intake; the nature of the outbreak and the clustering of cases near the Rossdale plants consistent with waterborne transmission. No other plausible explanation for this large giardiasis outbreak was ever proposed.

The climate of denial by Edmonton water officials and politicians apparent in the media record of this outbreak (Box 4.7) was not likely to have encouraged optimal preventive measures being pursued. In fact, a critical assessment of the safety and quality of Edmonton's water was commissioned in 1985–86 and confirmed additional deficiencies in Edmonton's water system including a major need to invest in the upgrading of staff expertise and capacity, to identify and resolve water quality problems (SEHA, 1986).

Fortunately, there was a happy ending for Edmonton residents. The drinking water system is now operated by Epcor Water Services, a corporation wholly owned by the City of Edmonton. Epcor has become highly regarded in Canada and North America for its drinking water quality expertise. Its status was evident in the Walkerton Inquiry: when the Ontario Water Works Association sought experts from outside Ontario to present evidence to Part 2 of the Inquiry, they selected senior personnel from Epcor. Likewise, the North Battleford Inquiry called on the General Manager of Epcor Water Services to provide primary expert evidence on water quality and water treatment. Finally, although the North Saskatchewan River continues to provide periodic treatment challenges for Epcor, the corporation has shown a commitment to learning from those challenges and sharing that experience with peers. For example, a paper was prepared to document a close call in 1997 when Edmonton's plants were challenged with massive *Giardia* (more than 2,000 cysts per 100 L) and *Cryptosporidium* (more than 10,000 oocysts per 100 L) loadings in raw water, which led to a breakthrough into treated water, fortunately without any corresponding evidence of illness in the community (Gammie et al., 1998). Sharing the experience of such events with others is an important service and the insights gained have been used to justify providing additional barriers for Edmonton's drinking water supply, including a large-scale installation of UV disinfection.

In this case, a long-term, sustained commitment to expertise with top-quality personnel and capital investment has turned a drinking water operation with many serious problems into an excellent operation. This success offers a more optimistic note on which to conclude the case studies of outbreak failures.

5

OVERVIEW AND RECURRING THEMES

5.1 SUMMARIES OF OUTBREAKS AVAILABLE IN THE LITERATURE

5.1.1 Introduction

There has been a long history of studies on waterborne disease outbreaks dating back to the pioneers discussed in Chapter 1. Some excellent reviews have been done to document progress during the early parts of the twentieth century, including those by Norcom et al., (1939), Cox (1939) and Gorman and Wolman (1939). Periodic reviews were continued through the middle of the twentieth century by Eliasson and Cummings (1948), covering 1938 to 1945, then by Weibel et al. (1964) for 1945 to 1960 and by Craun and McCabe (1973) for 1961 to 1970. This last review included discussion of the *Salmonella* outbreak in Riverside, California, in 1965 that led to an estimated 16,000 cases, 70 hospitalizations and 3 deaths. This outbreak was a case of using an unchlorinated groundwater supply; the specific source of the contamination was not determined. Lessons were clearly not learned from this outbreak,

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considering the subsequent fatal outbreaks in Cabool (1989) and Gideon (1993), Missouri, both involving unchlorinated groundwater.

Since the 1970s, the tradition of documenting and summarizing waterborne outbreaks was continued through the committed efforts of authors like Craun and Lippy. Many of these excellent reviews are summarized below to reveal the extent of the evidence base for understanding the causes of waterborne outbreaks. Unfortunately, the massive documentation available on outbreaks and their causes also makes depressing reading because the same kinds of mistakes continue to be made.

Having recognized the negative, we also need to acknowledge the positive progress in reducing drinking water disease outbreaks in affluent nations over the past century, which has been remarkable. Drinking water professionals need only apply the lessons that are there to be learned to achieve drinking water safety. If every drinking water professional who reads this literature decides that these types of failures will not happen with his or her system, outbreaks that would otherwise happen can be prevented. The specific preventive actions required for individual systems must be identified and implemented by those most familiar with each system, once they have been given the opportunity to understand the types of failures that have happened elsewhere.

5.1.2 Recent Summaries of Waterborne Outbreaks in the U.S.

This section summarizes reviews of outbreaks over the past 30 years. Craun et al. (1976) present a summary report on 99 waterborne disease outbreaks in the United States from 1971 to 1974 with reference to data from the late 1930s onward. For 1971 to 1974, *Shigellae,* Hepatitis-A and *Giardia* were the pathogens most commonly identified, causing 13, 13 and 12 outbreaks respectively, generally in non-municipal systems. Growing awareness of disease caused by *Giardia lamblia* led to increased reporting of this organism as a cause of several outbreaks. The authors note "*Since 1971 there has been a pronounced increase in the number of waterborne outbreaks, and the US now experiences an average of 25 outbreaks per year. The reason for this apparent increase in* [sic] *difficult to ascertain, but it may be primarily the result of increased reporting and follow-up activities.*" They conclude "*Constant surveillance, appropriate water treatment and proper operation of water systems are necessary to prevent outbreaks from occurring.*" The 1975–76 period showed that *Giardia* was being recognized as a cause for an increasing number of outbreaks (Craun & Gunn, 1979). Coliforms were recognized to be much less resistant to chlorination than *Giardia*, meaning that an absence of coliforms would not assure adequate water treatment for this protozoan pathogen. Craun (1979) summarized reports of waterborne giardiasis, including 23 outbreaks between 1965 and 1977.

Craun (1981) gave a more detailed account of the previous work and extended the reporting period to 1978. *Giardia lamblia* is noted as the most commonly identified pathogen, having caused 24 outbreaks from 1971 to 1978. Also reported were four notable outbreaks reviewed as case studies in Chapter 4, namely Crater Lake National Park, Oregon, in 1975, the first outbreak documented as being caused by an enterotoxigenic strain of *E. coli*; Rome, New York, 1974 to 1975, the largest reported outbreak of waterborne giardiasis to that time and the first in which a *G. lamblia* cyst was isolated in the municipal drinking water supply; Camas, Washington, 1976, the first outbreak of waterborne giardiasis in a filtered water supply; and, Bennington, Vermont, 1976, the first waterborne outbreak of campylobacteriosis reported in the U.S. An AWWA Committee on the Status of Waterborne Disease in the United States and Canada chaired by Craun provided a brief status report and observed that routine coliform monitoring in distribution systems served mainly as an indicator of microbial conditions in the system, but offered little value for identifying system flaws necessary to prevent outbreaks (Committee-AWWA, 1981).

Harris et al. (1983) noted, "*Since 1971, waterborne outbreaks have been reported via a passive surveillance system by state and local health departments and tabulated annually.*" For 1981, 32 outbreaks, 56% of which had confirmed etiology, were reported with *Giardia lamblia* most frequently identified as the cause. These authors recommended caution in interpreting the decrease in reported outbreaks for 1981, which may be "*due to less complete reporting rather than an actual substantive decrease.*"

Lippy and Waltrip (1984) reviewed outbreaks in the U.S. for 1946 to 1980. In re-evaluating the reported numbers of outbreaks for this time, they conclude that the number of outbreaks for the period should actually be double and the number of cases should be more than double. They identify many water system deficiencies, including frequent failure to implement a variety of simple measures for assuring reliable chlorine disinfection. These measures included restraints for securing chlorine cylinders; effective valves to switch cylinders; continuous chlorine residual monitoring; feedback control of chlorine dosage in response to demand to maintain an adequate chlorine residual; adequate contact time; appropriate pH; temperature and turbidity for effective disinfection; standby equipment and spare parts; and monitoring to validate disinfection performance. They concluded for the outbreak failures "*The glaring deficiencies were that disinfection was not in place where it was needed and not properly operated where it was in place.*"

Craun (1986) edited an excellent compendium of waterborne disease in the U.S. reflecting perspectives to the 1980s, including contributions from 10 other expert authors covering the nature of waterborne disease, waterborne outbreak occurrence, procedures for outbreak investigation and methods for prevention of outbreaks. He included a chapter reviewing outbreak statistics about cases, deaths, seasonal occurrence, pathogens and causes for the U.S. between 1920 and 1980. The physical scenarios for outbreaks in community systems over this 60-year period were classified in order of decreasing magnitude (number of illnesses caused per outbreak): inadequate filtration or allied treatment; inadequate disinfection when used as sole treatment; cross-connection or back-siphonage; untreated groundwater; contaminated water storage; interrupted disinfection when used as sole treatment; untreated surface water; contaminated mains/service lines or plumbing; and untreated spring water. Craun (1988) presented a summary detailing surface water supplies and health, including a brief historical review, discussion of the multiple barrier concept and detailed analysis of waterborne outbreaks from 1971 to 1985 — the 15-year period with the largest number of waterborne outbreaks since 1920. Craun (1991) summarized information on outbreaks in the U.S.A. from 1920 to 1990, noting an increase in outbreaks in systems with filtration from 1981 to 1985, which "*underscores the importance of proper design and operation of filtration facilities.*"

Levine et al. (1990) summarized data for 50 outbreaks in the U.S.A. from 1986 to 1988 and concluded, "*Although the total number of reported water-related outbreaks has been declining in recent years, the few large outbreaks due to* Cryptosporidium, *Norwalk-like agent,* Shigella sonnei, *and* Giardia lamblia *caused more cases of illness in 1987 than have been reported...since...1971.*"

Herwaldt et al. (1992) reported outbreak data for the U.S. for 1989 to 1990, including the *E. coli* O157:H7 outbreak in Cabool with four deaths and the Oakcreek Canyon outbreak caused by Norwalk-like virus.

Moore et al. (1993; 1994) reported 34 outbreaks associated with drinking water in the U.S. for 1991 and 1992. They provide tables for classification of deficiencies in water systems and investigations of waterborne disease outbreaks as well as tables detailing these outbreaks. In 1991–92, 68% of outbreaks were classified as acute gastrointestinal illness (AGI) of unknown etiology and although only 24% of outbreaks were associated with community systems, they caused 77% of total cases. Recommendations included protection of raw water sources from contamination by surface runoff and sewage discharges; adequate, continuous disinfection of water; improved operation and monitoring of filtration processes; essential maintenance of multiple barriers; and a need to maintain capacity at local and state levels to investigate outbreaks and perform surveillance.

Kramer et al. (1996a; 1996b) documented several significant outbreaks of the 30 reported in the U.S. for 1993 and 1994, including Milwaukee and Gideon. They noted the importance of rapid recognition and control of outbreaks and the role of local and state surveillance in facilitating responses.

Frost et al. (1996) reviewed the important role of surveillance in detecting waterborne disease and presented the New York City's Department of Environmental Protection expert panel recommendations for waterborne disease surveillance: "*designate an individual who is specifically responsible for coordinating waterborne disease surveillance; monitor visits to hospital emergency rooms for enteric disease; monitor sales of prescription and nonprescription medications for diarrheal illness; conduct special enteric disease surveillance studies of nursing home and retirement home populations; conduct surveillance of managed health care populations; conduct surveillance of high-risk populations.*"

Solo-Gabriele and Neumeister (1996) summarized American outbreaks of cryptosporidiosis, noting the first human case was reported in 1976: "*From 1976 to 1982, reported cases were primarily associated with immunocompromised people, and in 1982, the number of reported cases began to increase dramatically in conjunction with the AIDS epidemic.*"

Craun and Calderon (1999) expand on an earlier review to cover 1920 to 1996. *Giardia lamblia* was reported as the "*most frequently identified etiology of waterborne outbreaks...*" during the 1980s and into the early 1990s with *Cryptosporidium parvum* in second place through the 1990s (except for holding first place in 1993 after the Milwaukee outbreak). The low infective dose for each organism was noted, as was their resistance to typical chlorination procedures, requiring pretreatment and filtration processes to be properly operated and maintained to ensure drinking water safety. Strategies recommended to prevent waterborne outbreaks were "*increased protection of source water quality; water filtration and continuous disinfection; better monitoring of the effectiveness of water treatment; and increased protection of treated water as it is delivered to the tap.*"

Levy et al. (1998) compiled the outbreak data for the U.S. in 1995 and 1996, finding that 13 states reported 22 outbreaks involving more than 2,500 cases of illness. Barwick et al. (2000) reviewed U.S. outbreak data for 1997 and 1998 and found reports from 13 states with 17 outbreaks involving more than 2,000 cases of illness.

Craun and Calderon (2001) reviewed U.S. outbreaks from 1971 to 1998 caused by distribution system deficiencies and determined that 113 outbreaks resulted in more than 21,000 cases, 498 hospitalizations and 13 deaths. Each outbreak, on average, gave rise to about 200 illnesses. Seven deaths were due to salmonellosis (Gideon), four to *E. coli* (Cabool), one to gastroenteritis of unknown etiology and one to chemical contamination (ethylene glycol). They noted the value of monitoring chlorine residual as an indicator of distribution system contamination and the merits of pursuing increased distribution system monitoring after severe storms, power failures and any other events leading to low water pressure in the distribution system, which may allow ingress of contamination.

Curriero et al. (2001) analyzed data from 548 waterborne disease outbreaks in the U.S. from 1948 to 1994, 24% caused by surface water contamination, 36% caused by groundwater contamination and 40% caused by unknown factors. They reported the strongest association for extreme precipitation during the month of the outbreak for surface water sources, but found a two-month lag from extreme precipitation for outbreaks involving groundwater sources.

Craun et al. (2002; 2003) reviewed outbreaks in the U.S. from 1991 to 1998. Extensive categorization of outbreaks into types and by cause was provided. These outbreaks reinforced the importance of meeting treatment standards and new U.S. EPA proposals requiring sanitary surveys and hydrogeologic assessments. Groundwater systems need to be assessed for their vulnerability to contamination from sewage discharges and surface water infiltration.

Lee et al. (2002) documented 39 outbreaks in the U.S. during 1999 and 2000, based on reports from 25 states, resulting in an estimate of more than 2,000 cases and 2 deaths (the latter due to the Washington County Fair outbreak involving *E. coli* O157:H7, reviewed in Section 4.5.31). Notable in this discussion was a multi-state outbreak of *Salmonella* Bareilly in which bottled water was implicated in the illness of 84 people.

Levin et al. (2002) presented a list of concerns regarding drinking water challenges in this century: the state of public water infrastructure and the cost of water treatment; the impact of global warming on drinking water quality and quantity; disinfection of drinking water and possible health effects of disinfection by-products (DBPs); watershed protection versus land development; depletion and contamination of groundwater aquifers; rehabilitation of surface waters; development of better monitoring procedures and assessment for microbial risks; and re-evaluation of legal and health regulations.

5.1.3 Summaries of Drinking Waterborne Outbreaks in the U.K.

Waterborne diseases have been well documented in the U.K. Galbraith et al. (1987) reviewed the incidence of waterborne and water-associated disease in the U.K. from 1937 to 1986, the 50-year period following the typhoid outbreak at Croydon during which chlorination of public water supplies was routinely implemented in Britain. These authors documented 34 outbreaks with more than 11,000 cases and 6 deaths (5 due to typhoid fever caused by contamination of unchlorinated private water supplies and 1 due to chemical contamination). As of 1987, there had been only one reported outbreak of approximately 100 cases in the U.K. caused by *Giardia*. Cryptosporidiosis infections numbered about 4,000 between 1983 and 1986, but no estimate of waterborne cases was offered. Source contamination and defective chlorination continued to cause outbreaks.

Nazareth et al. (1994) reviewed a 6-month pilot study (October 1991 to March 1992) of waterborne disease surveillance in England and Wales, which demonstrated the merits of prescribing a standardized approach for obtaining data on events related to water. Five of 12 events during the study period resulted in human illness, with 3 due to cryptosporidiosis.

Furtado et al. (1998) documented 26 waterborne outbreaks in England and Wales from 1992 to 1995. Ten outbreaks in chlorinated public water supplies were due to *C. parvum* infection while 9 outbreaks in private supplies were associated with a variety of organisms: *Giardia*, *Cryptosporidium*, *Campylobacter* spp. and *E. coli*. The latter two were attributable to poor maintenance of equipment or inadequate treatment procedures. They noted that if filtration is inadequate or if the raw water entering treatment plants is heavily contaminated with cysts or oocysts, consumers may be exposed. Source water quality and filtration process performance should be monitored closely.

Chalmers et al. (2000) reviewed risks for waterborne transmission of *E. coli* O157, reporting that from July to December 1998, 37% of private water supplies in England and Wales contained *E. coli*. Although these measures were not specific for *E. coli* O157, they did indicate fecal contamination and highlighted the risk associated with untreated private water supplies. Risk from this pathogen need not be a concern if source water is reasonably protected, the drinking water supply is properly disinfected and distribution systems are protected from contamination.

Frost et al. (2002) reviewed *Campylobacter* spp. outbreaks for England and Wales between 1995 and 1999, reporting only four attributed to waterborne transmission. All were associated with rural locations rather than municipal drinking water supplies, likely reflecting the normal practice of disinfection of such municipal supplies in England and Wales, which makes an outbreak caused by this pathogen very unlikely.

Said et al. (2003) focused on outbreaks in private water supplies in England and Wales from 1970 to 2000. Private water supplies were involved in 36% of drinking water outbreaks, even though they supplied only 0.5% of consumers, and gave rise to a 22-times higher risk of contracting diseases than public water supplies. In the 25 outbreaks studied, either water was not chlorinated or chlorine treatment failed. There were problems with contamination from livestock or manure-spreading. Heavy rain preceded a quarter of the outbreaks. Surveillance data for 2001 to June 2002 found mainly private water supplies implicated in outbreaks and incidents (PHLS, 2002). *E. coli* was found in 16% of private water supplies tested.

5.1.4 Summaries of Drinking Waterborne Outbreaks in Sweden

Waterborne outbreaks in Sweden have been documented by Andersson and Stenström (1987); Andersson et al. (1997); Andersson and de Jong (1989) and Andersson and Bohan (2001). Andersson and Stenström (1987) surveyed 32 outbreaks from 1975 to 1984, including what they believed to be the first verified outbreak in western Europe caused by *Giardia lamblia*. *Campylobacter* was the most commonly identified agent during this period. Five outbreaks occurred in surface water systems, all during the winter, and 26 occurred in unchlorinated groundwater systems with contamination of water due to blockages, broken pipes and cross-connections in the distribution system. Typical soil conditions permitted rapid infiltration of groundwater sources by spills.

