Potential Contamination Due to Cross-Connections and Backflow and the Associated Health Risks

An Issues Paper

by

EPA's Office of Ground Water and
Drinking Water

1.0 Nature and Purpose of the Paper

This paper is one of nine papers that examine issues related to drinking water distribution systems. The nine papers are products of two expert workshops. The first workshop, in June 2000, discussed issues associated with distribution systems that may pose public health risks and identified those issues of most concern. The distribution system issues of most concern identified at the workshop are the following: Microbial Growth and Biofilms; Cross-Connections and Backflow; Intrusion; Corrosion and Aging Infrastructure; Decay of Water Quality over Distribution System Residence Time; Contamination During Infrastructure Repair and Replacement; Nitrification; Covered Storage; and Permeation and Leaching. The second workshop, in March 2002, discussed the first drafts prepared on those issues.

In support of the nine distribution system issue papers, EPA developed two tables that list many of the biological and chemical contaminants represented in the papers and their potential health effects: the Microbial Contaminant Health Effects Table (for acute and chronic health effects) and the Chemical Contaminant Health Effects Table (for chronic health effects). For those contaminants mentioned in this paper and included in these tables, a reference to the tables is provided for further information on potential health effects.

The purpose of this document is to review existing literature, research, and information on the occurrence, magnitude, and nature of the public health risks associated with cross-connections and backflow, from both acute and chronic exposures, and methods for detecting and controlling the occurrence of cross-connections and backflow within distribution systems. More specifically, the goal of this document is to review what we know regarding: (1) causes of contamination through cross-connections; (2) the magnitude of risk associated with cross-connections and backflow; (3) costs of backflow contamination incidents; (4) other problems associated with backflow incidents; (5) suitable measures for preventing and correcting problems caused by cross-connections and backflow; (6) possible indicators of a backflow incident; and (7) research opportunities.

2.0 Executive Summary

Within distribution systems there exist points called cross-connections where nonpotable water can be connected to potable sources. These cross-connections can provide a pathway for backflow of nonpotable water into potable sources. Backflow can occur either because of reduced pressure in the distribution system (termed backsiphonage) or the presence of increased pressure from a nonpotable source (termed backpressure). Backsiphonage may be caused by a variety of circumstances, such as main breaks, flushing, pump failure, or emergency firefighting water drawdown. Backpressure may occur when heating/cooling, waste disposal, or industrial manufacturing systems are connected to potable supplies and the pressure in the external system exceeds the pressure in the distribution system. Both situations act to change the direction of water, which normally flows from the distribution system to the customer, so that nonpotable and potentially contaminated water from industrial, commercial, or residential sites flows back into the distribution system through a cross-connection. During incidents of backflow, these chemical and biological contaminants have caused illness and deaths, with contamination affecting a number of service connections. The number of incidents actually reported is believed to be a small percentage of the total number of backflow incidents in the United States.

The risk posed by backflow can be mitigated through preventive and corrective measures. For example, preventative measures include the installation of backflow prevention devices and assemblies and formal programs to seek out and correct cross-connections within the distribution system and, in some cases, within individual service connections. Corrective measures include activities such as flushing and cleaning the distribution system after a detected incident. These may help mitigate any further adverse health effects from any contaminants that may remain in the distribution system.

3.0 Definition of Key Terms

A cross-connection is a point in a plumbing system where it is possible for a nonpotable substance to come into contact with the potable drinking water supply (BMI, 1999). According to the University of Southern California's Foundation for Cross-Connection Control and Hydraulic Research (USC FCCCHR) (1993), a cross-connection means,

> "any unprotected actual or potential connection or structural arrangement between a public or private potable water system, and any other source or system through which it is possible to introduce into any part of the potable system any used water, industrial fluids, gas, or substance other than the intended potable water with which the potable system is supplied."

Common examples of cross-connections include a garden hose submerged in a pesticide mixture, a piped connection providing potable feed water to an industrial process, such as a cooling tower, or a submerged outlet of an irrigation system. Connections to firefighting equipment are other very common cross-connections. Most cross-connections occur beyond the customer service connection, within residential, commercial, institutional or industrial plumbing systems. Identifying cross-connections can be challenging because many distribution systems are expanding to serve new customers and changing to accommodate customer needs. Further, temporary and permanent cross-connections can be created in existing facilities without the knowledge of the water system managers and operators.

