Chapter 2
Principles for Sound Drinking Water Management: A Review

2.1 Introduction

As stated in the previous chapter, the whole of the companion book (Dore 2015) was devoted to the major principles and concepts of sound drinking water management. The objective of this chapter is to summarize these principles. The key principles may be stated as follows: source water protection; classification of drinking water technologies according to the contaminants they remove; risk assessment methods and the incorporation of risk in water management; well-formulated infrastructure asset management plans; and the reduction or elimination of long-term risks. These topics are summarized in separate sections, *brevatim et seriatim.*

2.2 Source Water Protection

What is the first step in preventing waterborne disease outbreaks? In the multi-barrier approach, the first component is the establishment of protection of source waters. This may require a watershed protection plan, including supporting legislation. Implementing watershed protection requires an understanding of the key principles of watershed management, which are now well known. Both the US and Ontario have sound legislation on watershed protection, which is lacking in the provinces of Alberta and British Columbia, as we show in Chaps. 7 and 8. For the legislation and approach to watershed protection in Ontario, see Chap. 4.

A simple way of summarizing the principles of source water protection is to focus on *point source pollution* and *nonpoint source pollution*.

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2.2.1 Point Source Pollution

Point source pollution can originate from sewage treatment plants, industrial plant effluents, and animal and crop farms. Point sources of water pollution are still a major problem in most developing countries due to lack of adequate administration, infrastructure, regulation or its enforcement. In Canada, the U.S., and most other developed countries, the quality of effluents discharged from sewage treatment plants and industrial facilities is highly regulated, and thus these effluents do not generally pose a significant threat to the quality of receiving surface waters, unless wastewater treatment is inadequate or faulty. But animal production and farms are an exception. Below is a discussion of farm animal production problems and water pollution control in the United States, where animal production farms still pose a major threat to water quality. In the U.S., there are about 450,000 farms with animal feeding operations. About 85 % of these facilities are small with less than 250 animals, but there are many animal feeding operations with more than 1,000 animals (USEPA 2002). These large farms are called "Concentrated Animal Feeding Operations," or CFAOs. In Canada, they are called "Combined Feeding Operations."

For CFAOs, farm owners/operators are required to have a permit that ensures safe disposal of all the manure, urine, and dead animal matter. The farms are subject to inspection and must have a comprehensive nutrient management plan that considers the safety of all nearby water bodies including groundwater. All CFAOs are required to keep records of the quantity of manure produced and how the manure was utilized, applied to land, sold to third parties for the manufacture of fertilizers, or used for methane generation as an energy source.

Apart from the regulatory requirements, there are additional voluntary guidelines from the U.S. Department of Agriculture (USDA) for best management practices (BMPs) on farms as well as tax incentives for demonstrating the implementation of BMPs. There are financial and technical assistance programs for implementing nutrient management plans as well as environmental education programs. And there are performance measures for the implementation of the "Unified National Animal Feeding Operations Strategy" (USEPA 2002).

Farm animals should be required to be fenced and not allowed to be within a specified distance of public watercourses. Many of the disease outbreaks listed in Table 1.1 occurred because animal fecal matter got into the public watercourses in Europe, the USA, and in Canada. The Walkerton outbreak was made worse due to the fact that there were torrential rains for more than 2 days, and it was this rain that carried the *E. coli* bacteria from surrounding cattle farms into the drinking water wells. But there were also failures of other mechanisms that led to the 7 deaths and kidney impairment of more than 200 people.

2.2.2 Nonpoint Source Pollution

Nonpoint sources of pollution, also called diffused pollution, mostly originate from unknown origins and locations; it is the pollution that shows up downstream; it may include pollution due to the death of wild animals in a water course at an unknown location, or even bird feces. Nonpoint sources of pollution associated with surface runoff include sediments, nutrients, pesticides, pathogens, metals, oils, and many chemical contaminants entering water bodies from roads and roofs and other unknown locations. Controlling nonpoint sources of pollution is rather difficult and complicated because of its diffused characteristics and difficulty in pinpointing the origin of contaminants flowing to surface waters. Watershed management and implementing BMPs are considered effective tools for nonpoint source pollution control.

To deal with nonpoint source pollution, the USEPA recommends the application of Ecological Risk Assessment (ERA) to watershed management (USEPA 1998). As defined by the USEPA, "ERA is a process to collect, organize, and analyze scientific information in order to evaluate the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors" (USEPA 1998). Watershed ERA can be summarized as follows. The conceptual models describe the various physical, chemical, and biological stressors, their sources, assessment endpoints, and the possible pathways, and also disclose how the assessment endpoints respond to the stressors via possible pathways, as shown in Fig. 2.1 (USEPA 2007).

