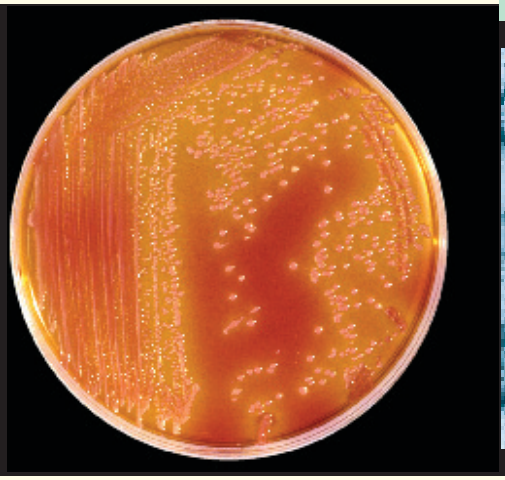
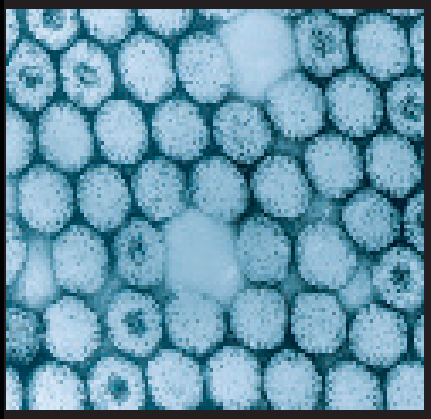
Waterborne Pathogens

MANUAL OF WATER SUPPLY PRACTICES M48







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Preface

Waterborne pathogens can cause life-threatening disease in the immunosuppressed populations of the world and illness in the general population. Reports in print and electronic media of recent waterborne outbreaks and emerging pathogens have expanded public awareness of water quality issues. This awareness places greater demands on government agencies and utilities to effectively inform the public about waterborne agents and related health issues. If outbreaks do occur, having accurate information available is a critical need.

The Organisms in Water Committee of the American Water Works Association (AWWA) prepared this manual for water utility management, water quality, and public relations personnel to use as a reference tool. The manual provides scientific information in a concise, readable format that will be helpful to media, city and state government, and water customers who inquire about waterborne pathogenic organisms. Public health and environmental workers will also find it a convenient reference.

This manual includes chapters on waterborne disease outbreaks; water quality in treatment and distribution systems; water quality monitoring, sampling, and testing; and sections for organisms classified as parasite, bacteria, or virus. Each organism is described in terms of its taxonomic classification and biology, the disease it causes, its mode of transmission, its occurrence, the effectiveness of water treatment methods in controlling it, and monitoring recommendations. Each chapter has a reference section, and a detailed glossary is included at the end of the manual.

Pathogenic organisms reviewed in this manual have been identified in epidemiological investigations of waterborne outbreaks or have the potential to cause such outbreaks. The second edition of the M48 manual expands upon the first with new and revised chapters all reviewed by the section chair. This edition reflects current emerging and re-emerging waterborne pathogens, contemporary procedures, and current literature. The revision also includes improved detection and identification methods and a chapter on molecular detection.

The reader is directed to Appendix A, Additional Resources, at the back of the manual. Appendix A is a list of resources and web links for more information on treatment, security, USEPA resources, and related information.

This is the second edition of the *Waterborne Pathogens* manual. AWWA and the Organisms in Water Committee would appreciate any comments on the manual. Contact Elise Harrington, AWWA Water Quality Engineer, at (303) 794–7711, 6666 W. Quincy Ave., Denver, CO 80235.

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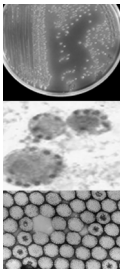
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I

Introduction to Water Quality

Waterborne Disease Outbreaks: Their Causes, Problems, and Challenges to Treatment Barriers

Water Quality in Source Water, Treatment, and Distribution Systems

Water Quality Monitoring, Sampling, and Testing

Molecular Detection of Waterborne Microorganisms

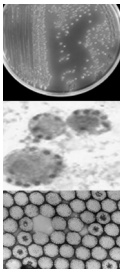
Water-related stories are commonly reported on national television news—stories such as toxic algal blooms in coastal waters and watersheds, waterborne disease outbreaks in major cities around the world, and efforts to protect drinking water supplies from feedlot waste or other contaminants. As world economies become increasingly global, waterborne diseases travel independent of national borders. For example, imported agricultural products washed with polluted waters and shipped to the United States have been associated with several waterborne disease outbreaks. These news events have political, economic, and cultural ramifications that either promote or erode water quality and its association with public health.

Utilities must be active and vigilant to reduce the likelihood of outbreaks of waterborne pathogens—regardless of their geographic location. Utilities throughout the world are now focusing more on proactive security measures, which may include protecting against biological, chemical, and radiological contaminants as well as physical threats. The first step to ensure safe water is to assess current levels of contaminants, including chemical, physical, and microbiological, in source waters. Next, a program of watershed protection, education, and continual improvements to reduce and/or contain these contaminants is begun. Then water treatment plant performance must be enhanced by optimizing treatment processes. For systems with groundwater, attention must be focused on data evaluation over time, and they must be alert to potential groundwater contamination that may take decades to become apparent. Water distribution system water quality can degrade once the water has left treatment, and programs should be tailored to meet the utilities' site-specific challenges on a routine basis. Proactive contamination prevention programs for distribution systems include vulnerability assessments, security for storage and distribution systems,

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backflow prevention programs, and ongoing education to plumbing and landscape companies. In-house, private, public health, and university laboratories can help implement and maintain proper sampling techniques and monitoring strategies necessary to meet the goal of providing safe drinking water. Chapters 1 through 3 provide an overview of water quality issues related specifically to waterborne pathogens. Chapter 4 provides a discussion of the current information on molecular methods and the role these methods may play in complementing traditional detection of waterborne microorganisms.

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Chapter 1

Waterborne Disease Outbreaks: Their Causes, Problems, and Challenges to Treatment Barriers

Gunther F. Craun, Rebecca L. Calderon, and Michael F. Craun

INTRODUCTION

In the United States, state and local public health agencies are responsible for detecting outbreaks, monitoring disease, and performing epidemiological investigations of suspected waterborne outbreaks. When requested, the US Environmental Protection Agency (USEPA) and Centers for Disease Control and Prevention (CDC) help investigate waterborne outbreaks. Each state and territory also has a public health agency with an epidemiological officer whose duties include the investigation of waterborne disease outbreaks. USEPA and CDC also maintain a national waterborne disease outbreak surveillance program, periodically compiling and analyzing statistics for outbreaks that are voluntarily reported.

To be considered a waterborne outbreak, acute illness affecting two or more persons with similar symptoms must be epidemiologically associated with water exposure (Lee et al. 2002). The exception is a single case of chemical poisoning where the water was found to be chemically contaminated (i.e., infantile methemoglobinemia associated with high nitrate concentrations). During an outbreak investigation, water is usually found to be contaminated with coliform bacteria or a chemical; pathogens have been isolated from water samples in some outbreaks.

Most reported outbreaks are associated with water used or intended for drinking or domestic purposes from community, noncommunity, and individual water systems. Outbreaks are also associated with water not intended for consumption (e.g., the use of contaminated springs and creeks by backpackers and campers, and/or accidental ingestion of water while swimming) and water contaminated at its point of use (e.g., a contaminated faucet). The waterborne outbreak surveillance system does not include

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outbreaks that occur on cruise ships operating from U.S. ports or cases of endemic waterborne disease.

STATISTICS

Since 1920, 1,836 waterborne outbreaks, 882,592 cases of illness, and 1,152 deaths in the United States have been associated with contaminated drinking and recreational water. Most outbreaks (88 percent) occurred in drinking water systems. Outbreaks caused by the accidental ingestion of water while swimming or during other recreational use have been systematically reported only since 1971, and these events are not included in the statistics presented (Tables 1-1 to 1-3, and Figures 1-1 to 1-6). During 1971 to 1980, only 15 outbreaks were associated with water recreation; during 1981 to 1990, 67 outbreaks were reported; from 1991 to 2000, 160 outbreaks were reported.

The number of waterborne outbreaks reported in drinking water systems shows somewhat cyclical variations (Figure 1-1). From 1931 to 1950 and 1971 to 1990, the highest number of outbreaks, an annual average of 30, were reported. The fewest outbreaks, 12 per year, were reported from 1951 to 1970. An annual average of 17 outbreaks was reported during the most recent 10-year period, 1991 to 2000; this number of outbreaks is slightly higher than that reported during 1961 to 1970 (13 per year) and fewer than that reported during 1981 to 1990 (29 per year).