Andersson et al. (1997) reported 90 waterborne outbreaks in Sweden between 1980 and 1995, involving 50,000 illnesses and 2 deaths. The latter are not elaborated. *Campylobacter* was the most common agent identified in 11 outbreaks. In most water systems, source water was considered high quality and disinfection was not practised in many systems. The high costs of waterborne outbreaks to society were described.

Andersson and de Jong (1989) reviewed 66 outbreaks between 1974 and June 1988, affecting a total of 36,500 people. Thirteen outbreaks occurred in surface water systems and 52 in groundwater systems, most of which were not chlorinated. Groundwater was contaminated through cross-connections or by sewers adjacent to source water. One shipboard outbreak was included.

Andersson and Bohan (2001) reported 116 outbreaks over the period 1980 to 1999 in Sweden, affecting about 57,500 people, with the largest of unknown origin involving 11,000 in 1988. In this case, chlorination failed in a water treatment plant being refurbished. In another large outbreak, the supply was contaminated by stagnant raw water from a pipeline that was brought into use without being flushed. These two large outbreaks involved surface water systems, but groundwater systems were implicated in most of the outbreaks reported. *Campylobacter* spp. and *Giardia lamblia* were identified most frequently as the pathogens responsible.

5.1.5 Summaries of Drinking Waterborne Outbreaks in Finland

Finnish community water systems were reviewed by Lahti and Hiisvirta (1995). Twenty-four waterborne outbreaks affecting 7,700 people occurred from 1980 to 1992, about 40% of which occurred in community systems. Most involved groundwater supplies, which were generally not treated, following blockage of sewage pipes or leaks near wells or through cross-connections in the distribution system. Surface water treatment problems included inadequate disinfection, wastewater contamination of source water and cross-connections with sewage or sea-water. Two of three outbreaks occurred in the same surface water system where health concerns about chlorinated DBPs led to the chlorine dosage being lowered to an inadequate level, causing about 100 people to become ill.

Miettinen et al. (2001) documented waterborne outbreaks for 1998 and 1999. Groundwater is rarely disinfected in Finland, but surface water is generally treated to remove humic substances and is usually disinfected before distribution. Thirteen of 14 waterborne outbreaks occurred in groundwater systems, with contamination of source water following floods or surface runoff. The authors noted that customer complaints about smell and taste provided early warning of contamination in three of these cases. The largest outbreak occurred in a surface water system when chlorination (dosed to 0.2–0.3 mg/L) failed to inactivate Norwalk-like virus and 90% of a community of 2,500 was infected.

The role of *Campylobacter* spp. in causing waterborne outbreaks in Finland received special attention in a review by Hänninen (2002). Ten outbreaks were attributed to *Campylobacter* spp. between 1986 and 2001, involving more than 4,000 cases. The widespread use of undisinfected groundwater (45% of total national water supply) provided through ~1,500 water systems makes these outbreaks preventable because *Campylobacter* spp. are readily susceptible to chlorine disinfection.

5.1.6 Summaries of Drinking Waterborne Outbreaks in Canada

National data collection for waterborne outbreaks in Canada began in 1974, but these data were provided by a variable local infrastructure because each province is responsible for providing its own local health care and disease surveillance. Todd (1978) noted only ten outbreaks over the period 1974–75, mainly for institutional or individual water systems. For some of the outbreaks occurring among a few individuals in isolated northern communities, the cause was attributed to consumption of untreated river water in preference to trucked, chlorinated water because of objections to the taste of the disinfected water. Todd (1980) provided an even briefer discussion of 14 outbreaks during 1976 and 1977, revealing some outbreaks caused through municipal systems, with one affecting about 1,000 residents. Giardiasis emerged as a concern for community water supplies in Alberta.

Krewski et al. (2002) cited Health Canada data from 1992 to 1995. For 1992, there were 48 outbreaks and more than 1,400 cases of disease, with 37 occurring in Quebec, 7 in Saskatchewan, 3 in Ontario and 1 in British Columbia. The microbial pathogens identified as causes for some of the 1992 drinking water outbreaks included *Giardia* (10), *Campylobacter* spp. (4), Norwalk-like viruses (3), *Salmonella* spp. (2), hepatitis A (1) and *Shigella* spp. (1). In 1993, there were 24 outbreaks and more than 500 cases of disease, with 13 in Quebec, 6 in Ontario, 3 in Saskatchewan and 1 each in New Brunswick and British Columbia. The microbial pathogens identified as causes for the 1993 drinking water outbreaks included *Giardia* (8), *Campylobacter* spp. (2), and rotavirus (1). This summary for 1993 does not include the probable *Cryptosporidium* outbreak in Kitchener–Waterloo, reviewed in Section 4.5.12. One death was attributed to *E. coli* O157:H7 that may have been caused by non-potable water, but no details were provided. In 1994, there were 23 outbreaks and more than 600 cases of disease, with 13 in Quebec, 7 in Saskatchewan and 3 in Ontario. The microbial pathogens identified as causes for the 1994 drinking water outbreaks included hepatitis A (4), *Giardia* (3), *Campylobacter* spp. (1), *Cryptosporidium* spp. (1) and *Shigella* spp. (1). In 1995, there were 23 outbreaks and more than 300 cases of disease, with 10 in Quebec, 6 in Ontario, 5 in Saskatchewan and 2 in British Columbia. The microbial pathogens identified as causes for the 1995 drinking water outbreaks included *Giardia* (6), *Campylobacter* spp. (3), hepatitis A (2), and *Salmonella* spp. (1). Over these four years, there were several outbreaks with no pathogen identified as the cause.

Krewski et al. (2002) also presented data from the B.C. Centre for Disease Control summarizing waterborne outbreaks in British Columbia for 1980 to 2000. These data involve 28 outbreaks, and more than 1,670 laboratory-confirmed cases for various pathogens (more than 1,000 for *Giardia*, 229 for *Cryptosporidium* spp., more than 154 for *Campylobacter* spp. and more than 82 for *Salmonella* spp.). Epidemiological estimates of total cases were only provided for 5 of these outbreaks (including Penticton, Cranbrook and Kelowna) and those estimates totaled more than 19,000 cases of waterborne disease in Canada's third most populated province over this 20-year period.

Health Canada collected information on drinking water outbreaks caused by infectious agents between 1974 and 2003, even though these data were not routinely published. These records (W. Robertson, Health Canada, personal communication, 2004) summarize 334 outbreaks associated with drinking water reported across Canada for the 30-year period (including the data for the period from 1992 to 1995 summarized above by Krewski et al., 2002). The outbreaks involved more than 15,000 confirmed cases of illness, but the total number of affected individuals is likely much greater.

Among these 334 outbreaks, 183 (55%) were attributed to known microbial pathogens. Of these, 79 (43%) were caused by bacteria, 75 (41%) were caused by protozoa, 28 (15%) were caused by viruses and one (0.6%) was attributed to both bacterial and protozoan pathogens. The pathogen responsible was not identified for 151 (45%) of these outbreaks. Waterborne enteric viruses may have caused many of the outbreaks with no identified pathogen. Of the 79 outbreaks caused by bacterial pathogens, 32 were attributed to *Campylobacter* spp., 22 to *Salmonella* spp. and nine to *Shigella* spp. *Giardia* was implicated in 64 of the 75 outbreaks caused by protozoa, while *Cryptosporidium* spp. was identified in 10 outbreaks and *Toxoplasma gondii* was responsible for one. Of the 28 outbreaks caused by viral agents, 13 were attributed to hepatitis A, while the Norwalk and Norwalk-like viruses accounted for 13 and rotavirus was implicated in 2. Public drinking water systems were responsible for 21% of the outbreaks reported during this 30-year period and semi-public and private systems were responsible for 47% and 23%, respectively. Approximately 9% of outbreaks were attributed to consumption of untreated surface water or to unknown sources. Public water supplies were responsible for the majority (~9,200) of the more than 15,000 confirmed disease cases (W. Robertson, Health Canada, personal communication, 2004).

Brodsky (2001) reviewed outbreak data for Ontario, Canada's largest and wealthiest province, noting that only 39 reports on waterborne outbreaks associated with drinking water were documented for the period from 1974 to 2000. Between 1994 and 1998, Ontario provided no details for 6 of 16 drinking water disease outbreaks and no overall summaries of drinking water disease outbreaks were provided for 1994 through 2000.

Prior to the shock of Walkerton in May 2000 and the immediate aftershock of North Battleford in April 2001, drinking water disease outbreaks received limited attention from most governments across Canada.

5.1.7 Summaries of Drinking Waterborne Outbreaks in Japan

The occurrence and character of waterborne diseases in Japan was described as "*wrapped in darkness*" by Tosa et al. (2002), who described their review of outbreaks for 1982 to 1996 as the first such report on waterborne outbreaks in Japan. They attribute this in part to the language barrier, with most of the original outbreak reports appearing only in Japanese. They found that over this 15-year period there were at least 86 outbreaks involving more than 31,000 cases. They contrast this to foodborne outbreaks over the same period in Japan with almost 12,000 outbreaks involving more than 480,000 cases.

Tosa et al. (2002) attributed the proportions of the waterborne outbreaks according to pathogen as: *E. coli*, 48%; *Campylobacter* spp., 25%; *Shigella* spp., 10%; *Yersinia* spp., 3%; *Cryptosporidium* spp., 2%; viruses, 2%; and *Salmonella* spp., 2%. The high proportion attributed to *E. coli* was not explained in terms of specific pathogenic strains, so it is not clear if some of these outbreaks may have been due to fecal contamination without a specific pathogen identified, referring to the presence of *E. coli* as an indicator. One brief report of a waterborne outbreak in a small community in Shimane Prefecture was attributed to contamination by enterohemorrhagic *E. coli* O26:H11 (Hoshina et al., 2001). However, little information was provided about the source of the contamination (possibly antelope) or the scope of the outbreak, although this pathogen was isolated from stool specimens from 10 residents out of 116 served by the water supply.

The review showed that groundwater systems dominated outbreak failures at 57%, with 16% attributed to building water systems and 11% to water treatment facilities or distribution systems. The location of outbreaks was summarized as: schools (22%), community water supplies (town, village or region) (20%), restaurants (19%), outdoor resorts/picnics (13%), hotels (12%), office or apartment buildings (6%) and hospitals (2%).

5.1.8 Summaries of Drinking Waterborne Outbreaks in Switzerland

Waterborne outbreaks have been described for Switzerland infrequently. A typhoid fever outbreak in the resort town of Zermatt in 1963 caused by sewage leakage, chlorination failure and water storage contamination was widely known because cases among tourists were exported to other countries (Bernard, 1965). Only five waterborne outbreaks were reported to national public health authorities in Switzerland between 1988 and 1997 (Maurer & Sturchler, 2000). Two of these outbreaks were attributed to *E. coli* (40 cases in 1991 and 60 cases in 1992), but the strain was not specified. *C. jejuni* was implicated in two others (16 cases in 1995 and 100 cases in 1995) while one outbreak in 1997 (15 cases) was attributed to echovirus. The La Neuveville outbreak of 1998 (Section 4.5.30) with an estimated 2,400 cases attributed to multiple pathogens followed a 1997 outbreak of 30 cases that was not epidemiologically investigated.

5.1.9 Summaries of Drinking Waterborne Outbreaks – Multiple Countries

Lisle and Rose (1995) reviewed the occurrence of waterborne outbreaks of cryptosporidiosis in the U.S. (five outbreaks considered between 1984 and 1993) and the U.K. (eight outbreaks considered between 1983 and 1990–91) together with data on the occurrence of *Cryptosporidium* in surface and groundwaters for North America and the U.K.

The surveillance systems for detecting and reporting waterborne disease were compared among the U.K., the U.S. and Sweden (Stanwell-Smith et al., 2003). These three countries are somewhat unusual compared to the majority of affluent nations in having national systems that are able to detect and respond to waterborne outbreaks, although these systems rely heavily on the provision of local data.

Craun et al. (1998) evaluated outbreaks of cryptosporidiosis in the U.S., Canada and the U.K. from 1984 to 1996 with reference to earlier outbreaks. They found that *Giardia* and *Cryptosporidium* have been responsible for 32% of reported outbreaks since 1991. A discussion of attack rates and protective immunity suggested that prior exposure leading to protective immunity may explain some of the differences in observed attack rates. They concluded "*Reliance on monitoring of oocysts and total coliform bacteria is less critical than protection of source water quality, proper water treatment, good operation and monitoring of treatment plant performance, and an effective disease surveillance system...a multiple-barrier approach for protection and treatment of drinking water supplies is necessary to provide maximum protection from waterborne transmission.*"

Kramer et al. (2001) presented a summary for the World Health Organization/European Region (WHO/EURO) on waterborne diseases in Europe from 1986 to 1996, using data provided by 26 of 52 European countries that responded to a survey regarding waterborne outbreaks. This review did not address the water treatment methods, deficiencies in water treatment or distribution or mode of contamination. During this period, 778 outbreaks were reported in 19 countries, including 20 outbreaks reported by England and Wales with 2,810 cases and 51 outbreaks reported by Sweden with 27,074 cases. The other countries included: Albania (14 outbreaks), Croatia (29), the Czech Republic (18), Estonia (12), Germany (0), Greece (2), Hungary (27), Iceland (1), Latvia (1), Lithuania (0), Malta (162), Norway (0), Romania (57), Slovak Republic (61), Slovenia (45), Spain (208) and the Federal Republic of Yugoslavia (68).

There were clearly substantial differences in the quality, detail and scope of data provided. The number of countries reporting zero outbreaks in most cases likely reflects a lack of surveillance or a failure to reply to the survey rather than an accurate measure of drinking water safety. The report of zero outbreaks for Norway apparently misses the Skjervøy outbreak in 1988 (Section 4.4.21), which was reported in the literature. This survey, even with its limitations, is useful for orienting the coverage of this book because our considerations were limited to English language publications. Clearly, the occurrence of waterborne outbreaks should not be considered unique to those nations appearing in Chapter 4.

The most complete and current perspective on drinking water disease in both industrialized and developing nations is provided in an excellent book (Hunter, 1997). This comprehensive reference is organized according to individual pathogen or disease. Because it covers the developing world and considers endemic as well as epidemic disease, this reference contains several pathogens and diseases that are not considered here.

A more recent review of infectious intestinal disease in both industrialized and developing nations provides an excellent perspective on the evidence derived from epidemiologic studies for both epidemic and endemic disease (Payment & Hunter, 2001). The factors that were identified as contributing to the occurrence of waterborne disease include newly recognized pathogens that are more resistant to disinfection and the development of antibiotic-resistant bacterial pathogens; lowered immunity to waterborne pathogens creating higher susceptibility to outbreaks, caused by both improved sanitation that reduces overall population exposure to pathogens and the increased number of immunocompromised individuals; anthropogenic alterations to water systems including eutrophication, modified food webs, promotion of nuisance species and creation of breeding sites for disease vectors (e.g., mosquitoes, snails); modified agricultural production including increased intensity and proximity to human habitation, which further increases opportunities for transmission of animal pathogens to humans; and aging and deteriorating water infrastructure, particularly in urban centres.

The published literature about the causes and occurrence of drinking water outbreaks is clearly an enormous resource. Those reviews over many years have detailed the same causes that continue to appear in even the most recent outbreaks.

5.2 RECURRING THEMES

5.2.1 Converting Hindsight into Foresight

The evidence provided over the past 150 years documenting our progress towards achieving safe drinking water is considerable. The challenges that remain seem to be in translating negative experiences into insights that can be used to prevent future disasters. Over the long term, the trend towards reducing serious health consequences from waterborne outbreaks has been excellent (Figure 2.6), but we seem to have fallen victim to complacency by allowing a number of serious, yet eminently preventable outbreaks to occur during the past decade. Some of these have been caused by our inability to learn quickly enough and implement effective responses to the serious treatment challenges posed by *Cryptosporidium*. Other outbreaks have had fatal consequences by allowing proven, basic barriers like chlorination to be overlooked or neglected and rendered ineffective (Cabool, Gideon, Saitama Prefecture, Washington County Fair and Walkerton).

Each outbreak has unique features and personalities involved that contribute to the problems and negative outcomes. Yet, if we seek to prevent such disasters from reoccurring, we must discover the most important and relevant insights and lessons from these outbreaks. We must also find the means to instill what is learned in those we entrust to produce safe drinking water. One attempt to do so has been the recent exercise of restructuring the Australian Drinking Water Guidelines to incorporate a comprehensive framework for the management of drinking water quality. This framework will be discussed further in Chapter 6, but its key feature is to shift the focus of drinking water guidelines from tables of numerical water quality criteria to an emphasis on achieving optimum performance of the processes known to produce high-quality, safe drinking water.

In pursuing this approach, one key problem identified was that the Australian Drinking Water Guidelines (NHMRC & ARMCANZ, 1996), an excellent but rather large document at 364 pages, was made even longer. The strategy for dealing with the growing size was to develop a short list of six guiding principles for providing safe drinking water that could be summarized on a poster, if necessary, to ensure that anyone engaged in producing drinking water for public consumption was aware of these basics (Hrudey, 2002a). These principles will be paraphrased as general themes (NHMRC, 2003a), which will then be used to organize and extract insights from the outbreak experience gained over recent years.

The themes are as follows:

1. Pathogens pose the greatest and most tangible risk to drinking water safety, making pathogen removal and disinfection the paramount concern.
2. Robust, effective multiple barriers to drinking water contamination are needed to suit the level of contamination challenge facing the raw water source.
3. Trouble is usually preceded by change so change should be taken as warning to be on alert for trouble.
4. Operators must be capable and responsive.
5. Drinking water professionals (providers, regulators and health officials) must be accountable to drinking water consumers.
6. Ensuring safety is an exercise in risk management, requiring sensible decisions in the face of uncertainty.

5.2.2 Pathogens Pose the Greatest Risk to Drinking Water Safety

The coverage of this book has been intentionally limited to outbreaks of infectious disease through drinking water exposure — that is, disease caused by waterborne microbial pathogens. Increasing knowledge and experience over the past 150 years demonstrate that the transmission of pathogens is an ever-present danger for any drinking water supply. Pathogens inevitably follow human activity; ultimately, human or animal fecal waste is the source of pathogens. The degree of danger posed by such wastes can be reduced when the level of enteric disease is lowered in the population at large, but some humans, pets, livestock or wildlife can always be expected to shed pathogens. Hence, potential sources of contamination will never be far from our sources of drinking water.