As shown in Fig. 2.1, the source is some public water body such as a lake or river. The "stressor" could be wild animals or farm animals contaminating the source, but this stressor is unknown to the watershed authorities. A good knowledge of the human activity in the watershed and possibilities of contamination, based on past history, and a series of measurements of contaminants at specific locations can minimize the impacts on the "endpoint." Complete mapping of subwatersheds and the location of farms within each subwatershed can be useful in minimizing non-point source pollution and its possible impacts.

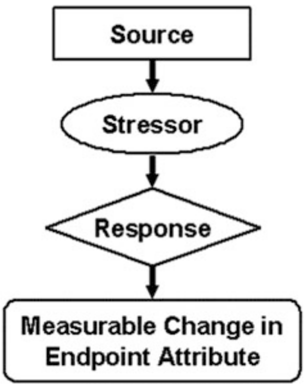

Fig. 2.1 Elementary model of ERA (USEPA 2007)

In May 1983, in Greenville Florida, the campylobacter pathogen entered the water source through infected bird droppings into open water towers. This was an example of "nonpoint" source water pollution, as this is a random act and although the "point" source was later identified, the problem was the *open water towers.*

2.3 Classification of Treatment Technologies

We begin by classifying some commonly used drinking water treatment technologies. The waterborne disease outbreak in Carollton Georgia in 1987 was in part due to failure of flocculators. There are also other examples of faulty equipment.

Most large water treatment plants use conventional water treatment which is: pre-sedimentation or screening, chemical coagulation and flocculation, settling, filtration (usually sand filtration), and disinfection, typically using chlorine or chlorine derivatives. Conventional treatment is used to reduce total suspended solids and turbidity. (For further discussion and classification of the conventional treatment train, see below). However, conventional treatment is not suitable for small water systems. We therefore focus here on treatment technologies that are suitable for small as well as large water systems.

Table 2.1 is a classification of treatment technologies on the basis of what contaminant(s) each technology can *remove*.

Table 2.1 Proposed water treatment classes

Class	Typical treatment technology	Contaminants removed
Class 1	Chlorination	Water disinfection; removal of most bacteria but not all pathogens
Class 2	High rate clarification and filtration	Disinfection plus suspended solid removal
Class 3	Ultra Violet	Class 2 plus inactivation of Protozoa and Viruses
Class 4	Ozonation	Class 3 plus removal of dissolved organic matter (no DPB[a] precursors)
Class 5a	Membrane filtration; includes activated carbon, granular or powdered	Class 3 plus removal of geosmin and other taste and odor compounds, DBPs, volatile organic Compounds; reduction of endocrine disruptors, micropollutants, pesticides, pharmaceuticals, and personal care products
Class 5b	Advanced oxidation processes (may be based on UV or ozonation)	Class 5a removal plus higher efficacy of the removal of chemicals and other micropollutants (e.g., pesticides, pharmaceuticals, personal care products, taste, and odor concerns)
Class 6	Reverse osmosis or distillation	Class 5 plus removal of salinity; but note that contaminants with molecules smaller than water (e.g., acetaminophen) will not be removed by RO alone

[a] DPB stands for "disinfection byproducts."

Class 1 represents the minimum level of treatment, which is disinfection by chlorination only. We consider chlorination the minimum disinfection treatment level since all water treatment plants are required to produce water that is free of pathogens. While most groundwater-based systems would rely on chlorine only (Class 1), many surface water small water systems will be Class 2, i.e., water that has suspended solids removed and is disinfected. In a Class 3 plant, protozoa as well as viruses will also be removed or inactivated, possibly with the aid of UV or ozonation. If, in addition, all dissolved organic matter is also removed before chlorination, then that would be water without disinfection by-products (DBP), and we classify such treatment technology as Class 4.

On the other hand Class 5 (i.e., Classes 5a and 5b) represents technologies that also reduce or remove chemicals, micropollutants, DBPs, protozoa, and suspended solids in addition to disinfection. In the scheme proposed above, each progressively higher treatment class indicates a greater removal of contaminants. However, this classification scheme is fairly broad in scope, an initial attempt, although other more finely graded classifications are possible. Note that we are classifying *treatment categories or classes, not final water quality.* What emerges from this classification is a way of comparing final water quality *indirectly*, on the basis of what treatment systems are used, and also assessing any possible long-term health threats.