Usually, more outbreaks were reported in noncommunity systems than in community systems (those serving at least 25 year-round residents). Noncommunity water systems also provide water to the public, but they do not give year-round service. These systems serve primarily transient populations such as institutions, industries, camps,

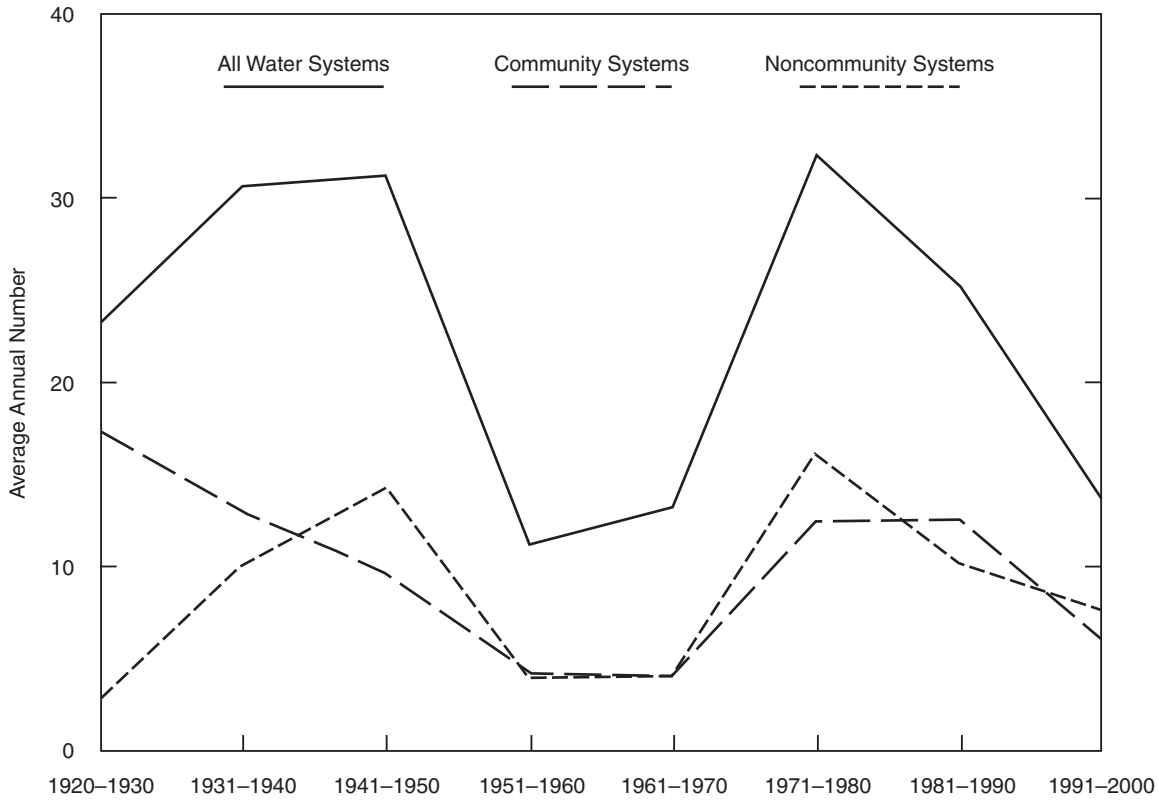


Figure 1-1 Waterborne disease outbreaks in the United States, 1920 to 2000

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Table 1-1 Illnesses and deaths associated with drinking water outbreaks in the United States, 1920 to 2000

Time Period	Number of Outbreaks	Cases of Illness	Illnesses per Outbreak*	Deaths
1920–1930	255	102,024	400	669
1931–1940	275	93,306	339	320
1941–1950	313	53,935	172	61
1951–1960	111	12,491	112	10
1961–1970	131	46,399	354	20
1971–1980	324	78,155	241	6
1981–1990	254	63,549	250	6
1991–2000	173	432,733	2,501	60
Totals	1,836	882,592	481	1,152

* Cases of illness are divided by number of outbreaks to calculate illnesses per outbreak.

Table 1-2 Drinking water outbreaks and illness by type of water system in the United States, 1920 to 2000

	Community Systems		Noncommunity Systems	
Time Period	Outbreaks per Year	Illnesses per Outbreak	Outbreaks per Year	Illnesses per Outbreak
1920–1930	17.2	513	2.6	138
1931–1940	12.8	748	8.1	60
1941–1950	9.6	467	14.2	57
1951–1960	4.1	247	3.9	51
1961–1970	3.9	1,023	3.9	111
1971–1980	12.3	483	16.1	113
1981–1990	12.4	289	10.1	268
1991–2000	6.1	6,929	7.7	123

parks, hotels, and service stations that have their own water supplies available for use by employees and the public. Individual water systems are used by residents in areas without community systems. After 1931, a similar reporting trend was observed for outbreaks in both noncommunity and community water systems. An annual average of six outbreaks was reported in community water systems from 1991 to 2000, one-third the number reported from 1920 to 1930. In noncommunity systems, an annual average of eight outbreaks was reported from 1991 to 2000, almost three times the number reported from 1920 to 1930.

Waterborne outbreaks have caused, on average, 481 cases of illness per outbreak. Case numbers vary considerably, however, depending on the type of water system and time period (Tables 1-1 and 1-2). Outbreaks in community systems usually cause more illness than outbreaks in noncommunity systems. During each decade, cases of illness per outbreak ranged from 247 to 6,929 (median = 498) in community water systems and 51 to 268 cases of illness per outbreak (median = 112) in noncommunity systems.

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The largest reported waterborne outbreak occurred in the spring of 1993 when contamination of the Milwaukee, Wis., drinking water system with *Cryptosporidium parvum* caused an estimated 403,000 cases of watery diarrhea (MacKenzie et al. 1994; Kaminski 1994). Because of this single outbreak, the average number of illnesses in community water systems during 1991 to 2000 was 6,929 cases per outbreak, more than six times the highest previously reported number of illnesses (Table 1-2). During 1961 to 1970, when two large outbreaks of 16,000 cases each were reported in community systems, an average of 1,023 cases of illness occurred. Excluding the Milwaukee outbreak, 29,733 cases of illness or 173 cases per outbreak occurred in community systems from 1991 to 2000, an illness rate comparable to that observed during 1981 to 1990.

Most deaths associated with waterborne outbreaks occurred before 1940 and were caused by typhoid fever (Craun 1986). Cases reported since 1971 included immunocompromised persons affected during the cryptosporidiosis outbreaks in Milwaukee and in Clark County (including Las Vegas), Nev., in 1993 and 1994. Among the 403,000 cases of illness in the Milwaukee outbreak, an estimated 50 deaths occurred. This estimate is based on a survey of death certificates during the 2-year period before the outbreak and the 2 years inclusive of and following the outbreak. There were 50 more cryptosporidiosis-associated deaths than would have been expected; 46 (85 percent) of these deaths were among persons who had acquired immunodeficiency syndrome (AIDS) as the underlying cause of death (Blair 1994; Hoxie et al. 1996).

In Clark County, most of the reported cases were among immunocompromised persons. Of the 78 persons with laboratory-confirmed *Cryptosporidium* infection during the outbreak, 61 cases were adult human immunodeficiency virus (HIV)-infected adults and 2 cases were HIV-infected children. Goldstein et al. (1996) reported that 32 of the 61 HIV-infected adults had died within 2 months following the outbreak period and at least 20 of the 32 had cryptosporidiosis as a cause of death on their death certificates. Forty of the HIV-infected adults died within the 12 months following the outbreak. However, the 1-year mortality rate for HIV-infected persons in the county was not increased (Kramer et al. 1996). The Clark County deaths are not included in the waterborne outbreak statistics.

Bacterial pathogens caused 15 of the remaining 22 deaths reported since 1971. Seven deaths resulted from community outbreaks of diarrheal illness caused by contamination of water storage tanks with *Salmonella typhimurium*; contamination of water mains with enterohemorrhagic *Escherichia coli* 0157:H7 was responsible for four deaths. Two deaths occurred during an outbreak of mixed etiology (*E. coli* 0157:H7 and *Campylobacter jejuni*) attributed to untreated, contaminated well water at a fair.

Two elderly residents of a nursing home died during an outbreak of shigellosis. One death occurred during an outbreak of undetermined etiology. Six deaths were caused by chemicals. Two persons died after consuming arsenic-contaminated well water, and single deaths were caused by accidental fluoride contamination of a community water system (two outbreaks), ethylene glycol contamination of drinking water used for hemodialysis, and high nitrate in a farm well.