Clearly, some health risks posed by chemical contamination deserve attention, with the most notable chronic risks being arsenic and excessive fluoride; the benefits to dental health of controlled fluoride exposure are well-established. These chemical risks are the only two that warranted mention in a WHO summary of major global disease that also listed six infectious diseases associated with water, sanitation and hygiene (WHO, 2002). In the WHO summary, all but one (hepatitis A) of the pathogens discussed in this book were combined under one category as diarrheal diseases. The other water-related diseases on this major list were malaria, schistosomiasis, trachoma and Japanese encephalitis, none of which are a factor with drinking water. Chemical risks can be a substantial danger in the specific circumstances where they arise, but except where dangerous goods spills, other chemical accidents or sabotage are involved, chemical risks do not generally give rise to intermittent, sudden and widespread disease outbreaks such as those reviewed in Chapter 4. Those interested in chemical outbreak incidents should refer to several of the excellent reviews by Craun, summarized in Section 5.1.2.

The large number of outbreaks reviewed in Chapter 4 in which drinking water drawn from sources accessible to humans, livestock or other animals was provided to consumers without any disinfection or treatment seems incredible given the inevitability of microbial pathogen risk. In some cases (Cabool and Gideon), that risky practice led to the deaths of trusting consumers. In these most severe cases, source waters were judged to be of high quality, but the waters became contaminated in storage or distribution to consumers. In other cases, the possibility that drinking water provided without treatment or disinfection might threaten the health of consumers has been ignored or discounted. Some of these outbreaks have occurred in remote areas where natural surface waters may have erroneously been assumed to be pathogen-free (Alpine, Alsvåg, Asikkala, Creston, Noormarkku, Temagami and Transtrand). The first of these nearly had fatal consequences. Other cases seemed to be frankly oblivious to the human health risks of pathogen contamination (Sunbury, Moama). The limited severity of these outbreaks is a testimonial to iron-clad immune systems, reminiscent of Professor von Pettenkofer (Section 2.1).

Several other cases of untreated or marginally treated drinking water causing outbreaks were not included in this book to keep its length manageable, but they are summarized in Table 5.1, with references for those readers interested in seeking further details. The inadequacy or absence of treatment is evident for many of these cases in which pathogens such as *Campylobacter* spp., *Shigella* spp. and *Salmonella* spp., which are readily disinfected, appear as the cause of the outbreak.

Table 5.1 Other reported outbreaks involving marginal or no treatment barriers

Year	Water Source and Location	Pathogen	Number of cases & basis for estimate	Reference
1980	Community supply, Nakusp, B.C., **Canada**	*Campylobacter*	12 lab confirmed 44 from survey 700–800 estimated	McNeill et al., 1981
1981	Boarding school, Chelmsford, **England**	*Campylobacter*	10 lab confirmed 257 from survey	Palmer et al., 1983
1982	Local spring, Meade County, Kentucky, **U.S.A.**	hepatitis A virus	68 serologically confirmed, 73 from survey	Bergeisen et al., 1985
1982	Trailer park, Bartow County, Georgia, **U.S.A.**	hepatitis A virus	16 serologically confirmed	Bloch et al., 1990
1984	Drinking fountain, Pietracuta, **Italy**	*Leptospira* spp.	3 deaths 33 serologically confirmed	Cacciapuoti et al., 1987
1985	Community well, De Lanaudière, Québec, **Canada**	*Campylobacter*	3 lab confirmed 344 from survey	Marcoux et al., 1987
1986	Community supply, Ashburton, Canterbury **New Zealand**	*Campylobacter*	19 confirmed	Brieseman, 1987
1986	Hospital supply, Heinola, **Finland**	*Campylobacter jejuni*	32 lab confirmed 94 from survey	Rautelin et al., 1990
1986	Trailer park, rural Vermont, **U.S.A.**	*Giardia lamblia*	23 lab confirmed 37 from survey	Birkwood et al., 1989
1986	Community supply, Disraeli, Québec, **Canada**	*Campylobacter*	3 lab confirmed 50 estimated	Tessier et al., 1987
1987	Community supply, Tring-Jonction, Québec, **Canada**	*Campylobacter*	3 lab confirmed 18 estimated	Alary & Nadeau, 1990
1987	Commercial ice, Pennsylvania, **U.S.A.**	Norwalk-like virus	13 serologically confirmed 191 from survey	Cannon et al., 1991
1990	Camp supply, near Christchurch, **New Zealand**	*Campylobacter*	11 lab confirmed 44 from survey	Stehr-Green et al., 1991
1990	Village springs, Prophitis Elias, Crete, **Greece**	*Shigella sonnei*	35 lab confirmed 138 from survey	Samonis et al., 1994
1990	Village supply, Tarves, **Scotland**	*E. coli* O157:H7	4 lab confirmed ages 4, 8, 9, 20	Dev et al., 1991
1992	Community supply, Ontinyent, Valencia, **Spain**	Norwalk-like virus	>3,500 estimated	Chover et al., 1995
1994	Community supply, Kramfors, **Sweden**	*Campylobacter*	64 lab confirmed 2,500 estimated	Lindback & Svensson, 2001
1994	Drinking fountain, Bages county, Barcelona, **Spain**	*Salmonella typhi*	9 cases of typhoid confirmed	Usera et al., 1995
1995	Community supply, Mark, **Sweden**	*Campylobacter*	48 lab confirmed 3,000–4,000 est.	Lindback & Svensson, 2001
1995	Resort, Island Park, Idaho, **U.S.A.**	*Shigella sonnei*	15 confirmed 82 from survey	Arnell et al., 1996
1996	Community supply, Eleoussa, Ioannina, **Greece**	*Shigella sonnei*	100 lab confirmed 288 from survey	Alamanos et al., 2000
1997	Island resort, N. Queensland, **Australia**	*Campylobacter*	7 lab confirmed 23 from survey	Merritt et al., 1997
1997	Water fountain, Vitoria, **Spain**	*Salmonella ohio*	2 lab confirmed 59 from survey	Molinero et al., 1998
1999	Construction site, central Queensland, **Australia**	*Salmonella saintpaul*	2 lab confirmed 28 from survey	Taylor et al., 2000
2001	Community supply, Torres de Segre Lleida, **Spain**	*Campylobacter jejuni*	8 lab confirmed 43 from survey	Godoy et al., 2002

5.2.3 Robust Multiple Barriers Are Essential

Systems must be robust to accommodate the inevitable errors that individual humans will make and the unpredictable challenges offered by nature. This is neither a new nor a recent revelation. The need for multiple barriers in securing safe drinking water has been documented for many decades and was certainly evident in some of the early debates about adding a filtration barrier for vulnerable surface water supplies, such as that in Milwaukee (Schwada, 1934).

The concept of multiple barriers for drinking water sources has been a guiding premise among public health professionals for the past century for the reasons outlined in Section 2.1. There have been countless appeals for the application of multiple barriers to achieve drinking water safety, yet no single definition of this expression has been adopted across the industry. The elaboration of the multiple-barrier concept adopted for the Walkerton Inquiry (Huck, 2000; O'Connor, 2002b) will be adapted for subsequent discussions. A multiple-barrier approach consists of effective and robust measures dealing with the following main elements:

- **source** protection and selection to keep the raw water as clean as possible, to reduce the risk of contamination breaching the drinking water system;
- **treatment**, often involving more than one process, to remove or inactivate contaminants, must be effectively designed, operated and maintained;
- **distribution** system security to protect against intrusion of contaminants and disinfectant residual use to assure delivery of safe water to consumers;
- **monitoring** to control treatment processes and detect contamination in a timely manner to inform risk management responses;
- **response** capabilities to adverse conditions that are well-conceived, thorough and effective.

A drinking water system must be made resilient to challenge by providing an ability to withstand upsets (Huck et al., 2001). A robust system will continue to perform adequately despite the failure of one or more mechanical or institutional components. The resilience of some elements of the system will influence the required resilience of others with the result that an overall robust system can be achieved in various ways.

A practical outline of how to implement a multiple barrier approach was offered by W.D. Bellamy (CH2M Hill, Englewood, Colorado) and is summarized in Box 5.1.

Box 5.1 Strategies for reducing pathogen risk (Source: Allen et al., 2000, reproduced by permission of W.D. Bellamy).

SOURCE WATER

- Conduct a sanitary survey to determine whether there is potential for minimizing contamination
- Provide source treatment, e.g., aeration, off-stream storage
- Start or participate in a watershed-protection program

PLANT FACILITIES

- Ensure proper coagulant addition and mixing by using jar tests and assessing mixing configuration and energies
- Assess flocculation mixing energies and hydraulic efficiency; possibly use a flocculant aid
- Ensure proper clarification by optimizing coagulation and flocculation, providing good clarifier hydraulics, minimizing flow disruptions and properly controlling solids
- Ensure proper filtration by optimizing coagulation, minimizing hydraulic surges and recycle effects, monitoring the filter media and bed, setting a low turbidity or particle goal, monitoring backwash operations, continuously monitoring inlet and treated water and possibly using a filter aid
- Optimize disinfection by monitoring disinfectant dosage, disinfectant residual, and detention time; make any necessary adjustments for flow, temperature, pH, disinfectant demand and other process changes

INSTRUMENTATION AND CONTROL

- Provide turbidity measurements on raw, clarified and filtered water (all filters) and particle counts of filtered water to demonstrate proper treatment and trends in changing water quality
- Provide streaming-current, pH, total organic carbon and ultraviolet light monitors to assist in determining changes in raw or treated water quality and any necessary changes in plant operations
- Institute treatment plant operator training and certification

DISTRIBUTION

- Monitor problem areas in which low [chlorine] residual or bacterial growth is a problem; control through operational or physical changes
- Actively manage a cross-connection detection program
- Provide routine maintenance through flushing and cleaning
- Develop an asset management and capital improvement plan that proactively addresses system integrity and water quality

Multiple barriers are often the target of economists, managers and decision-makers, who see them as unnecessarily redundant, making them a drain on economic efficiency. But like most strictly economic arguments, this is overly simplistic and ignores important technical realities. Multiple barriers are cost-effective because a risk reduction versus cost curve for a single barrier is normally steepest (risk reduced per unit of cost) for the initial risk reduction, but will inevitably flatten out as risk is reduced (Figure 5.1).

By placing suitably selected barriers in series to capture the steep risk reduction at lower cost for each barrier, a much lower cumulative risk can be achieved than by investing the same amount in a single barrier. How low we choose to push risk reduction is determined by how much we, as a society, are willing to pay. Unfortunately, consumers are not often consulted about whether they would be willing to pay more to achieve a safer system; these decisions are often made without any explicit debate about the relative merits of risk reduction measures. Regardless, we cannot escape the reality that reliance on a single barrier to achieve very low risk will inevitably encounter diminishing returns in risk reduction for the increasing investment made.

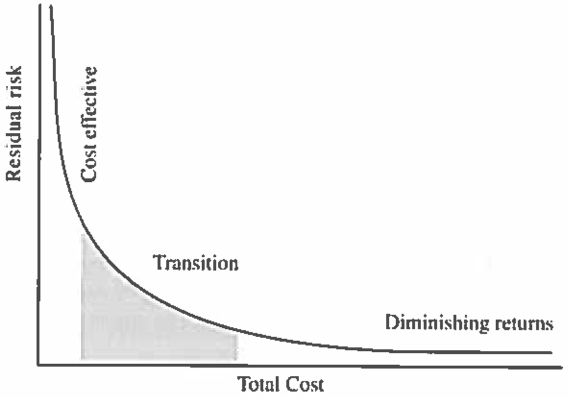

Figure 5.1 Generic risk reduction – cost curve for a single barrier to contamination

An illustration of this premise is to consider the cost-effectiveness of delivering high-quality bottled water to a desperately poor community lacking adequate quantities of even marginally clean water to permit personal hygiene. Such a measure would be not only extremely expensive, but also very ineffective in reducing the risk of gastrointestinal disease transmission because person-to-person transmission arising from poor personal hygiene would prevail.

Haas and Trussell (1998) provided an analysis of how the reliability of multiple barrier systems could be analyzed for the specific case of trying to treat wastewater to a potable water standard. Clearly, any such application would require very effective and reliable multiple processes, given the observations in Chapter 3 that no single treatment process provides universal effectiveness.

5.2.3.1 Source protection and selection

Source protection as a sole measure for drinking water safety will, in most cases, encounter diminishing safety returns, particularly if it must be pursued retroactively in balance with competing land uses. There may be other valid environmental reasons for reducing source contamination by human pollution sources, but in a watershed that allows any human or animal activity, total reliance on watershed protection will be unlikely to reduce risk levels to those that society has rightfully come to expect for its public drinking water supplies. Similar arguments apply to source protection for groundwater sources where unwarranted confidence has at times been placed in the security of a source based on historical quality, as well as failing to determine or consider what happens below the surface.

Relying strictly on source quality was evident in all the outbreaks where water was subjected to no treatment or to only marginal disinfection before distribution. Failure to achieve source protection or, at least, well-informed source selection was evident in many high-profile cases including Walkerton, Milwaukee and North Battleford, all cases where source contamination was well known for a long time, yet the threats to drinking water safety were not adequately managed. Other cases where the cause of the outbreak seemed predetermined by drawing intake water from a chronically or intermittently polluted location include Eagle-Vail, Edmonton, Jackson County, North Thames, South Devon and Ogose. In such cases, where sewage contamination challenges the water intake, the role of fine particles conveying aggregates of pathogens, leading to a non-uniform distribution of pathogens in the drinking water, must be considered more thoroughly. The investigators for both Milwaukee and Ogose noted that visitors were infected after having consumed as little as a single glass of water from the affected water system (Addiss et al., 1994; Yamamoto et al., 2000). Non-uniform distributions are more difficult to characterize with monitoring, so that little reassurance can be achieved by monitoring alone. Furthermore, these conditions will be likely to deliver infective doses to various individuals at random while leaving others spared.

5.2.3.2 Treatment

The review of water treatment technologies in Chapter 3 explained that there is no single practical universal treatment process that can assure drinking water safety. Unfortunately, too many water personnel and health officials have presumed that chlorination or another disinfection process is all that is required to achieve safety with respect to all pathogens.

Our best understanding of microbial risk suggests that outbreaks caused by bacterial pathogens such as *E. coli* O157:H7, *Campylobacter*, *Shigella* and *Salmonella* can be prevented by assuring effective chlorination. Achieving functional chlorination of the water supply could have prevented the fatalities at Cabool, Gideon, Saitama Prefecture, Washington County and Walkerton. This commitment means assuring maintenance of an adequate chlorine residual after the chlorine demand has been satisfied. That capability highlights the value of continuous monitoring of chlorine residual as a real-time measure of disinfection effectiveness and of challenges to the system in the form of contamination causing chlorine demand.

Giardia and *Cryptosporidium* expanded our concerns for pathogen control because only very large applied chlorine concentration–contact time (CT) combinations could inactivate the former and even those are ineffective on the latter. Consequently, we have learned that managing these risks to drinking water safety requires very effective fine particle removal, achieved by optimizing filtration processes. Prior to this understanding, filtration was too often judged only by an aesthetic standard for turbidity removal, a much less demanding requirement on water filtration process operations.

The ability of chlorination alone to deal with viral pathogens is not as well understood as the disinfection of bacterial and protozoan pathogens. In many cases, chlorination has proven effective in protecting against viral pathogens, but systems remain vulnerable to future outbreaks from viral pathogens if filtration is not included in the treatment barriers. This vulnerability seems most likely where residual micro-particles in water may be able to deliver infectious doses of viral pathogens by shielding them from effective disinfection.

5.2.3.3 Distribution

There have been many cases where otherwise safe drinking water has been contaminated within the distribution system, including the fatal episodes in Cabool and Gideon. In some ways, these problems may be the worst nightmare for drinking water providers because they are difficult to anticipate and detect. Yet many of the most troubling cases have revealed no effort whatsoever at assuring distribution system integrity. Such neglect can surely be corrected. Perhaps one exception that might be understood is the Klarup, Denmark outbreak, where a rig drilling a monitoring well to check for nitrate pollution of the groundwater damaged a sewer line and contaminated the groundwater supply. Although Klarup was a case of source contamination rather than distribution system contamination, such a scenario could also be imagined for contamination of stored or distributed water, without providing any direct warning to the water utility. The specific details of such a scenario are not predictable, but the generic problem of human activities damaging the integrity of water distribution or storage is certainly plausible, perhaps inevitable, given a large enough system. This reality obliges water providers to consider what scenarios could happen, how they might be detected and how the utility would respond to investigate and deal with concerns.

The many other distribution system cases reported here have revealed cases of cross-connections or other breaches of distribution system security that had been in place for years awaiting discovery (Saltcoats/Stevenston, Uggelose and Warrington). A water utility manager is likely to find her or his peace of mind disturbed by undertaking an inspection program for the distribution system, but failure to do so is surely courting disaster, particularly in older systems where records are poor and infrastructure conditions have deteriorated.

5.2.3.4 Monitoring

The monitoring barrier is covered by two separate points among the six themes. Monitoring will only be discussed here as an element of the multiple barriers without reference to the case studies.

A common misconception among those who have not studied drinking water systems closely should be highlighted. The tools available for monitoring drinking water quality are not currently able to monitor fecal indicators or pathogens in "*real-time*." In most cases, these tools will yield results many hours, if not days, after sampling, meaning that, in most cases, consumers will have already ingested the suspect water. There can be no product recall at this point.

While there may be some benefit to knowing that contamination has occurred, particularly if it is still occurring, this limitation severely restricts the scope of treated water quality monitoring for achieving a preventive approach to drinking water safety. As a result, the role of monitoring for fecal contamination should be viewed as one in a set of procedures for assuring that water has been adequately treated and has remained safe during delivery, but the limitations of such monitoring as a primary means for preventing outbreaks should be evident.

Having a sampling program that accurately represents the water quality that consumers are exposed to presents another problem. Water samples typically represent a miniscule fraction of the water delivered in both time and volume. Furthermore, fine particles and associated pathogens are not distributed uniformly in space and time. The time problem associated with intermittent grab samples can be overcome by performing continuous sampling as is now mandated by England and Wales' *Cryptosporidium* monitoring regulation (DWI, 2000). The volume problem can never be truly solved unless monitoring is performed on huge water volumes, temporarily held in storage before obtaining monitoring clearance to allow that specific water to be delivered to the consumer, an impractical scheme for anything but the smallest systems. However, turbulent flow regimes and effective mixing can substantially reduce the relative concerns about the adequacy of representative sample volume.