In North America most drinking water comes from surface water, which needs to be treated adequately. According to the American Water Works Report (AWWA 2008), chlorine gas remained the predominant disinfectant in the US, used by 63 % of respondents to a survey whereas those who used chloramine accounted for 30 %; chlorine dioxide for 8 %; ozone for 9 %; and ultraviolet light (UV) for 2 %. (The figures do not add up to 100 as some may use more than one disinfection method.) In Canada, according to the Environment Canada survey of Municipal Water and Wastewater Plants (2004), some 93 % used chlorine as the only disinfectant. Those using UV or ozonation accounted for only 6 % of the total. This shows the dominant role played by chlorine and chlorine derivatives in North America, where this Class 1 technology is concerned almost exclusively with the removal of pathogens, although we know that chlorine is not effective against protozoa and other pathogens. However for most large cities and populations, the conventional water treatment method of coagulation, flocculation, clarification, and filtration, and is typically followed by disinfection by chlorine or chlorine derivative. But the failure of a flocculator led to an outbreak of *cryptosporidiosis* in Carrollton Georgia in 1987; the failure of a chlorinator led to an outbreak of *giardiasis* in Bradford Pennsylvania in 1979. Thus the conventional treatment train is best described as being Class 3 *if it removes all protozoa;* it cannot be classified as Class 4 as chlorination will leave DBP precursors in the water. For this reason, in Ontario and indeed in the whole of North America, the main DBPs, called Trihalomethanes (THMs), nitrosamines, and Haloacetic Acids (HAAs) are regulated with maximum contamination limits. But there are also many thousands of other DBPs, called Halides, that are not regulated at all.

The most significant drinking water outbreak of *cryptosporidiosis* was in Milwaukee Wisconsin from March to April of 1993, the worst waterborne disease outbreak in US history. Two water treatment plants supplying water to Milwaukee used water from Lake Michigan. Both plants used conventional treatment of coagulation, flocculation, sedimentation, rapid sand filtration, and chlorination treatment (Solo-Gabriele and Neumeister 1996, p. 81). Again the failure to remove a protozoon indicates that these plants functioned as no more than Class 2 treatment systems.

Based on the evidence and the above classification system, we are led to the conclusion that the conventional treatment plants in North America are at best Class 3, and no more than Class 2 when they fail to remove protozoa.[1] Note that this conclusion is based on treatment technologies and not on the quality of final drinking water, which may be quite good in some areas, depending on the characteristics of the source water; our focus here is on treatment.

It should also be noted that after a large fall in unit costs of ozonation, many water utilities are choosing ozonation as the primary treatment option (Class 4). In Europe the treatment of choice is granular activated carbon, which we classify as Class 5a. Granular activated carbon (GAC) has been used extensively for the removal of dissolved organics from drinking water. In the early 1970s, it was reported that bacteria, which proliferate in GAC filters, may be responsible for a fraction of the net removal of organics in the filter. Following this discovery, pre-ozonation was found to enhance significantly the biological activity on GAC. The combination of ozonation and GAC is commonly referred to as the biological activated carbon (BAC) process, or biologically enhanced activated carbon process. This was implemented in many large water treatment plants in Europe in the 1980s. The efficacy of activated carbon in removing all sorts of contaminants has been further confirmed by Rodriguez-Mozaz et al. (2004).

Advanced oxidation processes (with ozonation or UV-based) is essentially the same as Class 5a, but experiments show a greater efficacy of removal of the same contaminants as those in Class 5a; for evidence, see Chap. 4 in this book. We therefore classify Advanced Oxidation processes as Class 5b.

In Germany, roughly 74 % of drinking water is drawn from ground and spring water, and the remainder is drawn from surface water sources, such as lakes and rivers (Althoff 2007). By 2010, 63 % of the groundwater bodies in Germany had achieved a rating of "good chemical status" (BMU 2014). Of the total 1,000 groundwater bodies, only 4 % have not achieved a "good quantitative status," i.e., 4 % of the aquifers did not have enough water. The status of surface water is such

[1] An anonymous referee of this book has suggested that the use of alum should be mentioned. Alum is used widely as a coagulant. Optimum coagulation to achieve maximum reductions of turbidity and microbes requires careful control of coagulant dose, pH, and consideration of the quality of the water being treated, as well as appropriate mixing conditions for optimum flocculation. Lack of attention to these details can result in poor coagulation-flocculation and inefficient removal of particles and microbes. Under optimum conditions, coagulation-flocculation and sedimentation with alum and iron can achieve microbial reductions of 1 or 2 log for all classes of waterborne pathogens. Thus by itself the coagulation-flocculation is never enough to meet regulatory requirements in North America.

that 88 % of water bodies achieved a "good" chemical status, while only 10 % of all surface water bodies had obtained at least a "good" ecological status (BMU 2014). Given the quality of groundwater, practically no disinfection is needed. The 2011 Profile of the German Water Sector (ATT 2011) states:

> The quality of drinking water is so good that the use of disinfectants in water treatment can even be forgone in many places without compromising the high hygienic drinking water standard.

