapter 31) provide the basis for safe production and will help to satisfy business owners and their customers that products are safe in an efficient, reliable and cost-effective way. It is achieved by focusing on hazard prevention throughout the product life cycle rather than relying on end-product testing.

An example from a multinational company that produces bottled water shows a typical production process and accompanying quality assurance and control measures (Figure 14.3).

1. **Source receiving and inspection**
   Water is carefully collected from the source, which may either be a well or municipal supply. Common method of receiving water is through stainless steel pipeline. Water from the source shall be tested prior to internal processing on microbiological and chemical aspects.
2. **Activated carbon filtration (municipal water only)**
   Activated carbon may be necessary to remove substances like chlorine and trihalomethanes. This filtration process should be monitored and tested regularly.
3. **Pretreatment**
   Water softener may be used to reduce water hardness.
4. **Demineralization process**
   Demineralization is the use of cation – and anion resin beds to remove minerals. Technologies include:
   a. Reverse osmosis: Use of high-pressure pump and special membranes, called semi-permeable membranes, to reverse the natural phenomenon of osmosis.
   b. Distillation: A process that boils the water and collects the condensate for bottling.
5. **Water storage and monitoring**
   Water is received into storage tanks. Storage environment and water carefully monitored daily.
6. **Micro-filtration**
   Using micro-filters, usually pharmaceutical grade, particles as small as 0.2 micron in diameter are removed. The pore size guarantees removal of microbiological contaminants.

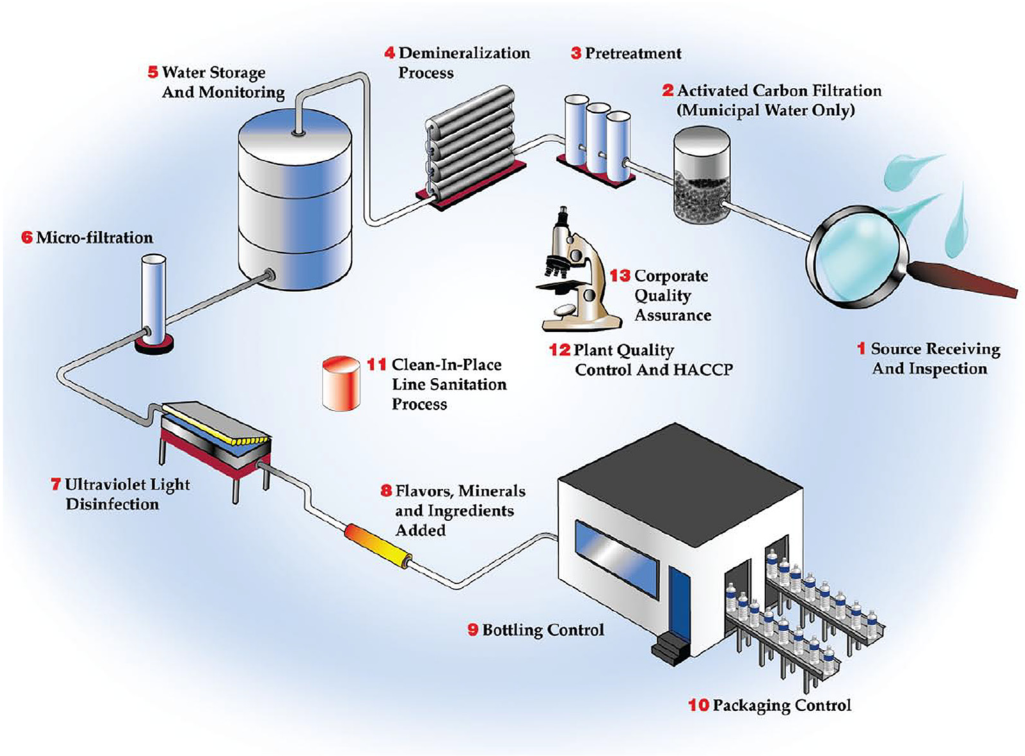

FIGURE 14.3 Bottled water production (http://www.nestle-waters.com/brands/water-quality/Pages/purified-water.aspx: assessed August 2012).

7. **Ultraviolet light disinfection**
   Application of ultraviolet light provides added assurance of product disinfection and safety. As with ultra-filtration this process should be continually monitored by instrumentation.
8. **Flavors, minerals and ingredients added**
9. **Bottling control**
   Bottling should be conducted under highly controlled conditions using state-of-the-art equipment. Each bottle shall be marked with a code that identifies the plant (location), bottling line and time produced. Filling room and environment are subject to high sanitary conditions.
10. **Packaging control**
    Packaging materials not meeting (internal) standards should be rejected before using them. Bottles, caps and labels should be controlled and monitored by lot.
11. **Clean-in-place line sanitation process**
    Line sanitation practices include preferably internal pipe and equipment cleaning methods (cleaning in place – CIP). Such processes should circulate detergent and

sanitizing solutions at the precise temperatures and time to affect total control and maximum effectiveness of the line sanitation process.

12. **Plant quality control and HACCP**
13. **Corporate quality assurance**
    Water, packaging materials and plant processes shall be carefully monitored to ensure they meet company specifications and (inter)national standards. Quality control and quality assurance departments, preferably independent from production, are responsible for the standards and specifications and monitoring of the plant quality programs. A comprehensive set of standards for industries active in bottled water production to ensure safety and quality has been published by the US International Bottled Water Association (IBWA, 2012). This code of practice for bottled water offers monitoring matrices for chemical, microbiological, radiological and organoleptic parameters.

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Further Reading

An extensive amount of information is available on the safety of water. Many documents are accessible (or can be downloaded) from websites. For further reading we recommend the following websites and documents (without the intention to be complete, many other sources may be valuable):

The European Hygienic Engineering & Design Group (EHEDG) issues guidelines which are regularly updated and complemented by new documents in various language versions (www.ehedg.org).

The International Life Sciences Institute (ILSI) disseminates science by publishing articles on original research, literature reviews and gap analyses, and meeting proceedings in peer-reviewed journals. ILSI Europe also publishes books, monographs, white papers and other reports through ILSI Press (www.ilsi.org).

The World Health Organization and Unicef have published many relevant documents on water safety. Most of them are freely available at www.who.int. In particular we recommend:

WHO (2011) Guidelines for Drinking-Water Quality. World Health Organisation, 4e edition, Geneva.

WHO (2007) Safe preparation, storage and handling of powdered infant formula; Guidelines.

WHO and Unicef (2012) A toolkit for monitoring and evaluating household water treatment and safe storage programmes. ISBN 978 92 4 150462 1.

The International Bottled Water Association produced a Bottled Water Code of Practice in 2012.

The European Food Safety Authority (EFSA) regularly publishes documents (opinions) on food and water safety. These documents can be retrieved from http://www.efsa.europa.eu. European legislation is available at http://europa.eu/eu-law/index_en.htm.