Finally, a much more subtle problem exists that is not widely appreciated in the water industry. This relates to the difficulty of accurately detecting contamination, even using techniques that seem highly reliable, when the contamination being sought is somewhat rare (Hrudey & Leiss, 2003). If a high standard of source protection and treatment is achieved, rare contamination of treated water should be the norm. This reality will make false positives a common challenge that must be addressed explicitly in monitoring and response protocols.

This subtle problem can be illustrated by a hypothetical analogy to screening for weapons in airport security checkpoints. Suppose a new scanning technology has the following detection capabilities: (a) when someone is carrying a dangerous weapon, 99.5% of the time the screening technology will respond positively; (b) when someone is not carrying such a weapon, 98% of the time it will respond negatively. If the situation is that about 1 in 10,000 passengers screened will be carrying a detectable, dangerous weapon, we can ask how well the screening evidence will allow us to manage this risk. In particular, if a positive result is obtained, how likely is that result to be correct?

Given the accuracy properties described, common intuition will lead us to expect that detection of weapons should be reliable. On average, 9,999 unarmed passengers must be screened to find the one who is carrying a weapon. The monitoring characteristics described yield a false positive rate of 2% (98% of the time unarmed passengers will show up as negative). This means that, on average, we will get 199.98 or roughly 200 false positives detected for every true positive. Consequently, the likelihood of a positive detection being correct is only 0.5% (1 in 201).

The inevitable preponderance of false positives whenever we seek to deal with rare dangers is likely to contribute to complacency (Hrudey & Leiss, 2003). A situation where personnel are not explicitly warned to expect a dominance of false positives (Figure 5.2) can be expected to lead monitoring personnel to learn that problems rarely arise when positives are detected, so vigilance and effective follow-up of any positive result becomes difficult to encourage. In the simplest terms, the monitoring warnings by themselves do not usually signal impending disaster.

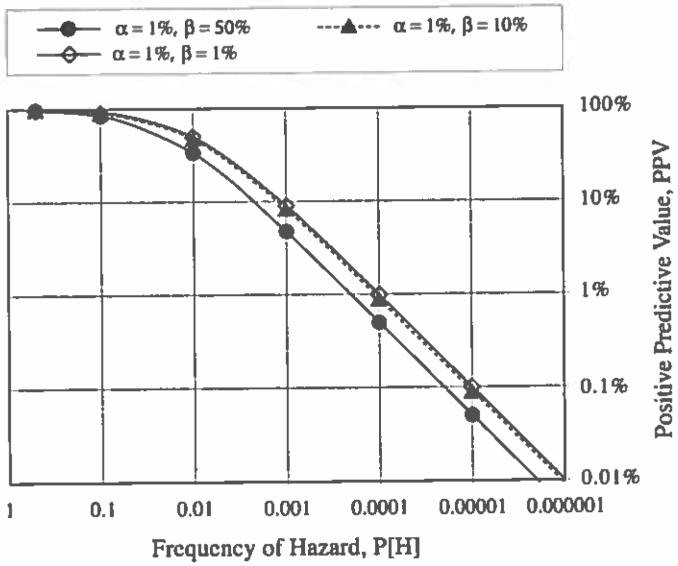

Figure 5.2 False positives dominate for detecting rare hazards. Positive Predictive Value (PPV) is the probability that a positive is truly correct, given that the monitoring results are positive for a hazard, α is the false positive and β the false negative rate of the monitoring method (Source: Hrudey & Leiss, 2003)

This hypothetical example demonstrates that the frequency of the hazard we are seeking to detect turns out to be a critical determinant of the ability of any screening evidence to predict danger accurately (Hrudey & Leiss, 2003). Applying that reality to monitoring water for rare contamination episodes reveals that we must be prepared to recognize that high numbers of false positive detections will occur with any monitoring technique that is less than 100% perfect (i.e., false positive rate must be zero). Accordingly, appropriate and informed follow-up monitoring with confirmation procedures, rather than inappropriate or unproductive reaction, is needed to validate any initial positive detection.

5.2.3.5 Response

This barrier, which may also be characterized as the human element, is prominent among the short list of six key themes introducing this section. The human element will be developed further in relation to the cases studies of Chapter 4 in Sections 5.2.5 and 5.2.6. However, the importance of responsive people in the system cannot be overstated. This was effectively stated in the Walkerton Inquiry Part 2 report by Justice O'Connor (2002b, p. 335): "*Ultimately the safety of drinking water is protected by effective management* *systems and operating practices, run by skilled and well-trained staff.*" This key role for effective people was echoed by two eminently qualified and experienced drinking water professionals retained by the Walkerton Inquiry to visit a number of water utilities in Ontario and report about the problems in the field (Geldreich & Singley, 2002). They concluded "*The ultimate protection of public health lies in the hands of the plant operator. The more knowledgeable the operator, the greater the public's protection.*" Similarly, LeChevallier et al. (1999) noted with regard to the need for research to improve our ability to achieve drinking water safety that "*knowledge is the first line of defense for those who provide safe drinking water.*"

Not only must those directly operating a system be responsive, but all those who play a role, from regulators to health professionals, must appreciate that when trouble begins, the initial warnings may not be easy to recognize. Regardless, they must be vigilant to detect even subtle warnings and follow up appropriately.

5.2.4 Trouble is Preceded by Change

The description of water treatment processes in Chapter 3 stressed that these processes function best under steady-state (constant in time) conditions. The corollary is that these processes do not function well when they face rapidly or dramatically changing conditions. This reality is, or should be, well-known among those working in the water industry.

Where possible, treatment plant designers and operators have sought to provide raw water storage to reduce fluctuations in raw water quality. Even where storage is provided, sudden heavy precipitation and runoff can initiate changes in raw water quality that can impair the ability of the treatment processes to achieve optimal treatment. Considering that heavy precipitation may also transport contamination into raw water supplies, the increased contaminant challenge and reduced treatment efficiency make a poor combination for ensuring drinking water safety.

The frequency of extreme or unusual weather as a key factor in waterborne outbreaks is striking. Severe weather was prominent among the worst outbreaks: Walkerton, Gideon, Milwaukee and Cabool. Walkerton followed heavy spring rains, Milwaukee followed severe winter storms. Unusual cold played a role in Gideon and Cabool. Many others have ranged from a lightning strike causing the outage of a supply pump in South Devon (Torbay) to a volcanic eruption causing heavy runoff at Red Lodge. The review of 548 outbreaks in the U.S. over almost 50 years found that 51% were preceded by precipitation events at the 90th percentile of intensity and 68% were preceded by precipitation events at the 80th percentile of intensity (Curriero et al., 2001). Similar observations have been consistent among the reviews of outbreaks dating back to 1920 (Gorman & Wolman, 1939).

The lessons to be learned from this can surely be generalized. Operators must know and understand the functional characteristics of their system to define what is normal. They must be wary whenever conditions change from within a normal range because this is when an outbreak is most likely to occur. If no effort is devoted to characterizing and understanding what is normal, there will be limited capacity to recognize the abnormal. Such poorly understood systems are certain to be at substantially higher risk for failure.

Operators must also be aware that the vast majority of unusual conditions will not cause an outbreak because, fortunately, outbreaks are rare events. However, unusual conditions that do not ultimately escalate to disaster should not be viewed as false alarms, but rather as learning opportunities to understand better the behaviour of the system under challenge. Drinking water providers should document these cases for the training of their own staff and the benefit of their peers, as was done with the close call experienced by Edmonton in 1997 (Gammie et al., 1998).

5.2.5 Operators Must be Capable and Responsive

The case studies of Chapter 4 reveal the critical role that humans play in most failure scenarios. Professor Trevor Kletz, a veteran of safety engineering for the chemical industry, summarized the vital role of humans in industrial failures as follows:

> To say that accidents are due to human failing is not so much untrue as unhelpful, for three reasons:
>
> 1. Every accident is due to human error: someone, usually a manager, has to decide what to do, someone, usually a designer, has to decide how to do it; someone, usually an operator, has to do it. All of them can make errors but the operator is at the end of the chain and often gets all the blame....
> 2. Saying an accident is due to human failing is about as helpful as saying that a fall is due to gravity. It is true, but it does not lead to constructive action. Instead it merely tempts us to tell someone to be more careful....
> 3. The phrase human error lumps together different sorts of failure that require different actions to prevent them happening again. (Kletz, 2001)

The inevitable consequence of these realities is that if our systems permit catastrophic failure whenever an individual makes a mistake, many catastrophes will result. Systems must be robust enough to accommodate the inevitable errors that individuals will make. This revelation is neither new nor recent, but lack of robust capability within a system continues to explain the recurring nature of failures.

Noting that operators must be capable and responsive seems trite, but this requirement is so vital that it must be stated, trite or not. If the conclusions of every formal investigation of an aircraft disaster were that pilots and other operators in the system were inadequately trained to deal with the challenges of their jobs, there would surely be an outcry from the traveling public to correct this problem. How is it then, that we can find so many failures that indicate inadequate training of operators, designers, managers, regulators and/or health professionals regarding such a fundamentally important service as drinking water and yet have only a muted response towards improving the training and status of drinking water personnel?

The greatest protection that consumers can achieve from the dangers posed by contaminated water is to be assured that the operators of their drinking water system know and fully understand the system, its capabilities and its limitations (Geldreich & Singley, 2002; O'Connor, 2002b, p.335). No amount of regulation or stringency in drinking water quality criteria will serve consumers better than having their drinking water providers well-trained with the ability to learn effectively from their mistakes, external challenges and close calls so that future problems can be avoided or minimized. Close calls or previous water quality failures should be studied so that operators come to understand the relationship between their own operational indicators and resulting water quality failures (Gammie et al., 1998). Even apparently small faults should be addressed because they can accumulate and lead to larger problems. Allowing such fault accumulation will ultimately negate the security offered by a multiple-barrier system. The case studies in Chapter 4 demonstrate amply that waterborne outbreaks are usually caused by a combination of faults. Considered from another perspective, that means there are usually multiple missed opportunities to prevent an outbreak. That collection of missed opportunities inevitably appears like incompetence when viewed through the hindsight of an investigation or inquiry.

Ultimately, drinking water providers must accept that providing continuously safe drinking water to all of their consumers at all times is a daunting task. This scientifically and technologically challenging undertaking continues to grow in its sophistication. These are the characteristics of a knowledge-based industry. Consumers would not tolerate having their telephone system or home computer serviced by inadequately trained personnel, yet training and education standards for water treatment and distribution personnel remain low in many jurisdictions. Smith (1995) observed in her critique of the parties involved in the Milwaukee outbreak that some states in the U.S. have more rigorous training requirements for hairdressers than they do for water treatment operators. She makes an excellent point, regardless of the details, that water treatment operators should be seen as holding a responsibility for public health at least as vital as any other health professional. Few in the healthcare professions are afforded a greater opportunity to affect the health of so large a number of people through their actions or inactions.

Likewise, the provision of safe drinking water demands technologically and scientifically sophisticated management and leadership. Water authorities driven strictly by their economic bottom line, without regard to their scientific competence, sooner or later invite serious water safety failures. Governments who believe that the public is willing to sacrifice drinking water safety for modest cost savings will find that failures ultimately tied to such false economies are not viewed kindly by the public.

At the other end of the spectrum from large and complex systems are small water systems, which face a different set of challenges. Often the nature of running a small water system is not technically demanding or complex, although there are certainly exceptions. We need to find the means to support the operators of small systems, whether such systems are too demanding for their limited skills or too simple to challenge those with more sophisticated skills. Most of the outbreak cases reviewed in Chapter 4 occurred in small systems. These smaller systems clearly pose the greatest risk for outbreaks, even if they are limited in the number of affected consumers.

Many of the outbreaks in small systems in sparsely populated areas seem inexcusable. Examples reviewed in Chapter 4 include many communities with ample fresh water and limited human potential to pollute the water resource (Rome, New York; Aslvåg and Skjervøy, Norway; Heinävesi, Finland; Temagami, Canada). In most cases, remote communities do not inherently present more fundamentally difficult technical challenges to the provision of well-designed and functional services than those encountered in more populated areas. Unit costs are often higher for small populations where economies of scale cannot be realized. Where specific environmental conditions such as permafrost interfere, there have been decades of technological development and experience to draw upon for providing excellent municipal servicing (Smith, 1996). The main problem may simply be attitude or awareness. Those living in remote areas surrounded by abundant fresh water may not be prepared to invest in appropriate system design to assure that their drinking water will be safe. In some cases, they may fail to recognize the need to make such investments to assure safety.

The good news is that the challenges of providing safe water in most small systems can be made manageable with appropriate commitments of funding, training, support and personal will. The New Zealand approach to small systems outlined in Chapter 6 deals with training and support. Personal dedication and will to assure safety is addressed in the next section.

5.2.6 Drinking Water Professionals (Providers, Regulators and Health Officials) Must be Accountable

Because drinking water safety depends so greatly on the actions of the operators with their hands on the control panels, a culture of vigilance must be created among them so that they fully appreciate the serious burden of their responsibility. This certainly does not mean that operators need to be perfect or superhuman (Hrudey & Hrudey, 2003). As noted earlier, humans will inevitably make mistakes no matter how careful they may try to be (Kletz, 2001). However, those entrusted with the health of an entire community must be expected to care about how well they do their job. When operators are not sure what may be wrong, they must be encouraged to seek help. A management culture that does not want to know about problems, so that operators are discouraged from discovering and dealing with problems, is certainly a pathway to failure. Management must be committed to safety first. Operators who uncover problems and bring them to management attention should be recognized and rewarded for their initiative. The depressing history of operations revealed in the North Battleford case study (Section 4.6.6) offers a clear example of a management culture that must be avoided.

For any public service as vital to community health as the provision of safe drinking water, dishonesty or repeated violation of required operating procedures is absolutely intolerable. In the Walkerton outbreak, many inexcusable errors were made and clearly revealed in evidence. Even so, the Commissioner of the Inquiry stated that: "*It is simply wrong to say, as the government argued at the Inquiry, that Stan Koebel or the Walkerton PUC were solely responsible for the outbreak or that they are the only ones who could have prevented it*" (O'Connor, 2002a, p.24). This conclusion was based on the overwhelming evidence of failures in the management and regulatory systems that should have made such continuing aberrant behaviour impossible. Other cases where serious misconduct by operational personnel was a major contributor to the outbreaks were Eagle-Vail and La Neuveville, where alarms designed to prevent dangerous conditions were ignored or shut off with no follow-up.

The need and responsibility of other professionals (regulatory and health officials) to assure that a rare bad performer working for a drinking water provider will not be tolerated were apparently absent in the case of Walkerton. The Sydney water crisis provided an example of the expensive consequences of allowing a dysfunctional relationship to exist between the drinking water provider and health officials; fortunately, there were no health consequences. These cases show the need for a functional relationship where each group knows its responsibilities and a clear and, preferably, formalized understanding is established to assure constructive interactions, particularly in assessing any possible outbreak.

To assure that effective performance is achieved, responsibility and accountability must be established at all levels within the organization of a drinking water provider. In Canada, where drinking water providers typically operate for municipal governments, the Walkerton Inquiry recommended: "*Given that the safety of drinking water is essential for public health, those who discharge the oversight responsibilities of the municipality should be held to a statutory standard of care*" (O'Connor, 2002b, p.296). With such accountability in force, some of the ill-informed statements from politicians in the North Battleford and Edmonton cases might have been tempered by a realization that elected officials must be accountable for drinking water safety. Perhaps more important is the apparent need to influence the lack of concern some politicians have expressed for assuring drinking water safety. In a democracy, this means voters need to determine that their elected officials truly understand what rudimentary commitments are necessary to assure safe drinking water for their community. Then voters must hold their elected representatives accountable for ensuring that the necessary commitments to safe drinking water are made. If voters are indifferent to such issues, they can expect to live with a much greater risk of drinking water system failures.

There were a remarkable number of cases where consumers' apparent tolerance of an outbreak that resulted in no or inadequate system improvement was followed, not surprisingly, by a subsequent outbreak (Creston, Georgetown, Isle of Thanet, La Neuveville, North Battleford and South Devon). Likewise, there are several cases where warnings about specific flaws that increased the likelihood of an outbreak went unheeded (Bennington, North Battleford, South Devon, Uggelose and Walkerton). In Walkerton, the public was likely unaware of the personnel deficiencies, but the officials for the water provider and regulator had a responsibility to know and to act. A reluctance to seriously consider strong evidence that a drinking water outbreak is underway and initiate precautionary actions, such as boil water advisories, has been a problem in cases where water utilities or local politicians have challenged the need for such actions (Edmonton, La Neuveville, North Battleford and Penticton).

A water provider that seeks to make its water supply as safe as it can reasonably be needs to recognize its customers as allies, not adversaries. There is no cheap way to achieve safety. Consumers will ultimately be the ones who must pay for effective investments to achieve a safe drinking water system. Severe underfunding of a water utility by providing cheap water rates while running an inferior operation invites trouble (Gideon, North Battleford and Walkerton). Financial considerations are particularly important for communities with aged infrastructure that is in disrepair and likely to be more vulnerable to failure scenarios (Bennington, Bramham, Gideon, Greenville, Mjövik, Pittsfield and Saltcoats/Stevenston). Aging and decaying infrastructure is an increasing concern for larger urban areas and these factors may contribute to future outbreaks, if not addressed in a timely manner.

Consumers are also allies in the detection of problems because they are most directly affected by water quality changes and are well-positioned to notice any change detectable to the senses. There are several examples in the case studies (Gideon, La Neuveville, Milwaukee, Naas and Pittsfield) where consumers detected something unusual, which often provided the first signal of the contamination episode leading to the outbreak. Consequently, water quality complaints from consumers must be treated seriously and investigated fully, according to the specific details of the complaint. Because outbreaks are relatively rare events, even in poorly-run systems, most complaints will not signal impending disaster, but they may represent close calls and could highlight vulnerabilities. Regardless, a water provider dedicated to safety, if not customer satisfaction, will work diligently to avoid a corporate culture that ignores or denigrates consumer complaints.