Since there is no chlorine, there are no DBPs; in areas where the source is groundwater, there are no chemical residues in the water and of course no salinity. Thus for the groundwater sources we can conclude that German drinking water from the water treatment plants is equivalent to Class 5. In North Rhine-Westphalia, in the City of Cologne, they use groundwater as the source, which is then filtered through activated carbon, producing a very high quality of water. To quote from the City of Cologne[2] website:

> Some waterworks in Cologne used disinfectant to prevent an increase in the number of germs and thus hygienic deterioration of the drinking water quality on the way to the customer. Our water lab proved, however, that the perfect hygienic quality of drinking water can be guaranteed even without the use of chlorine dioxide or chlorine.

Where surface water is used in North Rhine-Westphalia, they detected perfluorooctanoate (PFOA) in drinking water at concentrations up to 0.64 μ/L in Arnsberg, Sauerland, Germany. In response, the German Drinking Water Commission (TWK) assessed perfluorinated compounds (PFCs) in drinking water and in June 2006 became the first in the world to set a health-based guideline value for safe lifelong exposure at 0.3 μ/L (sum of PFOA and perfluorooctanesulfonate, PFOS). PFOA and PFOS can be effectively removed from drinking water by percolation over granular activated carbon.

We should also note that for 90 % of the residents of Ontario, the source water is the Great Lakes, which also receive wastewater that is not always treated to remove chemicals, particularly pesticides, pharmaceuticals, and personal care products; this topic is deferred to the chapter dealing with wastewater and its impacts on drinking water (Chaps. 4 and 9).

We return to the classification of treatment classes given in Table 2.1. This classification scheme is fairly broad in scope, and other more finely graded classifications would be possible. Note that we are classifying *treatment categories or classes, not final water quality.* In this chapter we are interested in the main technologies for water systems and what contaminants can be removed from raw water. Table 2.2 is a description and minimum plant size for a number of treatment technologies.

The corresponding costs as a function of scale for these technologies are summarized in Fig. 2.2.

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[2] http://www.rheinenergie.com/media/portale/downloads_4/rheinenergie_1/broschueren_1/Colognes_Drinking_Water.pdf.

Table 2.2 Treatment technologies

Technology	Description	Treatment class
Chlorination	• Removal of bacteria only; but not protozoa or other pathogens resistant to chlorine	Class 1
HIGH rate treatment and clarification[a]	• Consists of a clarification system (Actiflo) and filtration system (Dusenflo mixed bed filters)	Class 2
	• Reduces turbidity, color, suspended solids, algae, taste and odor (T&O), metals and total organic carbon	
	• The resulting filtered water from the Dusenflo gravity filter can contain little or no Giardia and Cryptosporidium cysts	
	• Minimum plant size: 473 m^3/day	
UV system[b]	• Utilizes the ability of Ultra Violet rays to deactivate microorganisms	Class 3
	• This system on its own is chemical free and produces no disinfection by-products	
	• However, it can also be used in conjunction with other treatment processes forming a "multi-barrier" approach for treating water for drinking purposes	
	• UV will inactivate bacteria, viruses and protozoa, including Giardia and Cryptosporidium with a dose of 40 mJ/cm^2	
	• We assume some filtration system to remove sediments (e.g., sand filtration) would be required and is included in the cost	
	• Minimum plant size: 200 m^3/day	
MF-UF[c]	• Micro filtration and ultra filtration involve separating water from organic and inorganic matter contained in the water by forcing it through a micro porous membrane	Class 3
	• Pore sizes in microfiltration membranes are 0.1–10 μ thick while ultra filtration membranes are between 0.001 and 0.1 μ	
	• Microfiltration will remove Giardia and Cryptosporidium cysts, bacteria, and some viruses; however not all viruses can be removed via this process	
	• Microfiltration is also used in sterilization of beverages and pharmaceuticals, clearing of fruit juices, wine and beer, separation of oil–water emulsions and pretreatment of water for Nanofiltration and reverse osmosis	
	• Ultra filtration removes all viruses, bacteria, and suspended solids between 0.001 and 0.1 μm. Ultra filtration is used in paint treatment, oil–water emulsion separations, the food industry, and textile industry	
	• Minimum plant size: 379 m^3/day	

(continued)

Table 2.2 (continued)