A better perspective of the effects of waterborne disease outbreaks is obtained when the disease burden of the outbreaks and cases is considered. One simple measure of the burden that links the number of cases with their severity is person-days of illness (calculated by multiplying duration of illness by the number of cases). During 1971–2000, information about the median duration of illness data was available for slightly more than 42 percent of the outbreaks of identified or suspected infectious etiology. The reported information was used to estimate duration of illness for those outbreaks in which this measure was not reported, and person-days of illness was calculated by multiplying duration of illness by the number of cases for all infectious disease outbreaks. The estimated burden of enteric illness associated with outbreaks during 1971–2000 was 4,669,480 person-days of illness. The majority of this burden was due to protozoan outbreaks (90 percent), especially the Milwaukee

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outbreak. The remaining burden was due to unidentified agents (6 percent), bacterial agents (2 percent), and viral agents (2 percent). The burden as measured by person-days of illness varied from year to year as did the number of reported outbreaks and cases. The burden (person-days ill per year) during the most recent 5 years (mean = 3,478; median = 2,716; lowest = 1,477) was much less than the burden during 1991 to 1995 (mean = 743,567; median = 3,635,960; lowest = 7,102) or 1971–1975 (mean = 16,035; median = 14,854; lowest = 645).

OUTBREAK REPORTING

These statistics do not reflect the actual incidence of waterborne outbreaks or disease. Rather, the observed trends largely reflect surveillance activities of local and state health agencies during various time periods. Many factors influence the degree to which outbreaks are recognized, investigated, and reported in any single year, including interest in the problem and the capabilities for recognition and investigation at the state and local level (Berkelman et al. 1994). The likelihood that individual cases of illness will be detected and epidemiologically associated with water is dependent on many factors including: (a) public awareness of waterborne illnesses, (b) local requirements for reporting cases of particular diseases, (c) the surveillance and investigative activities of state and local public health and environmental agencies, and (d) availability of and extent of laboratory facilities. The recognition of outbreaks largely depends on the effectiveness of surveillance systems, and increased reporting often occurs as the causes and etiologies of waterborne outbreak become better recognized and state surveillance activities and laboratory capabilities increase (Foster 1990; Frost et al. 1995, 1996, 2003). Waterborne disease surveillance is enhanced by educational outreach programs targeting district public health offices, physicians, and the public. Monitoring programs also benefit from designating one individual to be responsible for disease reporting and outbreak investigations; all water-related complaints and health department inquiries are directed to this person. For example, during a 4-year period of intensive waterborne disease surveillance in Colorado from 1980 to 1983, 18 waterborne outbreaks were reported compared to only 6 during the previous 3-year period, when a passive surveillance program was in effect (Hopkins et al. 1985).

While it is generally agreed that reporting of waterborne outbreaks is incomplete, the extent of underreporting is difficult to estimate. Rough estimates suggest that only one half to one third, and even as few as 10 percent, of all waterborne outbreaks are detected, investigated, and reported (Craun 1986; Craun et al. 1992).

Outbreaks in community water systems are more likely to be recognized than noncommunity or individual water systems. Outbreaks affecting small populations are less likely to be recognized than those affecting large populations. Outbreaks characterized by more severe symptoms (bloody or profuse, watery diarrhea; vomiting; fever) are more likely to be recognized than those outbreaks with less-severe symptoms (mild diarrhea or general flu-like symptoms) because persons are more likely to seek medical attention. Outbreaks caused by protozoa and certain bacteria are more likely recognized than viral outbreaks because laboratory analyses are more widely available for clinical specimens.

Not all outbreaks are rigorously investigated. The resources available for an outbreak investigation differ from locality to locality, and the investigation of possible waterborne outbreaks depends on the availability of resources and trained personnel. Improved outbreak investigations can increase our knowledge about important etiologic agents, water system deficiencies, and sources of contamination (Craun et al. 2001).

Several investigators have attempted to estimate the extent to which epidemic waterborne disease is underreported. Hauschild and Bryan (1980) estimated that 1.4 million to 3.4 million cases of both foodborne and waterborne diseases occurred each year in 1974 and 1975. Carlsten (1993) estimated that 350,000 to 875,000 cases of epidemic waterborne disease may occur each year. Considering both epidemic and

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endemic waterborne diseases, Morris and Levin (1994) estimated 1.8 million cases and 1,800 deaths annually. Bennett et al. (1987) estimated the annual incidence of waterborne disease to be more than 900,000 cases, accounting for almost 900 deaths. Many believe that Morris and Levin and Bennett et al. have given extreme estimates. Epidemiological studies are currently being conducted by the USEPA and CDC to assess the magnitude of endemic waterborne risks in the United States.

CAUSES OF OUTBREAKS

Contaminated groundwater has caused more waterborne outbreaks than contaminated surface water. In each decade since 1920, contaminated, inadequately treated groundwater caused 44 to 56 percent of all reported outbreaks (Figure 1-2), whereas, inadequately treated surface water has caused 7 to 35 percent of all outbreaks (Figures 1-3 and 1-4). During 1991 to 2000, 46 percent of all outbreaks were attributed to contaminated, inadequately treated groundwater; only 7 percent were attributed to inadequately treated surface water.

Since 1971, the incidence of untreated surface water and groundwater as a cause of outbreaks has declined. Contaminated, untreated groundwater was responsible for 28 to 32 percent of all outbreaks during 1971 to 2000. In previous decades, almost half of all outbreaks were reported in untreated groundwater systems (Figure 1-2). Inadequate or interrupted disinfection of groundwater, however, has increasingly caused outbreaks. During the past quarter-century, 18 to 20 percent of all outbreaks were reported in disinfected groundwater systems. In previous decades, only 2 to 6 percent of all outbreaks occurred in these systems. The observed trends in outbreaks occurring in groundwater systems may be due to an increased emphasis on disinfecting groundwater sources with little or no effort to reduce sources of contamination. Also important may be a lack of effective, continuous disinfection, caused perhaps by a perception among some operators that groundwater needs no disinfection. Although most outbreaks in disinfected groundwater systems since 1971 were the result of inadequate chlorination, several occurred in systems using iodine and ultraviolet (UV) light for disinfection. To reduce waterborne disease risks in groundwater systems, USEPA has proposed the Ground Water Rule (USEPA 2000; 65 FR 91:30194–274) that will specifically state when corrective action including disinfection is required to protect consumers from bacteria and viruses. Other proposed requirements include periodic sanitary surveys to identify deficiencies, hydrogeologic sensitivity assessments for undisinfected systems, source water microbial monitoring for certain systems, and compliance monitoring for systems that disinfect to ensure adequate inactivation or removal of viruses.

From 1920 to 1930, almost 20 percent of all outbreaks were reported in untreated surface water systems (Figure 1-3). Surface water is now rarely used without treatment, and only 8 percent and 4 percent of all outbreaks were reported in untreated surface water systems from 1971 to 1980 and 1981 to 1990, respectively. Only two such outbreaks were reported from 1991 to 2000. Outbreaks in unfiltered, disinfected surface water systems have also decreased, causing only 4 percent of all outbreaks in 1991 to 2000 (Figure 1-3). During the previous two decades, 13 percent and 15 percent of all outbreaks were reported in unfiltered, disinfected surface water systems. This decrease in reported outbreaks in unfiltered surface water systems is likely due to the provisions of the Surface Water Treatment Rule (SWTR) promulgated by USEPA on June 19, 1989 (54 FR 124:27486–541). The SWTR is intended to protect against exposure to *Giardia intestinalis*, viruses, and *Legionella*, as well as selected other pathogens for public systems that use surface water or groundwater under the direct influence of surface water. The SWTR specifies disinfection criteria for community and noncommunity water systems and requires filtration for all but exceptionally high-quality surface water sources. The Interim Enhanced SWTR (USEPA 1998; 63 FR 241:69477–521), Long Term 1 Enhanced SWTR (USEPA 2002; 67 FR 9:1812–44), and Long Term 2 Enhanced SWTR (USEPA 2003; 68 FR 154:47639–795) provide additional