Finally, to complete the discussion of human factors on a more positive note, there are many examples of personal initiative that contributed to revealing an outbreak or reducing the scope of an outbreak. In Walkerton, Dr. Hallett showed critically important initiative in diagnosing the likely *E. coli* O157:H7 infections and notifying public health officials accordingly. David Patterson may have been the first individual to take personal ownership of the burgeoning problem and was a key contributor to marshalling the public health response to this disaster.

In Berlin, New Hampshire, an enterprising laboratory technician, who had just been trained in examining stool samples for parasites, identified *Giardia* cysts to diagnose correctly a young girl who had been discharged from hospital three times previously with her giardiasis remaining undiagnosed. In Carrollton, a college physician recognized the unfolding outbreak of cryptosporidiosis, which was only the second such waterborne outbreak reported in the U.S. In Cabool, an alert laboratory technician performed the extra culture steps needed to identify the outbreak as being caused by *E. coli* O157:H7. For the Isle of Thanet outbreak, the local infectious diseases consultant recognized the outbreak early and mobilized responses accordingly. In Milwaukee, an observant clinical microbiologist recognized the unusual occurrence of *Cryptosporidium* oocysts in stool specimens not requesting that analysis, providing important early evidence of the emerging outbreak. The local physician in La Neuveville who had suspected a previous waterborne outbreak acted quickly in the subsequent outbreak to inform public health authorities and mobilize actions to limit the scope of the epidemic. There are surely countless others who have played heroic roles in limiting or responding to outbreaks and many more who may never be recognized because their actions have prevented outbreaks from occurring.

5.2.7 Risk Management — Making Sensible Decisions Under Uncertainty

The Walkerton Inquiry described some essential characteristics of risk management, including:

- *"being preventive rather than reactive*
- *distinguishing greater risks from lesser ones and dealing first with the former*
- *taking time to learn from experience*
- *investing resources in risk management that are proportional to the danger posed."* (O'Connor, 2002b, p.75)

Managing risk effectively requires making sensible decisions within the constraints of knowledge and resources. Risk management is essentially an exercise of decision-making under uncertainty. Even if negligible scientific uncertainty could be achieved, the wide range of competing views for social priorities would still challenge decision-making, but at least the evidentiary basis for any decision would be clear. For drinking water outbreaks, cases with such clarity of scientific evidence are the exception rather than the rule.

Because there is always some uncertainty in the evidence, errors in decisions can be of two main types. A decision can be made to act when there is truly no need. This is termed a type 1 or a false positive error. Alternatively, a decision could be made not to act, when there is truly a need. This is termed a type 2 or false negative error (Hrudey & Leiss, 2003).

These types of errors can be illustrated by reference to some of the cases reviewed. The Sydney water crisis (Section 4.7) has been described as a case of issuing a boil water alert for Sydney residents on the basis of erroneous monitoring results (Clancy, 2000), making that decision a false positive (type 1) error. Walkerton was perhaps the most severe example of a false negative (type 2) error. Warnings at Walkerton about drinking water quality had been ignored for over 20 years. Ultimately, tragedy ensued. A boil water advisory was finally issued on May 21, 2000, at least nine days after the contamination of Well 5 occurred. This call was made on the initiative of health authorities, despite being actively misled about the status of the water supply. In several other outbreaks, fortunately with much less severe consequences, boil water advisories were not issued for a variety of reasons (e.g., Edmonton, Penticton).

Given these comparisons, a commitment to precaution for public health decisions demands a preference for false positive (type 1) over false negative (type 2) errors, because the consequences of the latter are usually more direct and potentially more severe. However, there are inevitably consequences to false positive (type 1) errors as well. In the Sydney case, tens of millions of dollars of public funds were spent on circumstances where investigation revealed that public health was not harmed. As noted above, the merits of the decisions involved have remained a source of debate. However, given their access to and understanding of the evidence provided at the outset of this incident, the public inquiry found that health authorities chose correctly in deciding to issue a system-wide boil water alert in the first instance (McClellan, 1998). Although the merits of each case will differ, the general reality remains that frequent false positive (type 1) errors will eventually create a "cry wolf" response with the public such that important measures like boil water advisories may be ignored when they are truly needed to protect public health.

Although the decision-making challenge for boil water advisories can be characterized in relatively stark terms after the fact, the reality for any outbreak situation is that the evidence is usually not clear as the events are unfolding. The detailed accounts for Walkerton and North Battleford certainly chronicle this problem. Stan Koebel's withholding of adverse monitoring results from the health authorities undermined their basis for issuing a boil water advisory. Justice O'Connor noted the irony that Stan Koebel's decision was likely motivated by trying to conceal the reality that he had allowed the operation of Well 7 without a chlorinator from May 15 until May 19 (O'Connor, 2002a, p.10). Stan Koebel knew that operating with no chlorination was wrong and would be criticized. The Inquiry concluded that he apparently believed that this error caused the illness that was emerging in the community rather than contamination of Well 5, the true cause.

The pattern of illness in North Battleford was confusing because the first case, reported on April 4, arose on a farm 13 km out of town, and the next two cases, reported on April 5 and April 17, were residents of the Town of Battleford. No clear connection of cases with the City of North Battleford emerged until April 23. The lag times for the onset of illness, medical attention, submission of stool samples, analysis and reporting of results combined with the confusing pattern of disease in the community did not provide clear evidence for issuing a boil water advisory until April 24. In contrast, the contamination of the North Battleford drinking water likely began on March 20 and disease became evident by March 26 (Figure 4.71). This pattern of boil water advisories made late in the course of an outbreak is apparent in many other cases (e.g., Cranbrook, Pittsfield).

The judgement of evidence in a waterborne outbreak usually presents a challenge for the parties involved. An effort to categorize evidence from an investigation as being "strongly," "probably" or "possibly" associated with a waterborne outbreak (Figure 5.3) was proposed by Tillett et al. (1998). They note the problems that arise from trying to discriminate increases in waterborne disease against a background of gastroenteritis from other causes.

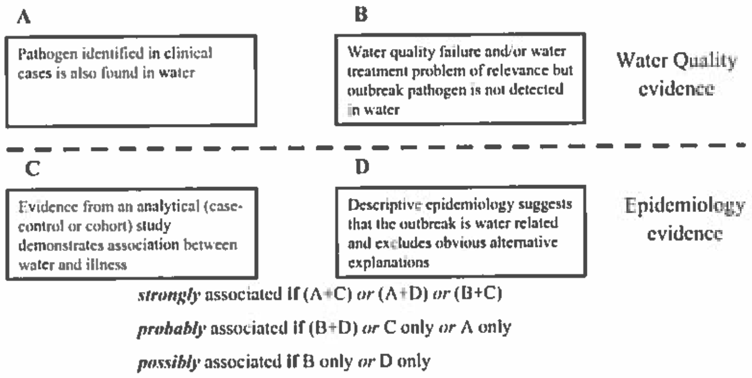

Figure 5.3 Classification of evidence for association of disease with drinking water (Source: Tillett et al., 1998, with permission ©1998 Cambridge University Press)

Relying on evidence from laboratory testing of stool specimens is limited by several stages (Moe, 2001): an infection may not produce symptoms; an infected person may not seek medical attention; the healthcare provider may not take a stool specimen or the patient may not provide one; the appropriate laboratory test may not be requested; the test may be done incorrectly or may be unable to detect pathogens present; and the lab may not report the result in a timely manner or at all. This sequence of obstacles combines with the time required for all of these steps to occur to preclude laboratory screening results from being an efficient indicator of a waterborne outbreak. Even if all of these obstacles to detecting an individual infection are overcome and a pathogen is reported as detected, many of these pathogens are spread by other routes. Consequently, a sudden rise in occurrence of positive lab results does not necessarily signal a waterborne outbreak.

There are other challenges in gathering evidence. Because of the time lags between a contamination episode, when symptoms arise and when confirmation may occur, it is usually not possible to go back and collect water samples that will accurately represent the suspected episode. This reality makes gathering confirmatory evidence of contamination difficult, unless contamination is continuing or there is access to archived materials such as ice, filters, sludge or another medium that might retain pathogens from the period in question. Of course, such archival sources should be analyzed to the maximum useful extent when an outbreak investigation is launched.

A critically important source of evidence is the epidemiologic investigation, effectively applying the science that John Snow pioneered (Section 2.1). These approaches may be described as either descriptive or analytical epidemiology (Tillett et al., 1998). Descriptive epidemiology focuses on who was ill, when, where and having done what. These descriptions seek to define possible exposures to pathogens, given the incubation period following exposure to contaminated drinking water, considering the plausibility of the timing between exposures and observable outcomes and looking for common themes (e.g., what connections did any case have to the City of North Battleford?)

The nature of the descriptive evidence will be sufficient to generate hypotheses about the causes of illness, but it cannot be expected to test those hypotheses in any rigorous manner. The second approach of analytical epidemiology involves collecting data suitable for statistical analysis to provide a pattern of evidence that others can independently evaluate for strength of association between drinking water exposure and disease, without relying primarily on the interpretations and judgements of the investigators. Unfortunately, there are many practical limitations to analytical studies, including the issue of recall bias that was raised in the discussion of the studies done on Milwaukee to estimate the number of cases that occurred (Craun & Frost, 2002; Hunter & Syed, 2002). Likewise, although analytical studies can test hypotheses about the association of exposure to drinking water and the occurrence of disease, they cannot by themselves prove that drinking water caused an outbreak. In fact, they are normally limited by statistical power for even demonstrating correlation, because the sample size must be large to demonstrate true differences in water exposure between those individuals classified as exposed or unexposed, unless the effect of exposure is very dramatic. If the sample size (number of individuals) is small, the differences in exposure is small or the misclassification error in classifying individual exposure is large, the ability of an analytical study will be very limited for generating evidence useful to demonstrate an association between water exposure and disease.

The situation found in Milwaukee, where large numbers of people who were non-mobile and exposed in nursing homes to distinctly different drinking water supplies, provided uniquely strong evidence to implicate water supplied by the Howard Avenue plant. Opportunities for collecting such convincing evidence are uncommon. Consequently, results from analytical epidemiology studies that fail to demonstrate an association between drinking water exposure and disease at a reasonable level of statistical confidence may simply lack the statistical power to support the association; they do not absolve the water supply of causing an outbreak.

These features of evidence are combined in a logical set to classify such evidence as being strong, probable or possible (Figure 5.3). According to this scheme, the evidence for the outbreaks at Saltcoats/Stevenston, Swindon/Oxfordshire and Warrington being waterborne was all judged to be strong while the evidence at the Isle of Thanet was judged as only probable. The main problem with this scheme for judging evidence is that much of the epidemiologic evidence will not be available until the outbreak is over, so such classification of evidence may only be useful in a retrospective sense. Hunter (1997) presents an excellent overview of the entire rationale and process for outbreak investigation within the broader context of understanding and controlling outbreaks.

Interpreting the meaning of evidence during an outbreak and deciding whether or not to call a boil water advisory is an important problem. Gammie (2001) offers advice on a number of factors to consider when developing a protocol with the responsible health authority for deciding on evidence that would support issuing a boil water advisory that includes:

- quantitative criteria for interpreting adverse microbial monitoring results (coliforms, *E. coli*, *Giardia* and/or *Cryptosporidium*),
- loss of chlorine residual at the water treatment plant (for how long?),
- exceeded treated water turbidity limits (by how much and for how long?),
- unusual plant upset conditions, and
- natural disasters or unusual weather that adversely affect water quality.

Unfortunately, boil water advisories are often not very effective in protecting consumers. Various studies on compliance with boil water advisories in outbreak situations have found that compliance is not high enough to protect all of the consuming public, either because the population did not learn about the advisory or because they did not adequately understand the meaning and full intent of the advisory. In Walkerton, only 44% of respondents reported that they heard about the boil water advisory by any means (directly, via others or through other media) when it was first issued on local radio (BGOSHU, 2000). In Gideon, 31% of persons polled (30 of 98) had consumed city tap water after a boil water order had been issued, including 14 who subsequently became ill (Angulo et al., 1997). Reasons for non-compliance included not remembering or disbelieving.

A possible outbreak was investigated when a sewer line broke and was suspected of having contaminated drinking water in Bolton, England. A study of compliance with a precautionary boil water notice found that only 58% of households changed their consumption of water based on the notice (O'Donnell et al., 2000). A study of 2,000 hospital employees among 300,000 households advised to boil water found that even within this group that was expected to be more aware of health considerations, 12% did not comply, 20% used unboiled tap water for washing food and 57% used unboiled tap water for brushing teeth (Willocks et al., 2000). Given these findings, other measures are likely to be necessary in a serious contamination/outbreak scenario, including provision of bottled water and treatment across the distribution system with super-chlorination (Gammie, 2001). For prolonged contamination scenarios, some level of emergency treatment with portable systems such as membrane filtration might be considered, but this is likely to be feasible for rapid implementation only with smaller communities.

Of course, apart from compliance problems and inconvenience, boil water advisories represent an essentially reactive response. Risk management that is truly preventive is needed before an outbreak is allowed to occur (Mayon-White, 2002). Achieving a committed preventive approach requires an authentic effort to identify problems and take corrective action, long before those problems can lead to crises. This kind of approach needs a pragmatic framework to cover the whole spectrum of factors that may contribute to an outbreak; such a framework will be introduced in Chapter 6.

5.2.8 Other Recurring Themes

A few other recurring themes deserve mention.

5.2.8.1 Resorts

A large number of the outbreaks occurred in resort communities or facilities, including Alpine, Crater Lake, Eagle-Vail, Gulf of Taranto, La Neuveville, Moama, Oak Creek Canyon, Penticton, the Swedish ski resorts, the Washington County Fair and the Yukon restaurant. In one sense, a more casual attitude to sanitation services at resort facilities and communities may not seem surprising, but on closer examination, the justification is suspect. A given community should not choose to take its collective chance on an outbreak by flaunting regulations or guidance for protecting the health of its own citizens. Such a risky choice might be easier to understand within a community that may be truly poor and totally inward-focused. However, in a resort community or facility, which actively seeks tourist visitors for the money they bring, a choice to allow visitors to be exposed to unsafe water seems particularly objectionable. Certainly, providing stringent standards of water safety should not be optional in circumstances where visitors will be the most likely to become ill because of their lower immunity compared with residents routinely exposed.

5.2.8.2 Concerns with chlorination

Another theme that arises more than once is the problem of communities objecting to chlorination to make their drinking water safe, either on aesthetic grounds or because of concerns about health effects associated with chlorination DBPs. One of the sad ironies of the Walkerton tragedy was that the Koebel brothers kept chlorination low because they disliked the taste of chlorine and were pressured by some residents to lower chlorination for the same reasons (O'Connor, 2002a, p.183). Similar issues were raised in Bramham and North Battleford. Likewise, many outbreaks have occurred where neither chlorination nor any other disinfection was practiced; this risky behaviour was likely motivated by the adverse aesthetic characteristics of chlorination in some cases. Lahti and Hiisvirta (1995) reported that inadequate chlorine disinfection was responsible for an outbreak affecting ~100 consumers. In this case, the chlorination was kept low intentionally out of concern for the health effects from chlorination disinfection by-products. The Transtrand outbreak in Sweden was caused in part by community reluctance to allow chemical disinfection of the water supply. Studies showing an increase in mutagenicity of organic matter in water following chlorination in the 1980s received considerable media attention in Scandinavia. This was also linked to studies on chlorine bleaching of wood pulp and the production of dioxins — a finding that led to elimination of free chlorine bleaching in that industry. Overall, chlorine and chlorinated by-products have been successfully targeted by environmental groups as being inherently dangerous. The vehement opposition to chlorination in Erickson (Creston) for more than a decade appears to have been motivated by conviction that health risks from chlorination are substantial, as stated by vocal opponents with reference to a series of publications by Health Canada. The experience of this community with two waterborne outbreaks caused by lack of adequate disinfection seemed to have little effect on their fear of chlorine.

5.2.8.3 Gender distribution of cases

An unusual finding is that in a number of outbreaks there has been a clear excess of cases among females, although we are aware of no basis in the characteristics of the diseases involved that should necessarily favour females over males. This imbalance was striking in relation to two of the fatal outbreaks where all of the deaths were female (all four in Cabool and all seven in Walkerton). For the total cases of illness, 63% were female in Cabool and 58% were female in Walkerton. In Milwaukee, based on the telephone survey of clinical cases, 69% were female (MacKenzie et al., 1994). Other outbreaks have noted an uneven distribution of illness, including Edmonton, where 71% of cases were female (King-Collier & Macdonald, 1983a); Carrollton, where the attack rate was higher in females than in males (67% versus 55%), even when these data were controlled for age and water consumption (Hayes et al., 1989); Saltcoats/Stevenston, where 63% of confirmed cases were female (Smith et al., 1989); Bradford, where 56% of cases were female (Atherton et al., 1995); and Cranbrook, where the attack rate was 17.8% for females versus 7.6% for males (BCCDC, 1996). In a number of outbreaks, the higher proportion of female cases might have reflected higher exposure because of more time spent in the home, a higher rate of water consumption among females, a higher proportion of female residents in nursing homes or among the vulnerable (aged) exposed population or a higher likelihood to seek medical attention. The possibility also exists that the higher proportion of females apparent is merely an artifact of the relatively small number of outbreaks being considered. For example, in Saitama, Japan the two kindergarten children who died from *E. coli* O157:H7 were both boys.

5.2.8.4 Public health context

Finally, there is a need to place these issues into a broader public health context. We noted in the opening of this book that the occurrence of disease and death from drinking water is remarkably rare in affluent industrialized nations. This rarity stands in stark contrast to the awful toll of disease and illness caused by unsafe water in the poorer regions of the planet. Furthermore, within affluent nations, public health officials are not likely to consider safe drinking water a serious challenge compared with other infectious disease issues, such as the anticipated flu pandemic that may cause, over a two-year period, between 1 and 2.3 million hospitalizations and 280,000 to 650,000 deaths in industrialized nations alone (Webby & Webster, 2003; WHO, 2003d). Likewise, there is the recent experience with SARS involving 8,098 cases in 29 countries and 774 deaths in 11 nations (WHO, 2003b) or West Nile Virus with 9,858 cases and 262 deaths in the U.S. alone in 2003 (CDC, 2003b).