Technology	Description	Treatment class
Ozonation[d]	• Ozonation systems utilize the ability of ozone to inactivate microorganisms through oxidation	Class 4
	• The system consists of an ozone pretreatment unit, a BioSand filter, and a BioCarbon filter	
	• The roughing filtration system removes suspended solids and coliforms as well as some Cryptosporidium	
	• The BioSand Filter is used to treat parasites, color, cysts, manganese, mercury, iron, and turbidity while the BioCarbon Filter treats dissolved organic carbon, tannins, pesticides, iron, bacteria, color, and odors	
	• Minimum plant size: 11.4 m^3/day	
Advanced oxidation (based on UV)	• A UV-oxidation process designed to provide disinfection and Taste and Odor treatment; it destroys Geosmin and 2-methylisoborneol	Class 5
	• Also oxidizes pharmaceuticals, personal care products, pesticides, and trace contaminants	
	• System consists of a UV reactor, H_2O_2 dosage, and storage system. We assume some filtration system to remove sediments (e.g., sand filtration) would be required and is included in the cost	
	• Minimum plant size: 818 m^3/day	
RO–NF[e]	• Removes all suspended solids, viruses, bacteria, pathogens, and all forms of biological contaminants	Class 6
	• Removes mono and multivalent ions, salts, and organics	
	• Essentially passes only pure water. Smallest pore size for membranes to date	
	• Minimum plant size: 1893 m^3/day	

[a] Produced by Veolia Water Solutions and Technologies in France under subsidiaries John Meunier and Kruger USA
[b] Produced by Trojan Technologies in Canada
[c] MF and UF information obtained from Koch Membrane Systems and Lenntech Water Treatment Solutions
[d] Information for ozonation obtained from Mainstream Water Solutions Inc.
[e] A thorough description can be obtained from Koch Membrane Systems

Table 2.2 and Fig. 2.2 show what treatment technologies are possible for consideration, depending on (a) source water characteristics, and (b) *target* water quality desired. Figure 2.2 indicates that ozone technology, a Class 4 water treatment, is more expensive than the Class 3 (UV and MF-UF) and Class 2 (HRC) treatment types. Class 3 treatments MF-UF and UV seem to be cheaper than HRC for plants which produce less than 100 m^3 of water per day and all the way up to 500 m^3/day, even though HRC is a Class 2 water treatment process. But in general Fig. 2.2

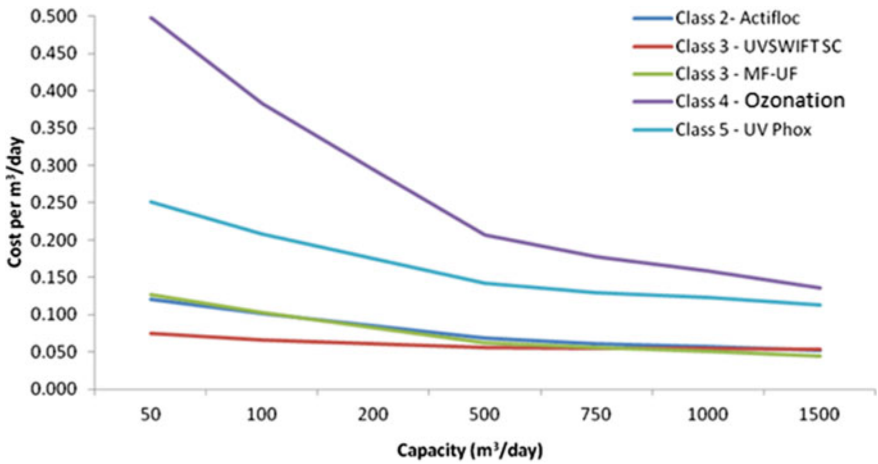

Fig. 2.2 Estimated cost curves: *Class 2* for HRC, *Class 3* for UV and MF-UF, *Class 4* for Ozonation, and *Class 5* for a UV-based AOP (Dore 2015)

suggests that the higher the Class of water treatment the higher the average costs per cubic meter. Notice how UV unit costs are lowest for almost all scales of operation.

It is possible that older small systems continue to use higher cost older technologies, as there is no incentive to modernize in the public sector. In other words, there are technologies currently available in the market that can provide higher contaminant removal at a much lower cost per cubic meter. Hence, we find that a technology which can provide Class 3 and 4 water treatment shows lower average cost per cubic meter than a small system, which is only providing Class 1 and 2 water treatments. Another possible reason is that there are site-specific costs that can contribute to the gap in the costs between technology and actual existing systems that are in the same class. For example, many of the small systems in British Columbia have higher transportation cost due to remoteness and the handling of hazardous materials such as chlorine. However, site-specific costs alone cannot account for this very large gap. We observe that some treatment classes at lower flow rates dominate in terms of cost-effectiveness. Class 3 MF-UF and UV provide water treatment at a much lower cost per cubic meter than some existing small systems in Classes 1 and 2 between output flow rates of 50–200 m^3 per day; but at higher flow rates this gap tends to decrease.