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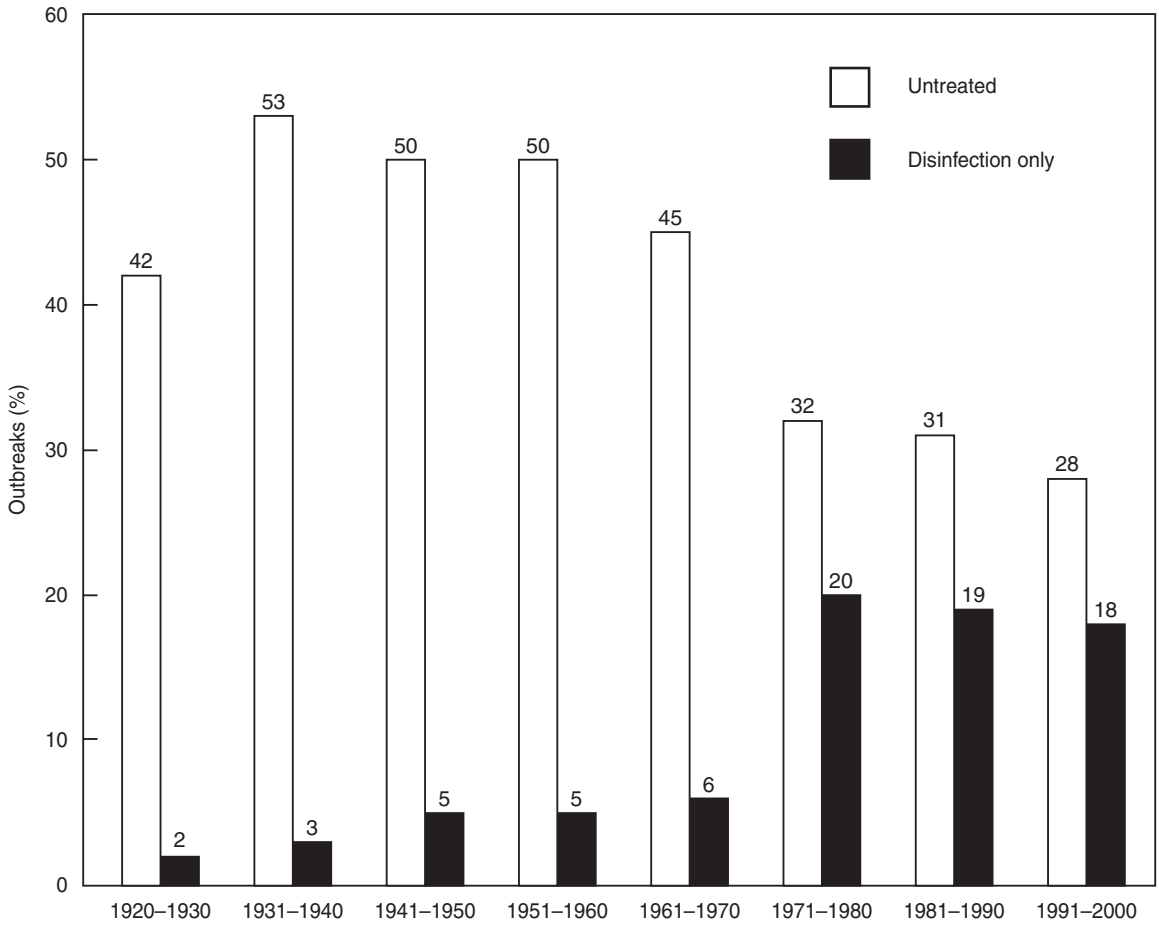


Figure 1-2 Waterborne disease outbreaks in groundwater systems in the United States, 1920 to 2000

protection against *Cryptosporidium* and other waterborne pathogens. Key provisions of the Long Term 2 Enhanced SWTR include source water monitoring for *Cryptosporidium* and additional treatment for filtered systems based on source water concentrations; inactivation of *Cryptosporidium* by all unfiltered systems; disinfection profiling and benchmarking to ensure continued levels of microbial protection while systems take steps to comply with new disinfection by-product (DBP) limits; and covering, treating, or implementing a risk management plan for uncovered finished water storage facilities.

Outbreaks in filtered surface water systems increased from 1981 to 1990, when 7 percent of all reported outbreaks occurred in these systems. This percentage is about the same for outbreaks reported in filtered systems during 1920 to 1930 (Figure 1-4). Inadequate filtration or pretreatment, or both, was responsible for only 3 percent of all outbreaks reported during 1991 to 2000 and only 1 to 3 percent from 1931 to 1980. Whether or not outbreaks in filtered water systems will remain at these low levels depends largely on the success of current efforts to protect source water quality; optimize filtration facilities to remove particles, turbidity, and pathogens; and provide consistent operation of water treatment plants with effective performance monitoring. Programs that identify weaknesses and optimize water treatment have greatly improved performance of surface water treatment plants (Consonery et al. 1997). The

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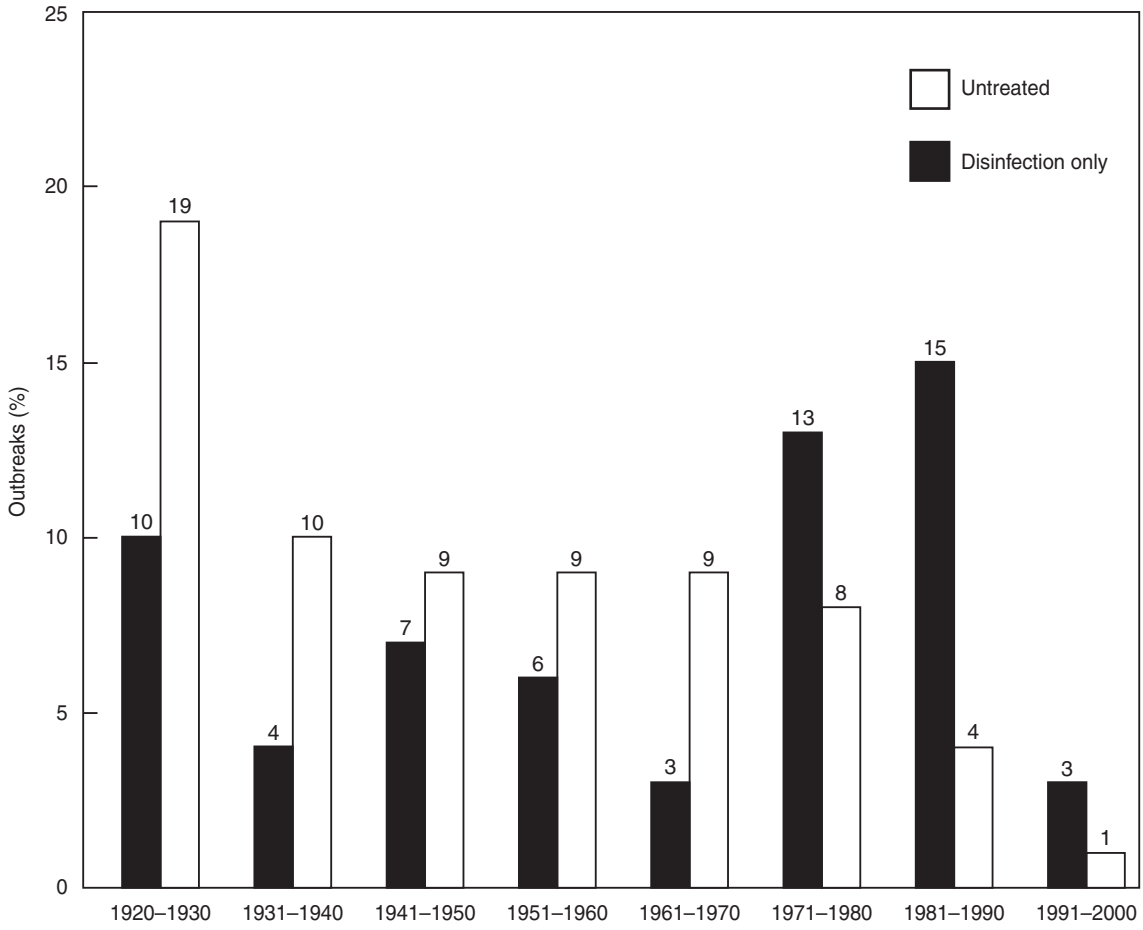


Figure 1-3 Waterborne disease outbreaks in unfiltered surface water systems in the United States, 1920 to 2000

USEPA's surface water rules also include monitoring and compliance regulations to ensure adequate filtration and disinfection. An additional regulation, the Filter Backwash Recycling Rule (USEPA 2001; 66 FR 111:31086–105), requires public systems that utilize direct or conventional filtration and recycle spent filter backwash or other water to return the recycle flows to the water treatment process so that microbial contaminant removal is not compromised.

In addition to protecting water sources and providing adequate treatment, protecting and maintaining the quality of water during distribution and storage is an important priority. Contamination of water in the distribution system from corrosion products, cross-connections and backsiphonage, inadequately protected storage facilities, and repairs to water mains and plumbing were responsible for 21 percent of the waterborne outbreaks reported from 1991 to 2000. From 1920 to 1990, contamination of distribution systems caused 11 to 18 percent of all outbreaks (Figure 1-5). Additional emphasis is needed on identifying and correcting sources of contamination in distribution systems to reduce the number of these outbreaks.

Miscellaneous deficiencies including unknown causes, ingestion of water not intended for drinking, and ingestion of water during recreational activities caused 20 percent of all outbreaks from 1991 to 2000 (Figure 1-6). In previous time periods, miscellaneous deficiencies were responsible for only 4 to 18 percent of outbreaks.