Backflow is any unwanted flow of used or nonpotable water, or other substances from any domestic, industrial, or institutional piping system back into the potable water distribution system[1] (USC FCCCHR, 1993). The direction of flow under these conditions is opposite to that of normal flow. The reverse pressure gradient that leads to backflow is caused by either backsiphonage or backpressure (USC FCCCHR, 1993; BMI, 1996).

Backsiphonage is backflow caused by negative or sub-atmospheric pressure in a portion of the distribution system or the supply piping (USC FCCCHR, 1993). When the system pressure drops to below atmospheric (negative gauge pressure), ambient pressure on the distribution system due to the atmosphere, water columns (from buildings or other elevated piping), or other sources will cause the direction of flow within portions of the system to reverse. If a cross-connection exists in the area where flow reverses direction, contaminants can be siphoned into the distribution system (USC FCCCHR, 1993). Water main breaks, firefighting efforts, high demands, and any situation where water is withdrawn from the distribution system at a high rate can lead to backsiphonage (USC FCCCHR, 1993).

Backpressure can cause backflow to occur when a potable system is connected to a nonpotable supply operating under a higher pressure than the distribution system by means of a pump, boiler, elevation difference, air or steam pressure, or other means (USC FCCCHR, 1993). Unlike

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[1] This paper defines the distribution system to be from the point at which the water leaves the treatment plant, or source, if untreated, to the point at which the customer's service line begins.

backsiphonage, it is not necessary to have a drop in distribution system pressure for backpressure to occur. Whenever the pressure at the point of a cross-connection exceeds the pressure of the distribution system, the direction of flow will reverse. There is a high risk that nonpotable water will be forced into the potable system whenever these connections are not properly protected (USC FCCCHR, 1993).

4.0 What Causes Contamination Through Cross-Connections to Occur?

This section of the paper describes how cross-connections and backflow occur, and what conditions and situations are necessary to cause them. Under intended flow conditions, distribution systems are pressurized to deliver finished water from the treatment plant to the customer. However, two situations can cause the direction of flow to reverse: pressure in the distribution system can drop due to various conditions or an external system connected to the distribution system may operate at a higher pressure than the distribution system. These differences in pressure can cause contaminants to be drawn or forced into the distribution system. Contamination introduced due to backflow into the distribution system may then flow freely into other customer connections. The following conditions must be present for contamination to occur through cross-connections.

- A cross-connection exists between the potable water distribution system and a nonpotable source.
- The pressure in the distribution system either becomes negative (backsiphonage), or the pressure of a contaminated source exceeds the pressure inside the system (backpressure).
- The cross-connection is not protected, or the connection is protected and the mechanism failed, allowing the backflow incident.

The extent of contamination in the distribution system depends, in part, on the location of the cross-connection, the concentration of the contaminant entering the distribution system and the magnitude and duration of the pressure difference causing the backflow. This section of the paper describes the theory of backflow and cross-connections, provides examples of conditions that can create backflow, and lists a number of factors that affect the likelihood and magnitude of backflow through a cross-connection.

4.1 Backflow Conditions

The occurrence of backflow is directly related to system pressure. Any pressure differential between the potable water and the non-potable source can lead to backflow. It is estimated that even well-run water distribution systems experience about 25–30 breaks per 100 miles of piping per year (Deb et al., 1995). Haas (1999) reported results from a survey of water systems that showed a range of average main breaks of 488 per year for systems serving more than 500,000 people, to 1.33 per year for systems serving fewer than 500 people.

Fighting fires also reduces a system's pressure (AWWA, 1999). For example, in 1974 in Washington State, the high rate of flow caused by the activation of a fire deluge system reduced pressure in a domestic water line, causing backsiphonage of a chemical and other pollutants into the potable water system (AWWA PNWS, 1995). Similarly, opening hydrants during the summer for recreational use causes pressure to drop. Regular system maintenance activities such as valve exercising programs, hydrant flushing, pump repair, pressure control valve repair, and valve replacement can also result in localized variations in pressure that cause backflow. Differences in elevation can compound the effects of pressure loss.

Additionally, if a high pressure source is connected to the distribution system, a drop in pressure is not necessary for backflow to occur—the presence of a cross-connection or failure of the prevention mechanism will allow backflow to occur.