Of course we need to distinguish between systems that use groundwater as the source and systems that use surface water. Most of the above analysis is concerned with surface water as the source for water treatment plants. Our general conclusion is that while any specific water treatment facility will need to take account of raw source water quality, the *actual* target quality for small systems seems to be to meet only the *minimum regulatory requirements*. Our results show that for surface water, unless the raw water is high in color and in turbidity, a UV-based plant would be economical and cost effective even when the additional cost of sediment removal is added.

This conclusion is especially true for small plants producing less than 100 m^3 per day. Such a plant could obtain the same or better quality water with UV for less than 8 cents per cubic meter per day. Our finding of the cost-effectiveness of UV is in agreement with USEPA (1996), Gadgil (1998) and Parrotta and Bekdash (1998).

The cost curves in Fig. 2.2 take into account both average capital and operating cost, but of course not site-specific costs. Nevertheless, Table 2.2 and Fig. 2.2 offer a spectrum of treatment technologies, which could be deployed for a wide range of flow rates and population sizes. Unfortunately in North America, most small systems rely on chlorination alone. That simply invites a possible future waterborne disease outbreak, as shown in Chap. 1.

The major factor in the choice of chlorination as a primary disinfection seems to be the legal, regulatory requirement of a chlorine residual of between 0.5 mg/L in Newfoundland and Labrador to a maximum of 4 mg/L in Ontario. USEPA requirements are that the chlorine residual shall not be less than 0.2 mg/L for any period greater than 4 h at the entrance to the distribution system, and cannot be undetectable in more than 5 % of the samples taken each month in the distribution system (CWWA n.d.). This secondary chlorine requirement in practice means that most small systems in North America choose their primary disinfection system to be chlorine or a chlorine derivative.

Such a chlorine residual requirement does not exist in most of Europe, and so water utilities are free to choose their primary disinfection method. We have argued that UV disinfection is cheap and affordable for most small systems and yet it is not implemented. Many large systems in Canada (e.g., Victoria, Municipality of Durham in Ontario, and Edmonton) do use UV disinfection system, supplemented by the required chlorine residual for the distribution systems.

2.4 Risk Assessment in Water Treatment

Major approaches for risk management to produce potable water discussed below include (a) the HACCP protocol, (b) WHO Water Safety Plan and the Bonn charter, and (c) Quantitative Microbial Risk Assessment (QMRA). Here we summarize the HACCP protocol only; for detailed discussion of the other risk management protocols, (see Dore 2015, Chap. 6, Sect. 6.3).

2.4.1 Hazard Analysis and Critical Control Point (HACCP) Protocol

In the 1960s the U.S. National Aeronautics and Space Administration (NASA) asked the Pillsbury Corporation to design and manufacture food for space flights. For safety, a protocol was devised to make sure that prepared foods were safe. This protocol became known as the Hazard Analysis and Critical Control Point (HACCP) protocol, which incorporated the systematic checks of the *Codex Alimentarius Austriacus,* first used in the Austro-Hungarian Empire (Dore 2015, p. 123). The HACCP protocol has since then received global acceptance as a procedure for handling and preparing food that is free of pathogens and is safe to eat.

The HACCP protocol is based on seven principles (Canadian Food Inspection Agency 2012):

Principle 1: Conduct a hazard analysis—Plans determine the food safety hazards and identify the preventative measures the plan can apply to control these hazards. A food safety hazard is any biological, chemical, or physical property that may cause a food to be unsafe for human consumption.
Principle 2: Identify critical control points—A *critical control point* (CCP) is a point, step, or procedure in a food manufacturing process at which control can be applied and, as a result, a food safety hazard can be prevented, eliminated, or reduced to an acceptable level.
Principle 3: Establish critical limits for each critical control point—A critical limit is the maximum or minimum value to which a physical, biological, or chemical hazard must be controlled at a critical control point to prevent, eliminate, or reduce risk to an acceptable level.
Principle 4: Establish critical control point monitoring requirements—Monitoring activities are necessary to ensure that the process is under control at each critical control point.
Principle 5: Establish corrective actions—These are actions to be taken when monitoring indicates a deviation from an established critical limit. Corrective actions are intended to ensure that no product injurious to health or otherwise adulterated as a result of the deviation, enters commerce.
Principle 6: Establish procedures for ensuring the HACCP system is working as intended—Validation ensures that the plants do what they were designed to do; that is, they are successful in ensuring the production of a safe product. *Verification* ensures the HACCP plan is working as intended.
Principle 7: Establish record keeping procedures—The HACCP protocol requires that all plants maintain certain documents, including a hazard analysis and a written HACCP plan, and record the monitoring of critical control points, critical limits, verification activities, and the handling of processing deviations.