Considering these other health risks, the dangers from unsafe drinking water in affluent nations over recent decades look rather insignificant. Some may argue that investing in further improvements must involve diminishing returns. Yet considering the nature of the failures revealed in Chapter 4, it is difficult to accept that the affluent societies involved cannot afford to do better. Causes identified in most of these failures are avoidable without massive new expenditures or dramatic new developments in technology. By failing to do our best to provide safe drinking water, we expose the most vulnerable in our society to harm: infants, the aged and the infirm.

5.3 ROUTINE MICROBIAL SAFETY OF DRINKING WATER

Drinking water quality criteria have been evolving as we learn more about the threats to microbial safety. Perhaps the greatest change in the past two decades has come with our realization of the critical importance of achieving excellent turbidity reduction, as a surrogate for fine-particle removal, particularly as we have learned more about pathogens that are very resistant (*Giardia*) or completely resistant (*Cryptosporidium*) to chlorine disinfection.

The relationship between allowing turbidity spikes through water treatment to reach consumers and causing potential waterborne disease was clearly laid out for the water industry by Logsdon and Lippy (1982). Several subsequent outbreaks, including the massive Milwaukee outbreak of 1993, proved the merits of optimizing fine particle removal to prevent waterborne epidemics.

The role of drinking water in causing endemic gastrointestinal disease has proven more challenging to characterize. Certainly, the role of turbidity as a potential indicator has created confusion. Poor turbidity removal performance will indicate vulnerability to the passage of pathogens, whenever they are present in substantial numbers in the raw water. However, unless pathogens are continuously present in substantial numbers in raw water, routine turbidity fluctuations in treated water will not normally serve as a good indicator of pathogen loading, primarily because pathogens are an insignificant fraction of the total fine particulate matter that typically produces turbidity in water. In most waters, these routine turbidity fluctuations reflect changes in inorganic colloids from soil and sediment. Such fluctuations need not have any relationship with pathogen loading, which will depend on fecal sources, making inorganic colloids an unlikely predictor for disease.

Outbreaks where distinct raw water turbidity spikes coincided with events contributing to a high pathogen loading were clearly a different matter (Morris et al., 1996). In these cases, failure of treatment to remove turbidity effectively corresponded to a failure to remove pathogens that were challenging the system. Several communities along the shores of Lake Michigan experienced severe turbidity fluctuations in treated water during March 1993, but only Milwaukee experienced an outbreak because it had the source of oocysts in its raw water source. No pathogens, no outbreak, no need for an epidemiologic study. These differences illuminate some elements of the controversy that has arisen around epidemiologic studies seeking to show an association between finished water turbidity and endemic gastrointestinal disease (Schwartz et al., 1997; Schwartz et al., 2000). These studies, with their evident weaknesses in data quality and interpretation, have attracted criticism (Sinclair & Fairley, 2000). Other studies linking turbidity and indicators of gastrointestinal illness evaluated scenarios slightly more credible for some linkage of turbidity to pathogens. One was performed on an unfiltered supply from a protected catchment with considerable wildlife presence as a potential source of pathogens (Aramini et al., 2000); the other was on a system that suffered from evident treatment failures giving rise to loss of chlorine residuals during the study period (Beaudeau et al., 1999). A general expectation that treated water turbidity will consistently predict pathogen concentrations is not justifed.

The possibility that drinking water that meets accepted microbial standards could be responsible for endemic gastrointestinal disease was raised by a pioneering intervention study (Payment et al., 1991). Families in this study were randomly distributed between treatment groups who had reverse osmosis treatment installed in their homes and those who drank home tap water delivered from a Montreal community water treatment plant drawing from a raw water source subject to sewage pollution. This study estimated that 35% of the endemic gastrointestinal disease among the tap water group could be attributed to their drinking water (these findings have been questioned because the two treatment groups were not blinded to which treatment they received: because illness was self-reported, the lack of blinding could have biased results).

A follow-up study used four interventions: *tap* (regular tap water), *tap-valve* (water with a valve to keep water flowing from the distribution system), *plant* (water bottled from the plant source entering the distribution system) and *purified* (water bottled from the plant source, but additionally treated by reverse osmosis) (Payment et al., 1997). In this study, the two bottled water groups were blinded from each other because they could not know which water source was provided in the bottles. The bottled water groups did know they were receiving bottled water so they were not blinded from the tap and tap-valve groups. No significant difference in gastrointestinal disease was observed between the *purified* and the *plant* (both bottled water) groups, suggesting no difference in pathogens in the treated water leaving the treatment plant compared with water treated by reverse osmosis. The *tap* and *tap-valve* groups both showed higher (15% and 25% respectively) gastrointestinal disease rates than the *purified* group over the entire study period. This finding suggests that if drinking water was causing any excess gastrointestinal illness, the entry of pathogens must have occurred in the distribution system, perhaps through depressurization caused by transient pressure fluctuation.

The issue of endemic gastrointestinal disease was further addressed by a randomized double-blinded intervention study performed in Melbourne. Six hundred families were randomly assigned either a functional or a sham water treatment unit, to be installed in their homes (Hellard et al., 2001). The functional units provided a 1 µm absolute depth filter and UV disinfection. Participants and personnel collecting data were blinded to whether a participant was receiving water from a functional or sham unit because the systems appeared identical and were fitted with tamper-proof seals. The Melbourne water system is chlorinated, but unfiltered, coming from a highly protected catchment with long raw water residence time (greater than 12 months). In this case, no difference was found between the two groups (the study design was capable of recognizing, with 80% power, a 15–20% difference between treatment groups at a 5% significance level).

More recently, a study building on the advances from the Melbourne study was performed using a protocol piloted by Colford et al. (2002) in California before being implemented in a $3 million randomized, triple-blinded, cross-over study supported by AwwaRF, the U.S. EPA and the CDC. The study, which has not yet appeared in the open literature, was described at the 2003 Conference of the International Society for Environmental Epidemiology. It was conducted in Davenport, Iowa, at an award-winning conventional water treatment plant drawing raw water from the microbiologically challenged Mississippi River (Sinclair, 2003). Raw water monitoring revealed that *Giardia* cysts were detected in 31.1% and *Cryptosporidium* oocysts in 13.5% of weekly 10 L samples. Fecal coliforms were present in all 392 samples tested (mean 340 per 100 mL, maximum 4,478 per 100 mL) and raw water turbidity ranged from 2 to 197 NTU with a mean of 24 NTU.

Despite the challenging raw water quality conditions, there was only a 2%, non-significant difference in gastroenteritis rates between groups drinking from the functional and sham devices, essentially verifying that excellent operation of full conventional water treatment on a challenging raw water source does not contribute to endemic waterborne disease. The findings are also based on the knowledge that the water utility was careful to minimize pressure fluctuations in the distribution system. Pressure transients, a problem common to many systems, can allow the ingress of contaminated water into treated water mains, one explanation put forth for the apparent distribution contamination source suggested for the second Montreal study (LeChevallier et al., 2003).

Overall, research into water quality and public health has begun to pay major dividends over the past decade. Studies are providing credible evidence that safe, wholesome drinking water can be delivered to individual households, as long as the best water quality management practices are followed at all levels. These insights show us what can be accomplished with our best systems. Now the challenge is to bring the performance of other drinking water systems up to these high safety standards.

6

OUTBREAK PREVENTION – SAFE WATER

6.1 INTRODUCTION

The outbreak case studies presented in this book reveal the patterns of outbreak causes that public health and environmental health professionals have been pointing out for decades. Treatment failures, inadequate treatment and poor source selection can be used as categories to summarize most of the apparent causes. Section 5.1 lists more than 80 years of summaries that provide insights about the physical aspects of failures.

By delving into the detail provided by the Walkerton and North Battleford Inquiry reports, we have revealed some of the human failings that have contributed to waterborne disease outbreaks. These perspectives are insightful when we consider the many other outbreaks not documented in such detail. The emerging messages indicate that, despite the remarkable advances achieved over the past century in improving and providing drinking water safety, there is still substantial room for improvement. Furthermore, because the source of human pathogens will always be present wherever humans are active or reside, we can only continue to enjoy safe drinking water if we value it as a priority. Improvements will continue to rely on better scientific understanding and technology, but these accounts also reveal the importance of the human element in assuring safe drinking water.

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Gorman and Wolman (1939) commented on the progress in reducing waterborne outbreaks from 1920 to 1936:

> Unfortunately, as a result of the general diminishing typhoid fever rate in both the United States and Canada, there has been created in the minds of the public and possibly to a lesser degree among health and water works officials, the impression that water-borne epidemics are no longer to be feared as they were in the past. Along with this impression, there has developed among too many public officials a feeling that, with the construction of a modern water purification plant, vigilance can be relaxed in matters pertaining to pollution of the source of supply and supervision over the health aspects of the water works system.

In 1938, Milwaukee experienced an outbreak affecting more than 30,000 citizens; it was described in the same issue of the journal as the comments of Gorman and Wolman (Committee-AWWA, 1939). That outbreak occurred while Milwaukee was building a controversial new water treatment plant. Construction of this filtration plant was opposed by those who were unwilling to pay for improved water treatment (Schwada, 1934).

These examples show that assuring safe drinking water requires more than knowledge of disease causation or water treatment technology. Society must recognize and value safe drinking water enough that public policy gives meaningful priority to ensuring safe water. Given that commitment, effective approaches must then be pursued to deal with the complex social and political challenges that may arise.

Abandoning or undermining the accomplishments of the best performers in the drinking water industry by creating more complex regulation will not promote wider access to safe drinking water. The case studies generally showed outbreaks caused by inadequate performance rather than inadequately stringent water quality standards. For example, the water quality requirements specified for Walkerton (effectively a CT > 7.5 mg-min/L) was more than adequate to prevent the disease and deaths that occurred. The Walkerton outbreak was caused by failures at many levels among many organizations and individuals, failure to perform duties and discharge responsibilities, leading to a failure to implement the specified regulatory requirement and operate it in a manner that could be sustained regardless of incoming raw water quality.

Justice O'Connor made this point clearly in presenting his recommendations for improvements in Ontario following Walkerton: "*However, readers should not conclude that Ontario's existing system needs radical reform. It does not.*

We can be proud of the high level of expertise and competence that our leading water providers exhibit. The challenge is to ensure that the best practices are implemented across the province" (O'Connor, 2002b, p.2). This theme is likely true for most jurisdictions that have achieved a very low frequency of waterborne outbreaks. However, the experience at Walkerton, as in so many other outbreaks, revealed many flaws that can and should be eliminated.

From a broad public health perspective, many more deaths are anticipated from the next flu pandemic. There will be other outbreaks like SARS and there will likely continue to be deaths from West Nile Virus. In those cases, reducing the burden of disease depends primarily on reactive approaches to assure that illnesses are diagnosed and treated as effectively as possible. Advising people to avoid mosquito bites to prevent the spread of West Nile Virus has practical limits in many locations during mosquito season; people might as well be advised to stay indoors at all times. In contrast, the failures that underlie so many waterborne outbreaks are eminently preventable through better system management and operation. Failure to implement such prevention betrays the trust in the safety of their drinking water that consumers should rightfully have.

While the management and human dimensions of outbreak prevention seem to be the most intractable challenges, there will continue to be important scientific and technical challenges. A continuing commitment to research on drinking water quality and treatment technology is necessary to ensure that we can respond to future emerging pathogens. A possible illustration of this need is the recent report that 20% of patients with SARS in Hong Kong also experienced watery diarrhea leading to the discovery of active viral replication in the intestinal tract of those patients (Leung et al., 2003). This discovery raises the likelihood of a fecal route for SARS transmission. The nature of that emerging issue reinforces awareness that new viral pathogens with waterborne transmission routes are likely to emerge. Consequently, maintaining broad-spectrum water treatment measures (filtration and disinfection) that can cope with new pathogens even when they have not been explicitly designed for such new pathogens is an important capability of improved water treatment technology. Maintaining research capability to respond to emerging pathogens and changing situations is also vital as we recognize the challenges we face and the limitations to our current capabilities.

6.2 CHALLENGES

There are several key aspects of waterborne pathogens that characterize the challenge they pose to drinking water safety. Some of these are readily evident from the outbreak case studies:

- Fecal (human or animal) contamination is present wherever humans, their domestic animals or wildlife reside; although exposure is reduced as sanitation and waste management are improved, complete elimination of potential exposure to fecal contamination is not possible.

- Loading of pathogens into a drinking water system sufficient to cause outbreaks of disease will be intermittent and infrequent when high levels of sanitation are achieved; however, extended periods without apparent difficulty do not guarantee future safety.
- Pathogens are likely to be heterogeneously distributed in water because of their origin in fecal particles and because of clumping promoted in treatment processes.
- Some pathogens have high infectivity, which, combined with a likelihood of pathogens clumping into fine particles, makes non-uniform consumer exposure to infective doses a likely mode of infection.
- Some pathogens (e.g., *Cryptosporidium*) are resistant to chemical disinfection making fine particle removal and alternative disinfection processes critical elements of a multiple-barrier approach.
- Conditions for pathogen challenge are often event-driven (e.g., extreme weather, unusual operating conditions), meaning that such events should be recognized as potential triggers.
- Multiple failures in a system must usually combine for disaster to occur, particularly as more barriers are made effective in seeking higher degrees of safety.

6.3 LIMITATIONS

Many of these challenges are intuitive for experienced drinking water professionals, but they are not necessarily established in the corporate memory of a water utility. The intuitive experience within a successful organization needs to become accessible to struggling organizations.

Responses to these challenges are compounded by a number of basic limitations in relation to public health significance of our monitoring capabilities:

- Monitoring methods for pathogens and useful indicators are generally neither sufficiently sensitive nor sufficiently specific.
- Monitoring for pathogens and useful indicators cannot be achieved in real time.
- Monitoring methods cannot be directly interpreted for public health significance because the viability and infectivity for most pathogens is usually not determined.
- Interpretation of monitoring results will be challenged by a preponderence of false positives because of the low frequency of pathogen hazards (Hrudey & Leiss, 2003).

- Population health surveillance is insensitive and is likely blind to low-level endemic disease and all but the largest outbreaks.
- Adaptation and tolerance (immunity) in resident populations may hide local, chronic problems while leaving visitors vulnerable to infection that may be difficult to trace back to the source.

6.4 ELEMENTS OF PREVENTION

Despite the challenges and limitations, the best drinking water providers have shown an ability to respond to a wide range of challenges with effective prevention programs. The processes in these organizations may bend under stress, but they do not break, so failures are not allowed to accumulate to the point where they can impact the health of a consumer. An optimal preventive approach will be creative and forward-looking:

- Informed vigilance is actively promoted and rewarded; this book is written to support that capability.
- Understanding of the entire system, its challenges and limitations is promoted and actively maintained.
- Effective, real-time treatment process control, based on understanding critical capabilities and limitations of the technology, is the basic operating approach.
- Fail-safe multi-barriers are actively identified and maintained at a level appropriate to the challenges facing the system.
- Operators, supervisors, lab personnel and management all understand that they are entrusted with protecting the public's health and are committed to honouring that responsibility above all else.
- Operational personnel are afforded the status, training and remuneration commensurate with their responsibilities as guardians of the public's health.
- Response capability is being improved, particularly as post 9-11 bioterrorism concerns are being addressed.
- An overall continuous improvement, total quality management (TQM) mentality will pervade the organization.

6.5 PREVENTIVE APPROACHES

6.5.1 Insights From Expert Reviews and Inquiries

The occurrence of a number of outbreaks has led to commissions of inquiry or expert reviews seeking to understand what went wrong and proposing means to prevent future outbreaks. These investigative reports have much insight and

experience to offer. A few selected highlights are summarized here to illustrate a foundation for developing preventive approaches.

6.5.1.1 The Badenoch and Bouchier Expert Group Reports

The outbreak of cryptosporidiosis at Swindon and Oxfordshire was profoundly unsettling to the British water industry and its regulators because Britain had pioneered many of the practices for effective water treatment. Having a substantial outbreak occur in Oxfordshire, near one of Britain's icons of research and learning, Oxford University, was neither expected nor acceptable. The Minister for Water and Planning set up an expert group under the Chair of Sir John Badenoch in March 1989 to investigate the extent of the *Cryptosporidium* problem in public water supplies. The first report appeared in July 1990, containing a number of insights that, had they been considered more widely in North America, may have prevented or at least substantially reduced the scope of several *Cryptosporidium* outbreaks, including Milwaukee in 1993 and North Battleford in 2001.

Here are some observations from Badenoch et al. (1990):

> To minimize the risk of cryptosporidial oocysts passing into public water supplies, water companies should pay particular attention to:
>
> i. the operation of rapid filters should avoid sudden surges of flow which may dislodge retained deposits....
>
> iv. by-passing of part of the water treatment process should be avoided...
>
> Water companies should install monitors to make it possible to measure the turbidity on each rapid filter to assist early detection of conditions which may favour the breakthrough of oocysts into the treated water...Water companies should assess the value of coagulant aids to assist flocculation and retention of oocysts...
>
> Since the standard method of disinfecting treated water supplies by chlorination is ineffective against cryptosporidial oocysts, alternative disinfectants are required, particularly to treat recycled waste water from the water treatment process.

A second report (Badenoch et al., 1995) was provided by this group in 1995, offering further useful insights:

> The processes of water treatment when rigorously applied are effective in removing oocysts from water supplies and the Group considers that this is the key component in reducing the risk of waterborne cryptosporidiosis.

> Continuous turbidity or particle count monitoring can give early warning of particle breakthrough and alert operators to an increased risk of the presence of oocysts in the treated water.
>
> Warning of a potential outbreak of cryptosporidiosis can come from observations of a general practitioner, from reports to clinical laboratories or from detection of oocysts in treated water. Action to be taken when oocysts are found in treated water needs careful consideration. Currently there is no way of defining an acceptable threshold level of oocysts and decisions on action must be based on local experience and agreement between water utilities, health authorities and local authorities.

The advice offered about coordination between water provider and health authorities as well as the need to proceed carefully when interpreting evidence of oocysts in treated water would have been helpful if it had been implemented for the 1998 Sydney incident. Some of the technical insights would also have been useful for the South Devon (Torbay) outbreak that occurred in August and September 1995, just before this report was released.