Examples of backsiphonage

Elevated piping can cause backsiphonage when there is a loss of pressure in the supply system. The loss of pressure will cause the water column to collapse and create a vacuum that can draw contaminants in through a cross-connection (BMI, 1999; USC FCCCHR, 1993). Backsiphonage can also occur within irrigation systems. For example, in 1991, a water main break lead to the backsiphonage of parasitic worms from a residential lawn sprinkler supply into two homes (AWWA PNWS, 1995).

Booster pumps for high-rise buildings can cause backsiphonage if the suction lines of the pumps are being used for service on the lower floors and a temporary or permanent cross-connection on the lower floors exists (e.g., a hose submerged in a bucket of cleaning solution). If distribution system pressure drops, the suction pressure can cause the backsiphonage through the lower floor cross-connection when the pump is operating, contaminating the higher floors (BMI, 1999; USC FCCCHR, 1993; US EPA, 1989).

Localized physical restrictions in water lines can produce backsiphonage through the venturi effect (BMI, 1999). When water flows through a restriction—for example, through a garden hose or from a larger water line into a smaller one—its velocity increases and its pressure decreases proportionately (US EPA, 1989). This decrease in pressure can yield negative pressure and siphon substances into the point of restriction (BMI, 1999). Devices such as chemical sprayers used on the end of garden hoses use this principle to siphon chemical from the container into the water stream (BMI, 1996).

Backsiphonage can occur when supply piping within an industrial facility is elevated over the rim of a vessel, and the outlet of that piping is submerged in a liquid contaminant. Negative distribution system pressure would cause the water column in the elevated pipe section to collapse, creating a vacuum that draws contaminants from the vessel into the distribution system (BMI, 1999; USC FCCCHR, 1993).

If a pipe with cracks or leaking joints is exposed to a wet environment, negative pressure can cause water to be drawn in (or to intrude into) the distribution system through backsiphonage (Kirmeyer et al., 2001). A separate issue paper addresses risks from intrusion due to pressure transients.

Examples of backpressure

Backpressure can occur with pressurized residential, industrial, institutional, or commercial systems which use pumps, including chemical feed pumps or booster pumps, or pressurized auxiliary water systems for irrigation, fire protection, car washes, and cooling systems (USC FCCCHR, 1993; FDEP, 2001). For example, backpressure resulting from tank cleaning activities by a gas company in Connecticut caused propane to backflow into the distribution system, causing fires in two homes and evacuation of hundreds of people. Gas company workers were purging a propane tank with water and did not realize the pressure in the tank was greater than in the water line feeding the tank, thus creating a backpressure of propane vapor into the distribution system (US EPA, 1989). Backpressure also occurred in 1991 at a facility that transforms wheat and barley into ethanol in Tucumcari, New Mexico. An unprotected auxiliary water line feeding emergency fire cannons was illegally tapped to a hose connected to an ethanol plant's flushing system, creating a cross-connection. After the plant finished its flushing operation, the plant resumed normal operations with the hose still connected, and backpressure from plant operations forced a number of industrial chemicals to backflow into the public water supply (toluene, phenol, benzene, ethanol, nonanoic acid, decanoic acid, octanol, octanoic acid, heptanoic acid, butanoic acid, silicon, diconic acid and four trihalomethanes). The concentrations of these toxins were enough to cause the mayor of the town to become very ill for 48 hours. Another individual drank a small amount of water and became ill with stomach upset. Fortunately, there were no deaths, and the distribution system was thoroughly flushed after the contamination was detected (AWWA PNWS, 1995). The likelihood of backpressure increases when the distribution system pressure drops to below normal operating pressure due to changes in valve setting, pipeline breaks, air valve slams, loose-fitting service meter connections, surge or feed tank draining, or a sudden change in demand (Kirmeyer et al., 2001).

The weight of water in piping of high-rise buildings is a source of backpressure on the distribution system. Backpressure can also come from thermal expansion (high pressures can be generated when water is heated in a closed container). Thermal expansion can occur in boilers, solar heating systems, and places where water- or foam-based fire sprinkler systems are located on the highest floors of tall buildings and temperatures of piping rise (BMI, 1999).