Any organization interested in risk minimization practice toward food and water can apply for certification for both the HACCP protocol and the International Organization for Standards (ISO) protocol, ISO 9001.[3] The latter certification

[3] ISO (International Organization for Standardization) is a worldwide network of national standards bodies from over 160 countries, which was established in 1947. The mission of ISO is to develop International Standards (i.e., ISO 9001, ISO 14000, ISO 27000, ISO 22000), and to make sure that goods, services as well as processes are safe, reliable, and of good quality. As the management system standard, ISO 9001:2008 sets out the criteria for a quality management system implemented by over one million companies and organizations. To ensure that food is safe, ISO 22000:2005 contains the overall guidelines for food safety management, helping to identify

demonstrates that quality and customer satisfaction are priorities for the enterprise. The HACCP audits are conducted using auditor checklists as well as local statutory and regulatory requirements. Food processors can be certified for ISO 9001 simultaneously while an audit is conducted of their HACCP plans, resulting in certification for both. To provide food processors dual certification, it is possible to obtain a combined ISO/HACCP certification in preparation for the ISO 22000 standard for the food industry. ISO 22000 can be applied independently of other management system standards or integrated with existing management system requirements. The importance of ISO 22000 is that it integrates the principles of the Hazard Analysis and Critical Control Point (HACCP) system and application steps developed by the *Codex Alimentarius* Commission. Perhaps this is the standard to which water treatment plants will aspire in the future. For example, the water utilities of Halifax, Edmonton, and the Regional Municipality of Durham in Ontario are certified under the ISO 14001 protocol; it would be good if they and others went further and sought certification under ISO 22000.

2.5 Water Infrastructure Asset Management

One of the aspects of water management that the Walkerton Inquiry also identified was the issue of the management of water infrastructure assets. Each water utility must have a complete inventory of all the treatment equipment, reservoirs, pumps, pipes, etc. and their ages and when each component should be replaced before there is failure.

The Queensland government of Australia has published an online[4] manual entitled Strategic Asset Management in order to assist its departments in the management of infrastructure assets. It identifies a number of methods for managing infrastructure depending on the application. However, the basic concepts and foundation are consistent throughout the manual.

The objectives of the Australian approach are: structured and accountable corporate planning; establishment of a relationship between service delivery and resource planning; creation of plans for capital, maintenance, and disposal; diffusion of appropriate processes to manage new assets; more effective and innovative service delivery; private sector participation in financing, provision, management, and maintenance of infrastructure; and enhanced coordination of public assets from a "whole-of-government" perspective.

In this approach all infrastructure goes through a 5-stage cycle: "plan, create or acquire, operate and maintain, refurbish or enhance, and dispose" (Queensland

(Footnote 3 continued)
and control food safety hazards. Detailed information can be found from http://www.iso.org/iso/home.html.

4 http://www.build.qld.gov.au/sam/sam_web/frames/guidelin.htm.

government of Australia 2002). The plan recognizes the fact that decisions at any one point in the life cycle have cost and output implications at other stages.

The asset management plan identifies the following six principles:

- Assets exist only to support the delivery of services.
- Asset planning is a key corporate activity that must be undertaken along with planning for human resources, information, and finances.
- Nonasset solutions, full life cycle costs, risks, and existing alternatives must be considered before investing in built assets.
- Responsibility for assets should reside with the agencies that control them.
- Strategic Asset Management within agencies must reflect the whole-of-government asset policy framework.
- The full cost of providing, operating, and maintaining assets should be reflected in agency budgets.

Figure 2.3 shows the organization of the plan as a matrix for each stage of the life cycle. It has a 5-step approach to production: Planning, Investment, Operational management, Maintenance, and Disposal of assets.

In meeting service demands, the utility must manage demand, maintain value, and manage risk. Risk management entails identifying risk and methods by which to mitigate the size of the risk.