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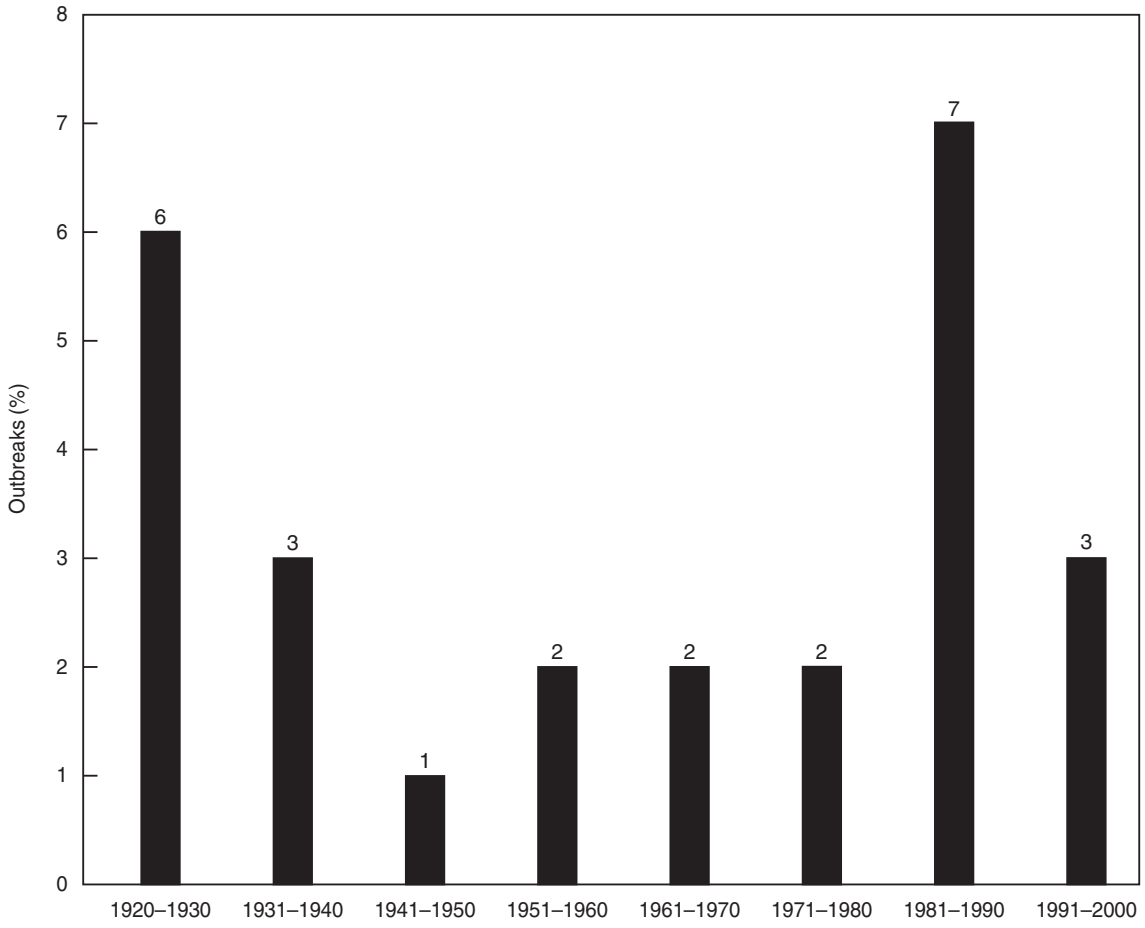


Figure 1-4 Waterborne disease outbreaks in filtered surface water systems in the United States, 1920 to 2000

MICROBIAL WATER QUALITY DURING OUTBREAKS

Of the 751 outbreaks associated with contaminated drinking water during 1971–2000, 665 (89 percent) were of known or suspected infectious etiology. Water samples were collected and examined for total and/or fecal coliforms or *E. coli* during the investigation of 459 (69 percent) of these outbreaks. Coliform bacteria were detected in 359 (78 percent) of these outbreaks. Coliform bacteria were reported less frequently during outbreak investigations in community systems (65 percent) than in noncommunity (84 percent) and individual systems (94 percent). Coliform bacteria were detected in most (91 percent) outbreaks of bacterial etiology; however, they were detected less frequently in outbreaks of viral or undetermined etiology (81–84 percent) and protozoan outbreaks (49 percent). Coliforms have several disadvantages as an indicator for the presence of waterborne viruses and protozoa even when these pathogens may be present in water systems. While most waterborne viruses are easily disinfected, some viruses or an aggregation of viruses may be more resistant than coliforms to water disinfectants. Protozoa are even more resistant to commonly used water disinfectants and can survive longer in water than coliform bacteria.

Water samples were examined for pathogens during the investigation of 122 (18 percent) infectious disease outbreaks during 1971–2000. The etiologic agent was

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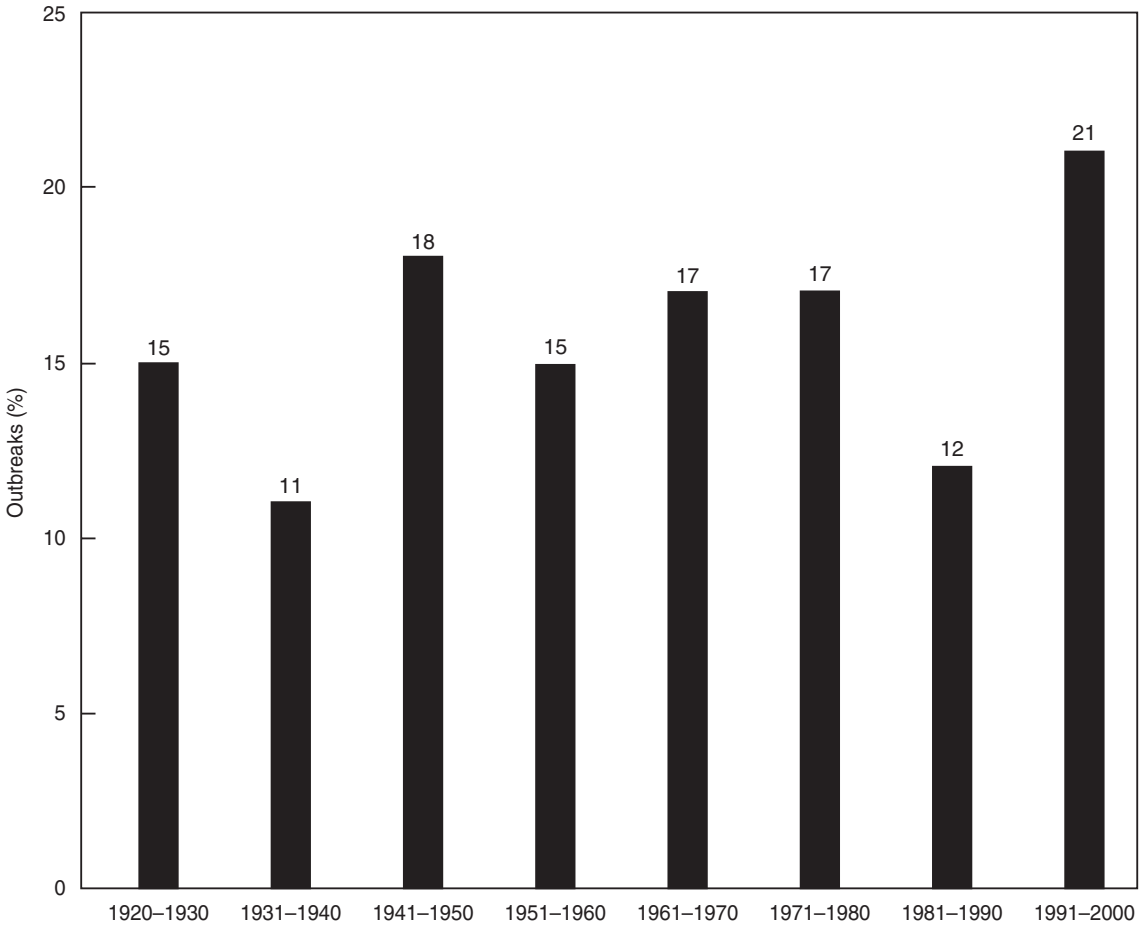


Figure 1-5 Waterborne disease outbreaks from distribution system deficiencies in the United States, 1920 to 2000

identified in water collected from 78 (64 percent) of these outbreaks. *Giardia* cysts or *Cryptosporidium* oocysts were identified in 49 protozoan outbreaks and bacterial pathogens were identified in 19 bacterial outbreaks. *Giardia* and *Cryptosporidium* were frequently detected in water samples when coliforms were not. Waterborne pathogens identified in 10 outbreaks of undetermined etiology included *Giardia*, enteroviruses, *Salmonella*, and toxigenic *E. coli*.