Compressed air systems such as carbonators can pose backpressure risks. The pressure of a carbon dioxide tank, for example, can be several thousand pounds per square inch (psi). This high-pressure carbon dioxide is passed through a regulator and mixed into a water system at anywhere from 60 to 150 psi. Carbon dioxide from either a tank or a regulator could be introduced to the distribution system pressure if a cross-connection is present and the compressed air system overcomes the distribution system pressure (Guy, 1997).

4.2 Factors Affecting the Occurrence and Magnitude of Backflow Contamination

Operating pressure

A minimum operating pressure of 20 psi at all locations in a distribution system is suggested by various manuals and codes of good operating practice (Kirmeyer et al., 2001). Some states also have minimum operating pressure requirements. Local operating pressure in a system varies among zones. In a highly pressurized system, a great deal of backpressure would be needed to force water to backflow; a system or part of a system with relatively low pressure would generally be more susceptible to backpressure. Systems with normal operating pressure lower than recommended by manuals and codes of good practice may have a higher risk of backpressure events.

Reduced pressures that can lead to backflow occur from a variety of sources. Water main breaks, hilly terrain, limited pumping capacity, high demand by consumers, fire fighting flows, rapidly opening or closing a valve within the distribution system, power loss, and hydrant flushing can reduce pressure and contribute to lower or extremely fluctuating water pressures (Kirmeyer et al., 2001). A study of a distribution system (LeChevallier et al., 2001) observed that during a pump test, routine operation, and a power outage, pressures as low was -10.1 psi were recorded, with durations ranging from 16 to 51 seconds. During these times of negative pressure, the chance that water external to the distribution system intruded into the distribution system due to backsiphonage or backpressure increased. In a simple single pipe model employed in the study, a surge generated by a simulated power failure to a pump predicted 69 gallons of external water would intrude into the pipe within 60 seconds. A surge caused by a main break predicted 78 gallons of water intruding within 60 seconds. A survey of 70 systems reported 11,186 pressure reduction incidents in the past year; 34.8 percent of the incidents were from routine flushing, 19.2 percent were due to main breaks, and 16.2 percent incidents were due to service line breaks (ABPA, 2000). Hills and other elevations compound pressure loss effects caused by main breaks, fire flows, and other events (ABPA, 2000). Limited pumping capacity may cause periodic termination of water supply in areas of the system. Without sufficient redundancy in the distribution system, backsiphonage conditions may occur if one or more major components of the distribution system go offline or otherwise cease functioning.

Physical security of the distribution system

Homeland security initiatives include attention to the physical security of water distribution systems. The subject of homeland security is well beyond the scope of this paper, but it is relevant to note that the potential for intentional contamination of a distribution system through cross-connections and backflow of chemical and biological contaminants is possible (Dreazen, 2001).

Maintenance activities

Maintenance levels and practices within the distribution system can affect the likelihood of occurrence of cross-connections and backflow. In a South Carolina system in 1978 fifteen people became ill due to backsiphonage of chlordane from an exterminator truck during meter repair (USC FCCCHR, 1993). In May, 1982 maintenance crews in Bancroft, Michigan shut down a main to replace a valve. The resultant pressure loss caused backflow of malathion from a hose end applicator , and resulted in the loss of water to the village for two days (USC FCCCHR, 1993). The herbicide Lexon DF backsiphoned into the distribution system in Gridley, Kansas in 1987 from a tanker truck when a main broke during excavation and contaminated ten residences and one business (USC FCCCHR, 1993).

Levels of public awareness

A lack of public awareness about the threat posed by cross-connections and backflow can lead to unintentional creation of cross-connections, such as through illegal and unprotected taps into the distribution system. In 1979, a professional exterminator left a garden hose submerged in a barrel of diluted pesticide, allowing chlordane to be backsiphoned into the distribution system during a service interruption (US EPA, 1989). This potential is magnified in multi-storied buildings that have many people living under one primary connection. Cross-connections are often installed by the public as a matter of convenience without regard to possible dangers, and others with reliance on inadequate backflow prevention (US EPA, 1989).

5.0 The Magnitude of Risk Associated with Cross-Connections and Backflow

This section describes the risk posed by contaminants that can enter the distribution system through cross-connections. The history of outbreaks and reported illnesses associated with cross-connections and backflow indicates some level of public health risk is associated with cross-connections and backflow. Risk is a function of a variety of factors including cross-connection and backflow occurrence, type and amount of contaminants, and their potential health effects. This section first describes the reported outbreaks of disease associated with cross-connections and backflow, then follows with a description of some contaminants that have been introduced to distribution systems via cross-connections and backflow, and the difficulties in detecting and reporting backflow incidents.