A third report of the expert group was precipitated by the troubling cryptosporidiosis outbreak in northwest London and Hertfordshire in March of 1997. This report, under the Chair of Professor Bouchier, offered several additional valuable insights, particularly about recognizing and avoiding the risk of *Cryptosporidium* from contaminated groundwater sources, including Table 6.1 and the following extracts (Bouchier et al., 1998):

> [O]utbreaks of drinking water-related cryptosporidiosis do not just 'happen'. Worldwide there is an increasingly strong correlation between these outbreaks and inadequacies in drinking water treatment. A key element in providing appropriate treatment is the assessment of risk from *Cryptosporidium*. Risk assessment should be based on a combination of factors including the degree of exposure of the catchment to oocysts, the treatment processes currently in place and the history of cryptosporidiosis in the community. Monitoring systems and water treatment requirements should be reviewed against the level of risk.
>
> Not all groundwater is consistently high quality. Utilities should be especially vigilant for the possibility of intermittent rapid transmission of water from the surface into boreholes, wells and springs. The catchment, resource and source characteristics should always be reviewed against water quality data…
>
> The isolation of oocysts in groundwater soon after rainfall recharge is a high risk circumstance which warrants immediate investigation. This should include an assessment of historical reported rates of human cryptosporidiosis.

> Groundwater levels should be monitored regularly and compared with abstraction, rainfall and quality data. A rise in level will normally either be caused by reduced abstraction or by increased rainfall recharge. An unexpected rapid rise in level should be investigated and the possibility of ingress of water of recent surface origin should be considered, particularly if it can be correlated with recent rainfall or changes in water quality or water temperature.
>
> Sudden, unexplained peaks in groundwater turbidity should be investigated by the use of particle size analysis and microscopic investigations…
>
> Turbidity monitoring through the water treatment process is a vital element in checking that treatment barriers are working properly. The unifying factor in all outbreak situations is the potential for peaks in turbidity to be present in the treated water leaving the works.
>
> [M]ost waterborne outbreaks occurred due to deficiencies in water supply including those in which the treatment was inadequate or the works were operated above design capacity or some part of the treatment was bypassed. As recognized in the earlier Expert Group reports a conventional treatment works (that is, coagulation aided filtration) operated in accordance with good practice, is normally an effective barrier against *Cryptosporidium*.
>
> Water utilities should review their working relationships with local health authorities and environmental health officers in the form of Incident Management Teams. Criteria should be established for identifying outbreaks and procedures put in place for activating Outbreak Control Teams.

These expert reports provide a wealth of practical advice for the issues that an individual water utility must consider to deal effectively with the challenges posed by *Cryptosporidium*. Some of the observations appear obvious now, in the hindsight of several large outbreaks, but they challenge a number of common practices that had evolved, some through complacency.

Table 6.1 Factors for consideration in the risk assessment of groundwater contamination (Source: Bouchier et al., 1998. Crown copyright material is reproduced with the permission of the Controller of HMSO and Queen's Printer for Scotland)

Predisposing groundwater to *Cryptosporidium* risk	Possible Verification Techniques
Well/raw water source factors:	
Supply source tapping shallow flow systems e.g., adits, springs, mine galleries	Check site plans, tracing
Adits with upbores or construction-stage ventilation shafts	Check site plans, site inspection
Masonry linings above pumping water level without additional sanitary seal	Closed Circuit TV (CCTV), check site plans
Poor casing integrity	CCTV, geophysical logging
Sewer/septic tank/slurry pit systems near wellhead or above adits	Site inspection
Inadequately fenced source especially around spring boxes, catchpits and galleries	Site inspection
Old poorly documented well construction	Site plans/Geological Survey National Well Record Archive
Hydrogeological factors:	
Known or suspected river aquifer connection nearby	Flow gauging, modelling hydrochemistry
Unconfined conditions with shallow water table	Well water-level monitoring
Karst or known rapid macro-fissure flow conditions, especially in shallow groundwater	Field mapping, farm surveys
Patchy drift cover associated with highly contrasting aquifer intrinsic vulnerabilities	Field mapping, shallow drilling
Solution features observed or inferred in catchment	Field mapping
Shallow flow cycles to springs	Tracing, hydrochemistry, water temperature logging
Fissure-dominant flow (as suggested by high transmissivity or specific capacity)	Downhole fluid/flow logging, pumping test analysis
Catchment (watershed) factors:	
High wastewater returns, including sewage effluents to losing river reaches, especially under base flow conditions	Hydrochemistry, microbiology, hydrometry
Livestock rearing in inner catchment, especially if intensive	Farm survey
Likely *Cryptosporidium* – generating activities in catchment e.g., abattoirs	Economic activity survey
Urbanising catchment	Land registry survey
Livestock grazed/housed near wellhead patio/courtyard	Site inspection

6.5.1.2 The Walkerton Inquiry Reports

The Walkerton Inquiry reports, Part 1 (O'Connor, 2002a) and Part 2 (O'Connor, 2002b), deal, respectively, with the causes of the Walkerton outbreak, including the role of the Ontario government, and with a strategy to avoid such a disaster happening again. The findings of Part 1 have been referred to extensively in the account of the Walkerton outbreak in Section 4.2. The findings of Part 2 are most relevant to this discussion on prevention. The Part 2 report made 93 recommendations to implement a multiple-barrier approach across Ontario, with particular attention for improved coordination of source protection, improved standards-setting with greater transparency, improved provincial oversight, including regulatory obligations under comprehensive legislation to manage water quality from source to tap and special considerations for small systems. The approach to developing these recommendations was influenced by the holistic perspective offered by the Australian NHMRC Framework for Management of Drinking Water Quality (NHMRC, 2001; Sinclair & Rizak, 2002; Rizak et al., 2003) with its comprehensive management approach from water source to the consumer's tap. The latter will be discussed in Section 6.5.2.4.

Particularly relevant to this discussion on prevention was this observation by Justice O'Connor (2002b, p.12):

> Perhaps the most significant recommendations in this report address the need for quality management through mandatory accreditation and operational planning. Sound management and operational systems help prevent, not simply react to, the contamination of drinking water. In this vein, I recommend requiring all operating agencies to become accredited in accordance with a quality management standard — a standard that will be developed by the industry and others knowledgeable in the area and mandated by the MOE. Accreditation is designed to ensure that operating agencies have systems in place at the organizational level that will enable them to deliver safe water. Also, as part of the quality management approach, I recommend that each municipality be required to have an operational plan for its water system.

In particular, an appropriate total quality management system would include the following (O'Connor, 2002b, p.336):

- the adoption of best practices and continuous improvement;
- 'real time' process control (e.g., continuous monitoring of turbidity, chlorine residual, and disinfectant contact time) wherever feasible;
- the effective operation of robust multiple barriers to protect public health;
- preventive rather than strictly reactive strategies to identify and manage risks to public health; and
- effective leadership.

The emphasis on systems that seek to assure that processes are functioning as designed is intended to achieve a preventive rather than a strictly reactive approach to safety. A management system primarily focused on monitoring specific numerical water quality targets (conventional drinking water guidelines or standards) is doomed to be reactive because data cannot be obtained in real time for most parameters. Important exceptions are process control parameters like chlorine residual and turbidity monitoring, which can be used to provide assurance, in real time, that treatment processes are functioning as intended. Otherwise, if processes are allowed to fail — if one or more water quality guideline(s) or standard(s) are exceeded — the failure will not become known until the output quality monitoring results are reported, a delay of many hours to days. Such a reactive approach does not prevent the public from consuming the contaminated water. This distinction is particularly important for microbial pathogens because they usually cause acute illness.

Oversight is necessary for assuring that well-known, proven treatment requirements are implemented and rigorously maintained. The objective of creating and mandating a process to identify and codify the best technical, operating and managerial practices within the drinking water industry is to have these best practices adopted across the industry. Done well, this process will provide the industry and regulators with the capacity and culture to recognize and resolve problems instead of just reacting to them, thereby preventing possible future tragedies.

Moreover, an emphasis on finished water quality monitoring by itself does not assure that effective measures are being taken to prevent the contamination from challenging the drinking water treatment system in the first place. Treatment processes cannot be made to be 100% effective or universal in their capabilities to remove challenging contaminants. Hence, another major focus of the Part 2 report was on the need to substantially improve the attention paid to protecting raw water sources from contamination. Specifically, Justice O'Connor's first recommendation in the Part 2 report was directed towards a major emphasis on comprehensive planning: "*Drinking water sources should be protected by developing watershed-based source protection plans. Source protection plans should be required for all watersheds in Ontario*" (p.18).

Finally, the water industry submissions to Part 2 of the Inquiry stressed that no quality management system can be effective without effective leadership. Allen Davies of Epcor, who was invited to present evidence on behalf of the Ontario water industry, stressed that leadership is essential for achieving high-quality performance (Davies, 2002, p.38). Enlightened leadership will recognize the importance and value of investing in knowledgeable and highly committed personnel. The availability of effective leaders may be one of the resource limitations currently facing the industry. Accordingly, fostering the development of effective leaders must be a high priority.

6.5.1.3 The North Battleford Inquiry Report

This report (Laing, 2002) offers a hard-hitting, focused account of a multi-faceted outbreak failure scenario. Although no fatalities were officially attributed to this outbreak, a large, interprovincial epidemic of cryptosporidiosis happened because of organizational failures at the local and provincial level. The Inquiry heard 32 witnesses over 30 days of evidence involving 120 exhibits. This report provides an excellent insight into the problems of providing water and sanitation services in a small rural community. As such, it is recommended reading for anyone who must deal with these issues in other jurisdictions.

The recommendations are directed primarily at the City of North Battleford and the Province of Saskatchewan, with details to fix both the local and province-wide problems. The wider implications of the Inquiry findings relate to the nature of management failures both within the municipal government, which was responsible for producing safe water, and the provincial government, which was responsible for ensuring that the local responsibilities were being met. A few examples of recommendations of potentially broader application are summarized here (Laing, 2002):

- The City is to prepare a written safe drinking water policy that commits to quality over quantity and to best industry practices and which encourages the water treatment plant manager to report any water safety concerns directly to city council if not being addressed by the city administration.
- The City is to raise its water utility rates to at least the median of the rates charged by other Saskatchewan cities.
- The Provincial regulator is to undertake detailed inspections of water treatment plants to be performed by a knowledgeable inspector at least biannually to document the implementation and maintenance of best industry practices in all key operational areas, with a copy provided to the medical officer of health for the health district.

The outbreak experience in North Battleford might not have received the careful scrutiny provided by Justice Laing's Inquiry if the outbreak had not happened less than a year after Walkerton. Because this record is now available, there is an opportunity for smaller communities to read the account of this outbreak and ask searching questions about whether the management problems revealed have any common ground with their own local experience.

6.5.2 Drinking Water Safety Programs

Over recent years, a number of initiatives have been developed to offer broad guidance for achieving drinking water safety. These programs are designed to deal with the processes and management procedures of the water business rather than the detailed quantitative standards that may apply under any given regulatory regime.

6.5.2.1 QualServe, International Water Treatment Alliance, Partnership for Safe Water, U.S. Environmental Protection Agency Composite Correction Program

The QualServe, International Water Treatment Alliance and Partnership for Safe Water programs are organized by the AWWA. The U.S. EPA provides technical program support for the Composite Correction Program. These programs all relate to promoting enhanced performance among drinking water providers.

QualServe provides three basic approaches to improvement. A self-assessment involves a survey of the organization's own employees to provide the internal view of how well the organization is performing. A peer review involves a site visit by volunteers from another utility during which they conduct interviews, tour the key facilities and prepare an assessment report to provide an external view of the organization. Finally, a benchmarking service has been developed to allow a water utility to rate its performance against 22 benchmarks across categories of organizational development, business management, customer relations and water operations.

The International Water Treatment Alliance offers a narrower focus on optimizing the performance of surface water treatment plant operations using self-assessment and peer review. As the name implies, this program is available internationally as part of the professional outreach efforts of the AWWA.

The Composite Correction Program (CCP) is the U.S. EPA's technical contribution (U.S. EPA, 1998) toward the Partnership for Safe Water, a coalition of several organizations interested in enhancing the treatment and safety of drinking water, including the AWWA and the AwwaRF (Renner & Hegg, 1997). The program documentation describes a detailed technical approach to implementing what the U.S. EPA refers to as the CCP (not to be confused with critical control point, CCP, terminology to be introduced in the next section about HACCP).

The Partnership for Safe Water focuses specifically on optimizing surface water treatment plant operational performance to minimize the risk of consumer exposure to pathogens in treated drinking water. This program recognizes four levels of performance achievement and has accomplished documented improvement in finished water turbidity for those utilities that have participated, even when they were performing well already. Given that turbidity is the most easily measured surrogate for fine particles in water and that all pathogens are fine particles (Figure 3.2), achieving excellent finished water turbidity provides broad-spectrum protection against pathogens. Participating water utilities perform a critical self-assessment of their physical plant, operations and administrative procedures bearing on the performance of surface water treatment plants. This program provides an excellent focus on operator performance and problem-solving skills, a critically important feature for assuring drinking water safety.

Considering that these programs and resources are readily available for water utilities to improve their water treatment operations, an eligible drinking water provider that fails to take advantage of them may be justifiably questioned by its consumers about its commitment to drinking water safety. Questioning their water provider about participating in such programs is a key opportunity for consumers to learn about their drinking water provider's policies and practices for assuring safe drinking water.

6.5.2.2 Hazard Analysis and Critical Control Point (HACCP)

The HACCP system was orignally conceived by NASA for assuring safety in manned space missions, but it is now most widely adopted as a certifiable approach for assuring food safety. Because of the obvious analogies, application of HACCP to drinking water safety was proposed (Havelaar, 1994) and is now widely advocated in many countries around the world. The basic principles of HACCP are most readily applied to the operational control of treatment processes, although some drinking water providers have sought to apply the HACCP approach more broadly.

The HACCP principles are summarized in Box 6.1. The HACCP system appeals to many water providers because of its compatibility with the food industry, whose members are often major water users within a service area. A formalized structure has evolved with HACCP in the food industry and the prospect of being HACCP-certified is also appealing. These considerations need not be an impediment to effective application of the useful HACCP principles. The caution is that HACCP must be sensibly and pragmatically adapted to identify hazards and then to assess and manage their associated risks for drinking water systems. If HACCP is adopted for this purpose, it can offer valuable contributions towards managing drinking water risks and preventing outbreaks.

Pursuing HAACP just to earn a certificate that might be displayed for customers on an office wall is undesirable. If HACCP is pursued primarily for public relations, little risk reduction may be achieved. A resulting sense of unwarranted self-satisfaction in these circumstances is more likely to enhance complacency than to promote vigilance.

The HAACP principles with appropriate updating of terminology to match current approaches to risk management can provide a useful foundation for a broader risk management approach, as described in the following sections.

Box 6.1 Hazard Analysis and Critical Control Point principles (Source: Codex Alimentarius Commission, 1997, with permission of the Food and Agriculture Organization of the United Nations)

The HACCP system consists of seven principles:

1. ***Hazard identification and preventive measures***
   - identify the potential hazard(s) associated with food production at all stages of production until the point of consumption
   - assess the likelihood of occurrence of the hazard(s) and identify the preventive measures for their control (consideration of likelihood allows the risk to be assessed)
2. ***Critical control points (CCPs)***
   - determine the points/procedures/operational steps that can be controlled to reduce or eliminate the hazard(s) or minimize its likelihood of occurrence
3. ***Critical limits***
   - establish critical limit(s) which must be met to ensure that the Critical Control Point is maintained under control
4. ***Monitoring procedures***
   - establish a system to monitor the control being achieved by the Critical Control Point by means of scheduled testing or observations
5. ***Corrective action procedures***
   - establish the corrective action to be taken when monitoring indicates that a particular Critical Control Point is not under control, i.e., when critical limits have been exceeded
6. ***Verification/Validation***
   - establish procedures for verification which include supplementary tests and procedures to confirm that the HACCP system is working effectively
7. ***Documentation and record-keeping***
   - establish documentation concerning all procedures and records appropriate to these principles and their application

6.5.2.3 New Zealand Public Health Risk Management Plans

The New Zealand Ministry of Health (NZMOH) recognized that the vast majority of the country's drinking water systems were small, yet faced important challenges in providing safe drinking water (NZMOH, 2001). The NZMOH also recognized that the traditional approach of relying primarily on water quality monitoring in relation to drinking water quality standards is inherently a reactive approach. Monitoring results are typically available only long after drinking water has left a treatment plant and been consumed. Thus, the NZMOH has developed a pragmatic, down-to-earth program for encouraging Public Health Risk Management Plans (PHRMP).

This approach was developed with full awareness of HACCP, but a conscious decision was made to focus on "*events*," defined as incidents or situations that may lead to hazards being introduced into or not being removed from water (Nokes & Taylor, 2003). In developing this approach, four barriers were identified that, if maintained effectively, will adequately control hazards:

- prevention of contaminants entering the raw water of the supply,
- removal of particles from the water,
- inactivation of microorganisms in the water and
- maintenance of the quality of the water during distribution.

This approach is meant to ensure that these barriers are present and functional to minimize the chance of failure that would give rise to "*events*." It was adopted on the premise that small water operators could relate better to the tangible concept of an event rather than a hazard, which some operators may find to be more hypothetical. The other key departure of this sensible approach from HACCP is in not trying to force fit the steps involved in water systems into the definitions of a Critical Control Point (CCP).

There has been much debate about what constitutes a CCP, even among strong advocates of applying HACCP for drinking water safety. The New Zealand approach of ignoring that debate altogether and focusing on the ability to control adverse events with these barriers is one that water operators can readily understand. Currently, the NZMOH has produced 40 specific, practical guides for various elements of typical water supply and treatment systems, all available at the NZMOH web site (www.moh.govt.nz/water). Their sensible, pragmatic approach for developing a PHRMP is implemented in 11 steps:

1. Produce an overview of the supply and decide which of the PHRMP guides are needed.
2. Identify the barriers to contamination.
3. Use the guides to identify events that may introduce hazards into the water.
4. Use the guides to identify causes, preventive measures, checks and corrective actions.
5. Decide where improvements should be made in the supply to better protect public health.
6. Decide on the order in which improvements need to be made.
7. Draw up a timetable for making the improvements.
8. Identify links to other quality systems.
9. Prepare contingency plans.
10. Prepare instructions for performance assessment of the plans.
11. Decide on communication policy and needs.