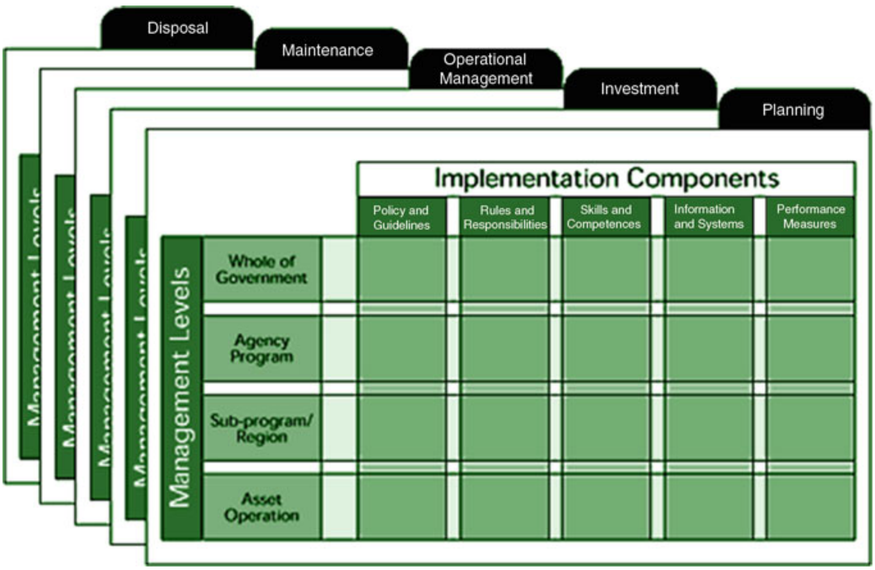

Fig. 2.3 The five matrices of the Australian strategic asset management

Upon implementation of an asset management plan a number of benefits should materialize. There should be a clear understanding of the purpose of the assets. Each asset should link to a specific service delivery objective. The capital should be in place to achieve the objective. Assets should be working properly and used in a way that extracts the highest level of service from them. The plan should lead to appropriate environmental and workplace health. Assets that are unused or not needed should be identified and decommissioned or sold. Information should be available as to the current value of assets at all times. Reserve funds should be utilized in a way that leads to optimum service. There should be an awareness of all opportunities and risks.

Since the objective of the utility is to serve the community, this service must be tracked. The best indicator of the performance of the utility and the asset management plan will be the level of service experienced by the community. Though individual assets and financial performance are important, the output level of service must remain the primary indicator of performance.

2.6 Planned Elimination of Long-Term Risks

In North America, over 90 % of the water systems use chlorine or chlorine derivatives to disinfect their water. In Dore (2015), (Chap. 9) we have outlined the long-term risks associated with the use of chlorine. Chlorine reacts with organic matter to form disinfection by-products (DBPs). Recently epidemiological studies have confirmed associations between human health effects and exposure to chlorinated DBPs. The evidence for carcinogenicity of DBPs is strongest for bladder cancer, while some but not all findings have reported positive associations between colon and rectal cancer and DBP exposure. In addition, some epidemiological studies also reported associations between consumption of chlorinated water and adverse reproductive outcomes, including preterm births and defects in the unborn child. The regulation of DBPs has played an important role for safe drinking water and public health; however, more than 50 % of the toxic halides formed during disinfection have not been defined. In some developed countries, particularly in EU countries, alternative methods of disinfection of drinking water such as Ozone and UV and cartridge filtration are being used to minimize the use of chlorine. But in the USA and Canada, chlorine remains the most widely used method of disinfection of drinking water. Therefore, it seems clear that (1) comprehensive toxicological evaluation of whole DBP mixtures are necessary, and (2) greater emphasis must be placed on continuing to reduce the allowable concentrations of all toxic halides in drinking water. As a long-term policy, it would be sensible to follow the example of the European countries that have completely eliminated the use of chlorine in drinking water.

In the past, the use of chlorine has been shown to have benefitted large populations all over the world. For example, typhoid fever had killed about 25 out of

100,000 people in the U.S. annually, a death rate close to that now associated with automobile accidents. Today, typhoid fever has been virtually eliminated. But the new evidence suggests grave long-term health risks associated with the use of chlorine. Section 2.2 contains a review of drinking water treatment technologies, which clearly shows that there are alternatives for disinfection that are cost effective. Therefore, we can conclude that chlorination of drinking water is now an obsolete technology and it is high time for North America to move away from chlorination and follow the example of the Netherlands, Denmark, and Germany.

2.7 Conclusion

In this chapter we have summarized the key principles of sound water management. These are source water or watershed protection; investment in treatment technologies other than chlorination, such as UV, ozonation, and membrane filtration; incorporation of some risk management protocol at the treatment plant, such as HACCP; systematic records of water infrastructure assets, through an asset management plan; and the planned reduction of long-term risks by moving away from chlorination as the primary disinfection method. In the chapters that follow we shall see which principles are typically violated. For example, in Chap. 3, which is about small water systems, while we will not use all the above principles as a "check list," we shall nevertheless assess some of the shortcomings of such systems.

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