5.1 Reported Outbreaks Associated with Cross-Connections and Backflow

From 1981 to 1998, CDC documented 57 waterborne disease outbreaks related to cross-connections, resulting in 9,734 illnesses. These include 20 outbreaks (6,333 cases of illness) caused by microbiological contamination, 15 outbreaks (679 cases of illness) caused by chemical contamination, and 22 outbreaks (2,722 cases of illness) where the contaminant was not reported. Craun and Calderon (2001) report that 30.3 percent of waterborne disease outbreaks in community water systems during 1971-1998 were caused by contamination of water in the distribution systems. Of these waterborne disease outbreaks caused by distribution system deficiencies, 50.6 percent were due to cross-connection and backflow (Craun and Calderon, 2001). Documented acute health impacts most often involve gastrointestinal disorders. The data from the CDC's surveillance of the outbreak of waterborne disease must meet certain documentation standards; therefore, these reports are reliable. However, CDC's reporting standards exclude some incidents that lack complete documentation and report only outbreaks of notifiable diseases (a set of diseases that CDC tracks; these do not include endemic diseases). As a result, these data are likely under-estimates and these under-estimates are compounded by the number of illnesses that go unreported. (Section 5.4 further discusses the difficulties of detecting and reporting waterborne disease outbreaks.)

Estimates of the proportion of waterborne illness attributable to cross-connections and backflow vary. A compilation by EPA's Health Effects Research Laboratory found that between 1920 and 1980, cross-connections and backflow caused 78 percent of outbreaks, and 95 percent of the cases of illness, attributed to community distribution system contamination in the United States (AWWA, 1990).

Data on health impacts are also available from other sources that collect information on backflow incidents, such as USC FCCCHR, and the Cross-Connection Control Committee of the Pacific Northwest Section of the AWWA. These independent organizations do not limit their data to well-defined outbreaks, but focus on incidents. Because not all incident reports document illness, estimates of illness resulting from an individual incident based on their data are less reliable than CDC estimates of reported outbreaks.

Our compilation of backflow incident data (summarized in Exhibit 5.1) found that 459 incidents resulted in an estimated 12,093[2] illnesses from 1970 to 2001. When we narrowed the analysis to 1981-1999, for comparison with CDC data on outbreaks for that period, we found that only 97 of 309 incidents produced reports of how many (if any) illnesses were caused, and 22 of these 97 incidents reported no illnesses. Of the remaining 75 incidents, only 26 appear in CDC's summaries as a waterborne disease outbreak. This suggests that CDC data underreport even known instances of illness caused by backflow contamination. From the 75 incidents that produced reports of illness, analysis of the qualitative and quantitative case reports estimated 4,416 illnesses, averaging 46 illnesses per outbreak.

5.2 Contaminants Associated with Cross-Connections and Backflow and Their Health Effects

A variety of contaminants have been introduced into distribution systems by cross-connections and backflow, indicated by the backflow occurrence discussed in this paper. The likelihood and severity of illness and number of people affected depend on various factors including how much contamination

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[2] If the number of illnesses was reported qualitatively, the analysis used the following assumptions to estimate a total figure. Specifically, if the number of illnesses was reported as "several", "many", or "numerous", the analysis assumed five. The analysis assumed that "some" meant three. One incident reported "dozens" of illnesses this analysis assumed 36. Another reported one family the analysis assumed three people.

enters the system, the dilution factor, the type of contaminant, the number of users exposed, and the health status of each person at the time of exposure.

Contamination from cross-connections and backflow can occur not only where the cross-connection is located but at sites upstream and downstream, as contaminants spread. The fate and transport of a contaminant are often system-specific and can be difficult to predict because they depend on multiple parameters such as the hydraulics of the distribution system and the physical, chemical, or biological properties of the contaminant. The contaminant may remain as a slug, resulting in very high concentrations in localized areas, or it may disperse, contaminating large volumes of water at lower concentrations. It may adsorb to the interior of pipes, necessitating their cleaning or replacement. It may degrade, or in the case of microorganisms, be inactivated or injured by residual disinfectant. It may also become concentrated within the biofilms and be slowly released through erosion or as a slug through biofilm sloughing. Scales within the piping may adsorb the contaminants for later release.