The New Zealand system of Public Health Risk Management Plans, which is now readily accessible and applicable to drinking water systems anywhere in the world, is an excellent contribution towards greater drinking water safety. This initiative deserves to be more widely known and used.

6.5.2.4 Australian Framework for Management of Drinking Water Quality

As mentioned above (Section 6.5.1.2), a comprehensive framework has been developed in Australia to outline a Total Quality Management (TQM) approach for drinking water quality and safety (Sinclair & Rizak, 2002; Rizak et al., 2003). It is a broad approach to the entire scope of providing drinking water and can readily incorporate the excellent details that have been developed by other initiatives (e.g., the New Zealand PHRMPs, the U.S. EPA CCP).

Figure 6.1 captures the 12 elements that make up the framework, starting with a policy commitment at the highest levels of responsibility in the organization to achieving drinking water quality. Commitment means more than just meeting regulatory requirements by the narrowest possible margins, but a fundamental commitment to continuous improvement that serves as a cornerstone for employee responsibility and motivation. From this flows a series of elements related to system analysis and management.

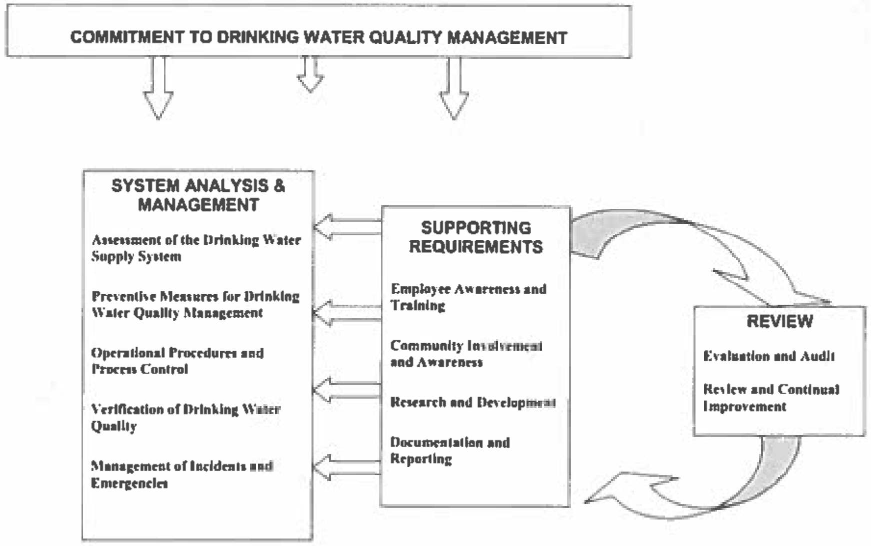

Figure 6.1 Framework for Management of Drinking Water Quality (reprinted by permission of the National Health and Medical Research Council, Canberra, Australia)

Assessment of the drinking water system includes water-supply systems analysis, review of water quality data, hazard identification and risk assessment. Preventive measures include multiple barriers and critical control points (as adapted from HACCP). Operational procedures and process control includes operating protocols, equipment capability, materials and chemicals, operational monitoring and, ultimately, preventive and corrective actions. Verification of drinking water quality includes conventional water quality monitoring, consumer satisfaction, short-term evaluation of results and corrective actions as required. Incident and emergency response include communication planning and response protocols.

The supporting requirements for this Framework are elements often overlooked in the short term, but which are vitally important to long-term performance. Employee issues include awareness, involvement and training, with consideration given to the role of contractors. Community issues include consultation and communication to ensure that the drinking water provider is meeting the needs of the consumer. Research and development has also been neglected in some perspectives when addressing assurance of safety. A commitment to research is vital to assure that emerging risks are managed as thoroughly as possible, based on some predictive capability. Applied research studies can include investigations and research monitoring, validation of process performance and design of equipment. Documentation and reporting are necessary to prove that systems have been working as planned.

Finally, to assure everyone concerned that the systems are functioning as they should be, there must be review processes. These include periodic evaluation of long-term performance and an external audit of drinking water quality-management performance. All must be subject to review by senior management for evaluation in view of the goal of continual improvement.

This framework has been used to restructure the Australian Drinking Water Guidelines into a TQM approach that will provide consumers with the means for judging whether their water provider is functioning as safely and effectively as circumstances reasonably allow. The elements of this approach are flexible enough to allow for implementation by each state in Australia, according to its own regulatory regime. The TQM approach is intended to facilitate and support an effective regulatory process by helping to define the details of best practice in every jurisdiction and by providing consistent approaches for demonstrating best practice to the regulatory authority. The TQM approach is not intended to replace an effective regulatory process that must be accountable to the public, only to improve the manner in which constructive improvements are achieved.

Now that the framework is being adopted in Australia, more detailed supporting documents are being developed to guide its implementation for individual water utilities. An important contribution for that purpose is a report by Nadebaum et al. (2004) that provides comprehensive guidance on performing the hazard identification and risk assessment portions for the Assessment of the

Drinking Water Supply element. The methodology is organized into six steps: 1. Understand your system, 2. Identify hazards, hazardous events and sources, 3. Estimate risk for each identified hazard/event, 4. Plan preventive measures for each identified hazard/event, 5. Implement and monitor preventive measures, and 6. Document a risk management plan. This methodology is supported by individual hazard fact sheets, case studies and summaries of hazards for microbial and chemical contaminants. This report provides an excellent basis for any water utility to initiate its own process for developing a preventive risk management plan for assuring drinking water safety.

6.5.2.5 From Source to Tap: Guidance on the Multiple Barrier Approach to Safe Drinking Water

The Canadian drinking water regulatory system is similar to that of Australia because individual provinces and territories have jurisdiction over drinking water regulation within their respective borders. The federal government has jurisdiction for drinking water supplies for federally recognized aboriginal reserves within the provinces and for federal facilities (e.g., National Defence bases). The Canadian Guidelines for Drinking Water Quality are established by a Federal-Provincial-Territorial Committee on Drinking Water. In response to growing concerns in Canada about drinking water safety after Walkerton, this committee collaborated with the Water Quality Task Group of the Canadian Council of Ministers of the Environment (CCME) to develop a guidance document that describes and suggests approaches to implementing a multiple-barrier approach to drinking water safety, covering the water cycle from raw water source to consumers' taps. This guidance document, which has clearly benefited from many of the efforts undertaken elsewhere in the world in recent years, is scheduled for release in 2004; see the CCME website (www.ccme.ca).

6.5.2.6 World Health Organization Drinking Water Guideline Water Safety Plans

While all of the foregoing initiatives were underway, the World Health Organization has been active in drafting the third edition of the WHO Guidelines for Drinking Water Quality. These guidelines, which were available in draft form on the WHO website during 2003, with publication scheduled for 2004, have also been substantially restructured. Lest consumers believe that all of these initiatives have been proceeding in isolation, they can be reassured that there has been considerable interchange of ideas among various parties around the world. This interchange included a meeting in Adelaide, Australia, in May 2001 of two WHO Working Groups for drinking water guidelines development — Microbial Aspects, and Protection and Control — with the Australian NHMRC Working Party assigned the task of developing the Framework for Management of Drinking Water Quality to support the rolling revision of the Australian Drinking Water Guidelines.

The draft third edition of the WHO Guidelines for Drinking Water Quality introduced the important concept of water safety plans as an approach to prevent or at least manage problems arising anywhere from the raw water source to the drinking water consumer. These water safety plans provide many key concepts and a core philosophy consistent with the Australian framework and with the New Zealand Public Health Risk Management Plans, including a primary focus on assuring safety by emphasizing effective preventive processes rather than by primarily relying on reactive monitoring of finished water quality against guideline numbers. The water safety plan approach is adaptable enough to apply around the globe, in affluent and poor nations alike.

The foundations of this approach are to have developed health-based targets for water quality that are verified through public health surveillance (WHO, 2003c). The water supply chain may be then assessed to determine whether it is capable of delivering drinking water quality satisfying these identified targets. The controls provided by these systems must be monitored to assure they are functioning as required to achieve the water quality targets. Finally, management plans must document the system assessment and monitoring programs, including a description of actions to be taken both during normal operations and when the system is under challenge.

A valuable insight underlying the water safety plan approach is that "*Most drinking water supply systems are characterized by long periods of steady state performance, and short periods of 'stress'* "(WHO, 2003c). Water quality problems, including outbreaks, are most likely to arise under stressful conditions, including: filter backwashing, raw water turbidity spikes and excess pathogen loadings, which may be caused by extreme weather, equipment failures and fluctuations in distribution system pressure allowing ingress of contamination. As detailed in Chapter 4, outbreaks have often been caused by one or more of these stressful conditions.

A water safety plan is achieved through several steps:

- development of an understanding of the specific system and its capability to supply quality water,
- identification of potential sources of contamination and how they can be controlled,
- validation of control measures to manage the risks posed by identified hazards,
- implementation of a system for monitoring control measures within the water system and initiating timely responses to problems,
- verification of water quality as the final assurance that the water safety plan is functioning as it is intended.

The description of water safety plans offers excellent advice, with several illustrations drawn from the Australian Framework for Management of Drinking Water Quality, on key components throughout a water system that need to be addressed. Water safety plans offer a practical, sound perspective for developing a system-specific program to characterize what needs to be done to achieve safe water and to verify that those measures are implemented and functional.

6.5.2.7 The Bonn Charter — A Drinking Water Quality Framework for the 21st Century

In October 2001, a workshop of senior drinking water experts from the U.S., Europe, Australia and Canada met in Bonn to discuss developing a high-level framework to guide the drinking water industry in achieving the goal of providing safe, good quality drinking water that earns the trust of consumers. This group reached consensus on a number of key principles:

- Good drinking water can only be provided through an integrated approach from catchment (watershed) to customer tap.
- An integrated approach will require close co-operation and partnership between governments, water suppliers, land users, other agencies, contractors, plumbers and customers.
- Transparency of the quality-assurance process, including the derivation of standards, is vital for customer confidence.
- A common framework for assuring water quality can be developed, but must be based on best available scientific and medical advice, with emphasis on proactive and prevention-oriented quality management systems, sufficiently flexible to take account of variable institutional, cultural, socio-economic and geographic situations in different countries.

This approach draws a distinction between input control systems (key principles, operational controls and management controls) and output control systems (mandatory standards, operational indicators and output quality monitoring) and advocates a balanced overall approach relying on the important contributions that each element offers towards achieving the overall goal. These issues were further developed at a workshop in Bonn in February 2004 with a view to launching the framework at the IWA World Water Congress in September 2004. The International Water Association has assumed the role of co-ordinating this initiative on behalf of the sponsors of the two Bonn meetings, AwwaRF, the Water Services Association of Australia and the Cooperative Research Centre for Water Quality and Treatment. This initiative provides an international consensus statement addressing the means for dealing with many of the issues raised in this book.

6.6 THE PUBLIC AND SAFE DRINKING WATER

In the introduction (Chapter 1) we observed that safety is a relative, not an absolute condition. Safety cannot demand zero risk without becoming meaningless. Arguably, drinking water in affluent nations is safer than it has ever been, yet large segments of society do not trust their drinking water.

Perhaps one way to deal with this mistrust is to empower consumers who wish to know about the safety of their drinking water. We considered what advice we could offer to individual consumers who would prefer to see their community supply operated at the highest reasonable standards so that they can be assured that they need not take matters into their own hands by purchasing home water treatment devices or bottled water. In response, we have developed a list of questions for consumers to ask their own drinking water provider:

- What is the raw water source for our drinking water?
- What are the main threats of contamination to that raw water source?
- What are the seasonal trends in raw water quality and flow that affect water safety?
- What influence can unusual weather events have on raw water quality?
- How is the raw water treated to assure consistently safe water?
- What are the training levels of your water treatment operators?
- What continuing education opportunities are they provided?
- What incentives are they provided for identifying problems and for improving performance?
- Who is in charge of water quality and safety (i.e., management)? What is their training and experience? What opportunities are provided to increase their expertise and learn from their peers?
- How are close call incident reports used to improve preventive actions?
- What experience has been documented about close calls for water quality failure?
- Who monitors the water quality routinely (i.e., laboratories)? Who do they report to? What checks are maintained to assure they are accurate?
- Who regulates our water (i.e., which government agencies)? What training do individual regulatory personnel have? How often do they check our water quality? Are their checks unannounced? Who verifies that they know what is needed to assure safe water?
- Is there a third-party audit of the entire water operation? What is its mandate? How frequently is this done? Who are the audit findings reported to?
- What information on water quality and operational performance is available to consumers?

- How does the consumer access this information?
- How does the water provider respond to consumer complaints?

There are many measures that can be implemented to improve the safety of drinking water. Ultimately, consumers must value the safety of their public drinking water supplies enough to show the financial and moral support necessary amid the many competing priorities in life.

7

CONCLUSIONS

The modern history of waterborne disease outbreaks in affluent nations reveals an initial transition from large, fatal epidemics of cholera and typhoid in the 1800s until the early 1900s when disinfection, filtration and improved sanitation virtually eliminated their severe impact. During the remainder of the 1900s until the 1970s, waterborne outbreaks continued to occur with low fatality rates and a variety of viral, bacterial and protozoan pathogens implicated. For a large number of these outbreaks, no specific pathogen could be identified. During the 1970s, *Giardia* emerged as a major cause of waterborne outbreaks including, many in systems with full conventional treatment (coagulation, filtration and disinfection). Then in the 1980s, *Campylobacter*, Norwalk-like viruses and *Cryptosporidium* became recognized as waterborne pathogens responsible for a number of outbreaks. The 1990s was largely the decade of *Cryptosporidium*, until *E. coli* O157:H7 emerged as a new threat and acute fatalities became a tragic feature of waterborne outbreaks once more.

There was a major shift in focus concerning drinking water safety in the early 1970s, first with the discovery of numerous trace organic chemicals in water, then with the surprising revelations that disinfectant chemicals produced trace by-products. Despite a continuing toll of preventable disease and death being caused by waterborne pathogens, suggestions that these trace organic chemicals

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posed a grave cancer risk made them seem to be a serious threat to drinking water safety. Many continue to believe that cancer risk should be the main concern with water safety, but more than 25 years of epidemiologic research has provided limited evidence and has left substantial uncertainty about which, if any, disinfection by-products pose any cancer risk to consumers.

Although the evidence in this book does not address chemical risks, it does, we believe, show that management of the certain danger of disease posed by microbial pathogens should take precedence over risks that remain largely unproven. Consumers should understand that the direct evidence for adverse health effects caused by drinking water exposure is substantial and concrete for microbial disease. Confidence about the importance of microbial health risks with drinking water is based on our long experience with these problems. Certainty about whether microbial agents cause human disease is compelling compared with the limited and uncertain evidence concerning trace chemicals and cancer. Outbreak diseases are generally defined by the pathogens that cause them (i.e., giardiasis requires *Giardia*), a feature that does not exist for any drinking water chemical and potential corresponding cancer. Most microbial diseases and their consequences are acute so there is a close relationship in time between exposure and disease. These pathogens are commonly present where humans, their livestock and other animals live; outbreak failures in affluent nations continue to happen and waterborne microbial disease in developing countries causes a terrible toll of illness and suffering.

Chemical risks are certainly important for a short list of specific problems in specific locations (e.g., high arsenic is causing cancer via drinking water) and may be more widely important for some chemicals, but the evidence in the latter cases (e.g., disinfection by-products) remains weak in contrast to the documented evidence of microbial risk. Under these circumstances, our drinking water providers and regulators should continue to take a precautionary approach to support meaningful research and to minimize exposures to chemical contaminants that can be controlled. These valid concerns for better understanding of potential chemical risks do not justify reduction or compromise on controlling the known and pervasive microbial risks. Of course, these debates are difficult to resolve because, unlike individual medical interventions (e.g., antibiotics, surgery), public health risk management only attracts immediate attention when it fails and can only be evaluated for success over the fullness of time.

The progress of the past 150 years in bringing safe, clean water into most households is remarkable for the 15 affluent nations that provided the case studies reviewed in this book. The poor sanitation and corresponding ill health depicted in Figure 2.2 hopefully reflects the past in most of these countries, while poor sanitation continues even today to cause disease, misery and death throughout the majority of the world. The distressing contrast between these extremes should make those fortunate enough to have safe, wholesome water delivered to their residence thoroughly grateful for their good fortune. Safe drinking water service should rank alongside clean air, adequate food and reasonable housing as one of humans' most valuable basic needs. These considerations surely rank above the countless technological toys and other luxuries that residents of affluent nations consume with their discretionary income. Because safe water is so vital, many of the experiences documented in the outbreak case studies seem to betray a trust that society rightfully places in its water providers. So many outbreaks appear to have been caused by neglect or complacency that is incompatible with recognizing safe, clean drinking water as a top priority in life. No amount of economic rationalization can make sense of providing mediocre service to the public for something so vitally important.

Many in our affluent societies are reacting to the publicity around some of these disasters by becoming increasingly distrustful of their public drinking water supplies. Some are investing substantial funds into water treatment devices that they maintain in their own homes while others are more frequently buying and consuming bottled water. However, apart from creating growing profits for the astute entrepreneurs and corporations who have recognized these trends, these responses do not serve the interests of society in assuring drinking water safety for all. Individual interventions are far more expensive per unit volume of water consumed than any conceivable cost for advanced treatment for community systems. Yet, if community water providers cannot engage their customers and correct the loss of consumer confidence that has been caused by cancer scares and relatively rare, but high-profile outbreaks, we may find that those who can afford their own individual "solutions" will become less willing to support the necessary investments to maintain high-quality supplies for their communities. Disparity in access to safe water is often found in poor countries, but is surely not a desirable outcome for affluent nations.

In closing, we wish to acknowledge the enormous amount of work done and the excellent progress that has been achieved by dedicated drinking water providers, regulators and researchers to achieve our current position where drinking water outbreaks are rare events in affluent nations. Given the ubiquitous presence of the pathogens that can cause outbreaks and the complexity of our water distribution systems, it is a remarkable achievement. We hope this book will assist those who are dedicated to maintaining and improving that remarkable performance by supporting all of the excellent work they do to produce continuously safe drinking water for their consumers under all manner of challenge. We also encourage those who do an excellent job to share their expertise widely to assure that every drinking water supply may become as safe as our best drinking water supplies have become.