COLIFORM REGULATIONS AND OUTBREAKS

Presence of coliform bacteria may indicate the possibility of fecal contamination, a relationship used to assess the microbiological quality of drinking water. USEPA has established a maximum contaminant level (MCL) and routine monitoring requirements for total coliforms in public water systems. The absence of coliform bacteria in a water supply is usually interpreted as evidence of safe drinking water (i.e., water free of pathogens and having a low risk of waterborne infectious disease). However, waterborne outbreaks have occurred even when the MCL for total coliforms was not exceeded. The USEPA's revised Total Coliform Rule (TCR) requires all public water systems to monitor for total coliforms at a frequency that depends upon the system type (community or noncommunity) and number of persons served (USEPA 1989, 54 FR 124:27544–68; USEPA 1990, 55 FR 118:25064–5).

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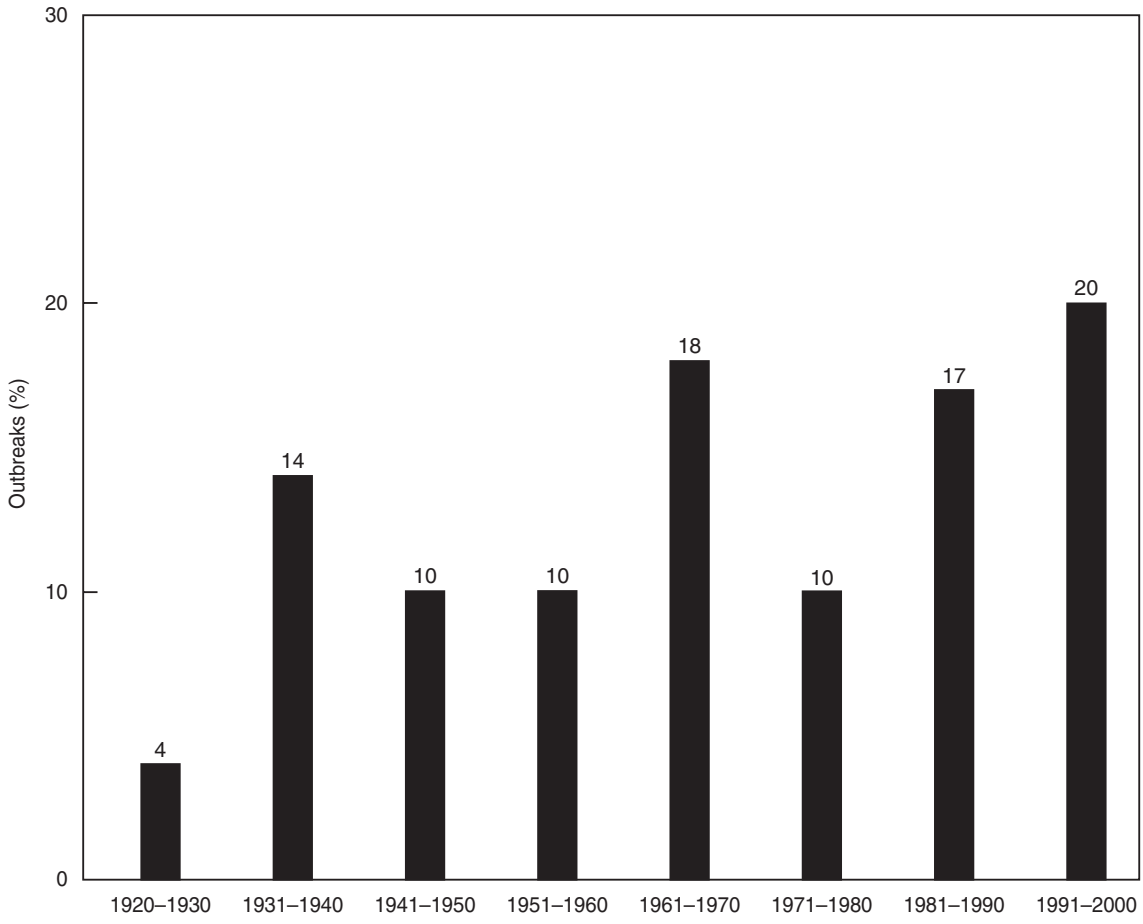


Figure 1-6 Waterborne disease outbreaks from miscellaneous and unknown deficiencies in the United States, 1920 to 2000

For systems that collect fewer than five samples per month, the TCR also requires a periodic sanitary survey. A review of coliform monitoring records during the period 1991–2000 found that the TCR is inadequate to identify public water systems that are vulnerable to an outbreak (Craun 2000; Nwachuku et al. 2002). Similar findings were reported in an earlier study (Craun et al. 1997) where MCL violations were based on the 1975 TCR. In these studies, TCR violations did not differ significantly for public water systems in which an outbreak had been reported and matched, and the comparison systems in which an outbreak had not been reported.

During 1991–2000, only 22 percent of community and 9 percent of noncommunity systems had violated the coliform MCL in the 12-month period before an outbreak, however, when coliform samples were collected during outbreak investigations for the same time period, coliforms were detected in 46 percent of community and 83 percent of noncommunity systems. This may be due to more intensive monitoring during the investigation, insufficient coliform monitoring requirements of the TCR, or both. During an outbreak investigation an intensive effort was often made to determine the water quality, and samples were frequently collected within a few weeks after a contamination event.

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ETIOLOGIC AGENTS

Waterborne pathogens in which humans are the sole reservoir of infection, such as *Vibrio cholerae*, *Salmonella typhi*, and hepatitis A, are no longer important causes of outbreaks in the United States (Craun 1990). During the late 1800s and at the turn of the 20th century, when water systems were not filtered or chlorinated, waterborne epidemics of cholera and typhoid fever were common in the United States. Filtration and chlorination of drinking water sources were largely responsible for the dramatic reduction of these diseases and decreased importance of water as a mode of transmission. From 1920 to 1960, typhoid fever continued to be transmitted by contaminated water, but no waterborne outbreaks of cholera were reported (Table 1-3). Since 1971, few waterborne outbreaks of typhoid fever have been reported. Hepatitis A virus caused 22 percent of all waterborne outbreaks from 1961 to 1970, but only 4 percent of outbreaks since 1971.

During 1991–2000, protozoa were the most frequently identified agents in outbreaks; 34 percent of the outbreaks where an agent was identified were either giardiasis (63 percent) or cryptosporidiosis (37 percent). Protozoan outbreaks were responsible for almost 95 percent of all cases of illness reported during this decade. This was primarily due to the outbreak in Milwaukee. In contrast, even though 30 percent of outbreaks in which an agent was identified were bacterial and 27 percent were chemical, these outbreaks contributed to few illnesses. In waterborne outbreaks of bacterial and chemical etiology, 2,981 illnesses and 538 chemical poisonings were reported. The most frequently reported bacterial agents since 1991 include toxigenic *E. coli* (32 percent), *Shigella* (29 percent), and *Campylobacter* (19 percent). The remaining bacterial outbreaks were nontyphoid *Salmonella*, *V. cholerae*, *Pleisomonas shigelloides,* and one outbreak of mixed etiology *E. coli* 0157:H7 and *C. jejuni*. Only 9 percent of the outbreaks reported during 1991 to 2000 were caused by viral agents. Viral outbreaks also contributed little (2,674 cases) to the total case burden during the decade. Most viral outbreaks were caused by norovirus (67 percent); hepatitis A virus caused 22 percent of the viral outbreaks.

Since 1991, *Cryptosporidium*, toxigenic *E. coli*, and *Campylobacter* have become increasingly important as causes of waterborne outbreaks in the United States. During 1991–2000, each of these agents caused from 4 to 8 percent of the reported outbreaks whereas, during 1971–1990, each agent caused less than 1 percent of the reported outbreaks. *Giardiasis* outbreaks decreased dramatically. During 1981–1990, 27 percent of reported outbreaks were caused by *Giardia*; during 1991–2000, only 13 percent of the reported outbreaks were caused by *Giardia*. Hepatitis A outbreaks decreased from 4 to 5 percent of reported outbreaks during 1971–1980 to only 1 percent during 1991–2000. Shigellosis outbreaks also decreased but not as dramatically—from 7 to 5 percent during the same time period. During each decade of the 30-year period, the percentage of norovirus outbreaks remained the same, causing slightly more than 3 percent of all reported outbreaks.

A significant number of drinking water outbreaks were caused by zoonotic agents, *Giardia*, *Campylobacter*, *Cryptosporidium*, nontyphoid *Salmonella*, toxigenic *E. coli*, or *Yersinia*. Zoonotic agents caused 56 percent of the community system outbreaks where an etiology was identified and 41 percent of the noncommunity system outbreaks where an etiology was identified. Outbreaks of zoonotic bacteria were primarily associated with untreated groundwater, inadequately disinfected groundwater, and distribution system contamination through cross-connections, backsiphonage, main breaks, main repairs, inadequately protected storage tanks, or uncovered reservoirs. Few of these outbreaks were associated with inadequately treated surface water. Although inadequate or interrupted treatment of surface water was the most important water system deficiency identified for outbreaks of giardiasis and cryptosporidiosis, the contamination of groundwater and distribution systems was also important. Norovirus and

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Table 1-3 Causes of drinking water outbreaks in the United States, 1920 to 2000

Time Period	Disease	Number of Outbreaks	Cases of Illness
1920–1940	Typhoid fever	372	87,675
	Acute gastroenteritis (AGI), unidentified	144	102,814
	Shigellosis	10	3,308
	Amebiasis	2	1,413
	Hepatitis A	1	28
	Chemical poisoning	1	92
1941–1960	AGI, unidentified	265	54,467
	Typhoid fever	94	1,917
	Shigellosis	25	8,951
	Hepatitis A	23	930
	Salmonellosis	5	38
	Chemical poisoning	4	44
	Paratyphoid fever	2	12
	Amebiasis	2	6
	Tularemia	2	36
	Leptospirosis	1	9
	Poliomyelitis	1	16
1961–1970	AGI, unidentified	39	26,556
	Hepatitis A	29	896
	Shigellosis	21	1,735
	Typhoid fever	15	108
	Salmonellosis	7	16,651
	Chemical poisoning	9	45
	AGI, toxigenic *E. coli*	4	188
	Giardiasis	3	176
	Amebiasis	3	39
	Paratyphoid fever	1	5
1971–2000	AGI, unidentified	363	83,397
	Giardiasis	126	28,427
	Chemical poisoning	86	4,477
	Shigellosis	44	9,196
	Hepatitis A	28	827
	AGI, norovirus	27	13,100
	Campylobacteriosis	19	5,604
	Cryptosporidiosis	15	421,473
	Salmonellosis	15	3,203
	AGI, *E. coli* 0157:H7	11	529
	Typhoid fever	5	282
	Yersiniosis	2	102
	Chronic gastroenteritis	2	94
	Cholera	2	28
	AGI, rotavirus	1	1,761
	AGI, *E. coli* 0157:H7 & campylobacterosis	1	781
	AGI, *E. coli* 06:H16	1	1,000
	AGI, *Plesiomonas shigelloides*	1	60
	AGI, *Cyclospora*	1	21
	Amebiasis	1	4

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hepatitis A virus are not considered zoonotic, but it is important to recognize that viruses are diverse and complex and have the ability to infect different hosts by genetic changes and expression of different phenotypic properties (Craun et al. 2003).

Important disease-causing agents in the United States now include protozoa and bacteria, with wild and domestic animals and humans serving as reservoirs of infection. Prevention of waterborne transmission of these pathogens requires protection of water sources not only from contamination by human sewage but also from fecal contamination by animals. It is important to reduce concentrations of waterborne pathogens in source waters so that the water treatment that is provided will remove sufficient numbers of waterborne pathogens to prevent infectious dose levels.

The infectious dose for *Giardia* and *Cryptosporidium* is relatively low (Rendtorff 1954; DuPont et al. 1995), and high concentrations of water disinfectants and long contact times are required to inactivate *Giardia* and *Cryptosporidium* (Sterling 1990). Although properly designed and operated granular filters with appropriate pretreatment can effectively reduce the number of cysts and oocysts, granular filters do not provide 100 percent removal. If a water source is heavily contaminated with these parasites, granular filtration may not be able to sufficiently reduce cysts and oocysts below infective dose levels.

Current water filtration and disinfection practices and USEPA regulations have reduced the risk of *Cryptosporidium* outbreaks in surface water systems. However, the role of protective immunity may be important to consider when assessing waterborne cryptosporidiosis risks and future control strategies (Craun et al. 1998; Frost et al. 1997, 1998, 2000). Recent serological-epidemiological evidence suggests that some conventionally-filtered surface water may be a source of low-level exposure and infection (Frost et al. 2002). Serological studies found elevated levels of *Cryptosporidium* infection without an apparent increase in illness in populations where filtered surface water systems meet current water quality standards and regulations. Populations using groundwater sources had lower *Cryptosporidium* infection levels, but when waterborne outbreaks occurred in groundwater systems, these populations had a high incidence of clinically detected cryptosporidiosis.

WATERBORNE PATHOGENS OF EMERGING CONCERN

Better laboratory methods and quicker, more thorough investigation of outbreaks have helped to identify pathogens responsible for waterborne outbreaks (Table 1-3). Outbreaks in which an etiology was not identified declined; 55 percent of all reported outbreaks during 1971 to 1980 were of undetermined etiology but only 46 percent were during 1981 to 1990. However, an etiologic agent was still not identified in 40 percent of all reported waterborne outbreaks during 1991 to 2000. These outbreaks, classified as acute gastroenteritis (AGI) of undetermined causes, may be caused by familiar waterborne pathogens that are not identified because investigations were conducted too late to collect clinical specimens or laboratory analysis was inadequate. Outbreaks have also occurred in which an etiologic agent could not be identified, even after extensive laboratory analysis. Newly recognized waterborne pathogens in recent years include *Cryptosporidium*, *Giardia*, norovirus, rotavirus, *Yersinia*, *Campylobacter*, and *E. coli* 0157:H7. Also recently identified is a waterborne protozoan pathogen similar to *Cryptosporidium* in some morphologic features and is now named *Cyclospora cayetanensis* (Ortega et al. 1993). *Cyclospora* has been identified worldwide in stool specimens from patients with diarrhea and in chlorinated drinking water during an outbreak in Nepal (Rabold et al. 1994). *Cyclospora* may be the organism responsible for a waterborne outbreak in a Chicago hospital in 1990 (Herwaldt et al. 1992).

Other unidentified and suspected pathogens may also be important causes of waterborne illness in the United States. For example, no causative agent has yet been identified for a distinctive chronic diarrheal illness characterized by dramatic, urgent,

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watery diarrhea persisting for many months. The first waterborne outbreak of chronic diarrhea was reported in 1987; untreated well water in an Illinois restaurant was implicated as the vehicle of transmission (Parsonnet et al. 1989). Nonbloody diarrhea with a median frequency of 12 stools per day persisted in 87 percent of patients after 6 months. Waterborne transmission is suspected for the atypical mycobacteria (Singh and Yu 1994). Another group of human opportunistic pathogens that might potentially be transmitted by water is the microsporidia (Curry and Canning 1993). A number of other potentially important waterborne pathogens include *Aeromonas* spp., *Helicobacter pylori*, *Toxoplasma*, hepatitis E virus (HEV), enteric adenoviruses, astroviruses, and caliciviruses, which include both the classic calicivirus and small, round, structured viruses, such as norovirus (Benenson et al. 1983; Benenson 1995). Norovirus is an important cause of waterborne outbreaks, and several other pathogens of emerging concern have been associated with the waterborne transmission of disease in other countries. Better assessment of their potential for causing waterborne disease in the United States requires additional information about their occurrence in water sources, their infective doses, and the effectiveness of water treatment processes to remove and inactivate them. Water suppliers should develop their understanding of these waterborne pathogens as more information becomes available in order to assess the vulnerability of their water systems.

SUMMARY

Waterborne disease has largely been controlled in the United States, but outbreaks continue to occur. From 1991 to 2000, 173 waterborne outbreaks and 432,733 cases of illness were reported in public and individual water systems. As evidenced by the cryptosporidiosis outbreak in Milwaukee, large populations can be affected by outbreaks, resulting in a large burden of disease. Although the number of outbreaks and severity of disease associated with drinking water outbreaks in the United States has decreased in recent years, we should not forget that outbreaks of mild or moderate illness, especially if the outbreaks are large, can result in significant economic and personal consequences. Even relatively small outbreaks may be important; depending on the etiologic agent, small outbreaks have been associated with increased mortality. The incidence of waterborne disease in the United States is underreported, and even reported outbreaks may not lead to complete epidemiological investigations or documentation of the full extent of the outbreaks. In addition, endemic waterborne disease risks may be important. Sporadic cases are usually never recognized as outbreaks, and specific epidemiological studies must be conducted to estimate these risks of endemic waterborne disease.

The residual number of waterborne outbreaks that still occur in the United States are preventable, and greater attention should be given to the protection of source water quality for groundwater and surface water; better monitoring of the effectiveness of water treatment; and increased protection of treated water as it is delivered to the tap.

Waterborne disease outbreaks are caused by zoonotic and nonzoonotic pathogens, and each may require different methods of prevention. For example, typhoid fever and cholera were waterborne diseases in the United States at the turn of the century. Chlorination and protection of water sources from sewage contamination were effective in preventing transmission of these diseases by water, because the pathogens are transmitted exclusively among humans, require large infective doses, and are susceptible to disinfection. *Cryptosporidium* and *Giardia* demand much greater emphasis on water treatment processes, but reliance on water treatment alone may not be effective. Wild and domestic animals are sources of the protozoa, and management practices may be needed to limit sources of contamination. With highly contaminated water sources, infective dose levels may be found in tap water even

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after filtration. Surface water sources treated only by disinfection may require filtration, and filtration facilities must be properly designed and operated. Outbreaks of cryptosporidiosis and giardiasis have occurred in groundwater systems with sources subject to contamination by surface water or sewage. Chapter 2 of this manual discusses proper source water protection and treatment. Chapter 3 discusses proper monitoring of source and treated water.

Waterborne outbreaks and endemic waterborne disease can be reduced in the United States by effective water treatment, protection of water sources, and increased surveillance programs that include periodic sanitary surveys. Better surveillance to detect possible waterborne outbreaks, more complete investigations of sources of contamination, and improved laboratory capabilities are needed to provide additional information about waterborne agents and reduction of waterborne risks. Epidemiological studies can help assess endemic waterborne disease risks and the effectiveness of water system control measures and regulations.

It is sometimes presumed that coliform-free tap water is unlikely to cause waterborne disease. However, waterborne disease outbreak data suggest this premise is not always correct. Improvements are needed for regulations intended to assess the vulnerability of a water system to an infectious disease outbreak. Additional indicators should be considered, monitoring of source water contamination and water treatment effectiveness should supplement water distribution system monitoring, and the monitoring frequency may need to be increased. The selection of appropriate indicators of fecal contamination and waterborne pathogens should be based on their survivability in water, susceptibility to water disinfectants, and capability to detect increased health risks. Multiple indicators may be needed. *Enterococci*, somatic and male-specific coliphages, and spores of *Clostridium perfringens* have been suggested as possible indicators that should be monitored in addition to coliform bacteria. While water quality monitoring can provide valuable information about contamination events, frequent engineering evaluations such as sanitary surveys are also needed to identify sources of contamination and warn of potential water system deficiencies. Most importantly, water system managers must take steps to correct water system deficiencies when they are identified.

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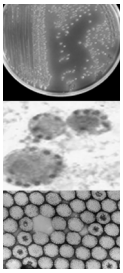
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Chapter 2

Water Quality in Source Water, Treatment, and Distribution Systems

Kim R. Fox and Donald J. Reasoner; Security by Kevin R. Gertig

Most drinking water utilities practice the multiple-barrier concept as the guiding principle for providing safe water. This chapter discusses multiple barriers as they relate to the basic criteria for selecting and protecting source waters, including known and potential sources of contamination, water treatment and disinfection processes, security, and educating providers and customers to ensure the highest quality drinking water.

MULTIPLE-BARRIER CONCEPT

The premise behind the multiple-barrier concept is that use of several barriers in a drinking water system is effective in preventing pathogens or other contaminants from reaching the consumer. If one barrier fails, the remaining barriers minimize pathogen presence in the treated water. Although the exact barriers for any single location may differ, essential barriers include

- source water protection
- water treatment plant processes
- disinfection practices
- distribution systems
- security
- education

Source water protection means providing the highest quality source water possible before treatment by controlling use on the watershed, minimizing sewage contamination, protecting the wellhead, and using other strategies that reduce and prevent source water contamination. Finding and developing higher quality source waters also may be necessary or economical.

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The water treatment plant barrier encompasses all water treatment processes, including (but not limited to) slow sand filters, enhanced coagulation processes, and membrane systems. The treatment plant must be both designed and operated correctly to maintain a contaminant barrier.

Disinfection processes are normally the final barrier to microorganisms. The disinfection barrier consists of a disinfectant residual throughout the distribution system that limits regrowth of microorganisms and possibly prevents subsequent contamination due to causes like cross-connections.

The distribution system—transmission mains and storage—must be properly maintained to ensure that water quality is not degraded.

Security procedures (such as secured gate access for employees only), physical barriers/items (including fences, cameras, alarms, etc.), and monitoring (on-line/real-time, etc.) protect the water from threats, malevolent acts (causing infrastructure damage), and intentional degradation of water quality, while providing a means to detect and respond to any such incidents.

Lastly, education of water utility personnel and management, public officials, and water consumers is crucial to maintaining safe drinking water.

SOURCE WATER QUALITY

The quality of surface water and groundwater sources used for drinking water supply varies broadly in the United States, ranging from nearly pristine in some areas to extremely poor in others. Ideally, source water should be free of microbial contamination from human and animal activities, free of toxic natural and synthetic chemical contaminants, and of adequate quantity to meet the needs of the population served. Because of increasing population, pollution from domestic and industrial activities, and, in many cases, lack of alternate water supply sources, many communities must use inferior quality source waters for their water supplies. The poorer the source water quality, the greater the need to provide multiple-step treatment to remove microbial and chemical contaminants.

Source water microbial quality may change drastically in a short time period (perhaps just minutes when related to precipitation events) and vary from day to day because of a variety of activities on the watershed. Natural storm events over the watershed create transient changes in water quality by contributing large amounts of both suspended and dissolved materials to the water. Other relatively constant sources of surface water pollutants include agricultural activities, wastewater treatment plants, septic system drainage, and a variety of industrial and manufacturing operations.

Groundwater Protection

Source water protection minimizes the amount of contamination introduced into water before treatment. A groundwater protection program covers three basic areas:

- protecting the aquifer
- locating wells away from potential sources of pollution
- proper well construction

To protect the aquifer, the extent and type of activities in the recharge zone of that aquifer must be controlled based on aquifer characteristics. A confined aquifer may have a protective barrier between surface contamination and the water. On the other hand, an unconfined aquifer may have porous top layers, and contaminated water in the recharge zone surface may percolate quickly into the aquifer. Specific measures to protect a recharge zone include owning and controlling the area or passing zoning ordinances and regulations that prohibit certain land uses within the

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recharge area. A formal sanitary inspection can determine how much of a recharge protection program or wellhead protection program is needed.

Wellhead protection prevents surface contamination from entering the well. Installing a well an adequate distance from sources of pollution is a simple means of wellhead protection. Other protective measures include proper design and construction of the well and the wellhead. Decisions must be made before construction concerning the depth of the well, depth of the well casing, depth of the grouting, well pit design, and other factors. Proper design and construction methods are specific to locations and vary with local and state regulations.

Surface Water Protection

When streams, rivers, open ponds, lakes, or open reservoirs must be used as sources of water supply, the danger of contamination is greatly increased. The physical, chemical, and bacteriological contamination of surface water make it necessary to provide greater measures of protection or increased treatment. The three main factors for protecting surface water include

- watershed control
- removing sources of pollution
- properly constructing catchment basins, intakes, and storage facilities

Protecting a surface water source begins with a watershed control program that analyzes watershed hydrology and land ownership, identifies watershed characteristics and activities that could endanger source water quality, and monitors industrial, residential, agricultural, or recreational activities that may adversely impact source water quality. Ownership of the watershed and restricting access is the most stringent control a water utility can have to protect source water quality. When considering operating expenses and capital costs to purchasing costs, it may prove less expensive in the long run to purchase watershed lands. However, control by ownership is less likely as the area of watershed increases. Another way to protect watersheds is to use and enforce zoning restrictions and ordinances. Problems with multiple jurisdictions occur when source watersheds cross political boundaries.

As with groundwater systems, a thorough, periodic sanitary survey to identify specific and potential sources of pollution is necessary to maintain surface source water quality. Ideally, sources of contamination should be identified and corrected before problems occur, but sources can be intermittent and not appear in a cursory sanitary survey. During or after a waterborne disease outbreak, identifying potential sources of the pathogen responsible for the outbreak may prevent future problems or may suggest ways to remove the contaminating source from the watershed or aquifer area. Source waters (both ground and surface) can become contaminated by pathogenic microorganisms from sewage or other waste discharges, septic tank overflows or seepage, urban or agricultural runoff, subsurface movement, recreational usage, or during storage or distribution.

Microbiological Characteristics of Source Water

Source water for a drinking water supply should be the best quality available. The Surface Water Treatment Rule (SWTR) (USEPA 1989c) provides source water quality criteria for water systems wishing to avoid filtration. For such systems, total coliform concentration should be less than 100 per 100 mL, or the fecal coliform concentration less than 20 per 100 mL in 90 percent of samples taken during the previous 6 months. In addition, water turbidity cannot exceed 5 on an ongoing basis, based on grab samples taken every 4 hours (or more frequently) that the system is in operation.

The system must also demonstrate that it maintains disinfection conditions that inactivate 99.9 percent of *Giardia* cysts and 99.99 percent of viruses every day of

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