The Chemical and Microbial Health Effects Tables, developed by EPA to support the nine issue papers, include many biological and chemical contaminants mentioned in the papers. However, additional contaminants not listed in these tables are described in this paper because the types of contaminants that have entered distribution systems through cross-connections are numerous and not discussed in any other white papers; thus more appropriately described in this paper. For those contaminants listed in the Health Effects Tables, this paper references the appropriate table for more information on potential health effects.

5.2.1 Chemical Contaminants

The use of chemicals at residential, industrial, and commercial facilities with direct or indirect connections to potable water systems presents an opportunity for contamination from cross-connections and backflow (USC FCCCHR, 1993). Many of these chemicals have some degree of toxicity, and exposure to these chemicals can have either acute or long-term health effects, depending on the nature and concentration of the contaminant, duration of exposure, and a person's immune status. Exposure from contamination through a cross-connection can be either acute or chronic. While waterborne outbreaks are under-reported in general, rarely are waterborne chemical outbreaks reported to CDC. The reasons for under-reporting of chemical outbreaks above and beyond that of microbial outbreaks include: 1) most poisonings of this nature (e.g., lead and copper from plumbing) probably occur in private residences, affect relatively few people and, thus, may not come to the attention of public health officials; 2) exposure to chemicals via drinking water may cause illness that is difficult to attribute to chemical intoxication, or it may cause non-specific symptoms that are difficult to link to a specific agent; and 3) the chemical outbreak detection mechanisms, as well as the reporting requirements are not as well established as they are for microbial agents (CDC, 1996). Most reported incidents are acute exposures, however, chronic exposures are possible if immediate water quality or health effects are not noticed, or if cross-connections remain uncorrected long-term. This can result in some of the chronic health effects described in the Chemical Health Effects Table (US EPA, 2002a), when the consumer is exposed to the chemicals listed for a long period of time. Depending on the contaminant, these chronic exposures can cause long-term health effects, including cancer, which may not be identified until many years after the initial exposure. Acute health risks include vomiting, burns, poisoning, and other reactions—some potentially life-threatening. For example, in Rochester, NY, a faulty carbonation system on a soft drink machine continuously leaked carbon dioxide into the distribution system for over 3 months, creating increased levels of copper in the distribution system (as high as 13,400 ppb) (Manioci, 1984). Contamination at the K-25 atomic bomb plant in Oak Ridge, TN, occurred for an unknown length of time (possibly on the order of decades) through cross-connections with cooling system and firefighting lines. Contaminants found at the source of contamination that may have entered the distribution system included strontium-90, arsenic, chromium, and antifreeze (Nashville Tennessean, 2000).

Because few backflow incidents are reported, it is important to note that a variety of chemicals have the potential to enter the distribution system through cross-connections, and the number of those reported only represent a subset. For example, agricultural applications contain many fertilizers, herbicides, and insecticides and industrial sources such as cooling systems, plating plants, steam boiler plants, and dye plants have a number of toxic chemicals in day-to-day use that have the potential to contaminate the distribution system (USC FCCCHR, 1993). The most common chemical contaminants reported, according to information EPA has obtained from backflow incident records, are (in order of decreasing occurrence): copper, chromium, ethylene glycol, detergents, chlordane, malathion, propylene glycol, freon, and nitrite. Chlordane and malathion are pesticides; ethylene glycol is used as antifreeze in heating and cooling systems, propylene glycol is used as antifreeze and as a food additive; detergents are extensively used in many industries; copper is used in plumbing; chromium VI was used in the past in cooling towers as a rust and corrosion inhibitor; and nitrite is a reduced form of nitrate, an agricultural fertilizer. This summary discusses these and other related chemical contaminants (grouped into four categories—pesticides, metals, synthetic organic compounds, and nitrates and nitrites) in terms of potential health effects and examples of reported backflow incidents.

Pesticides

Pesticides (including insecticides, herbicides, and fungicides) as a group are contaminants in 45 reported incidents. Chlordane, malathion, heptachlor, and diazinon were reported as contaminants in 11, 5, 3, and 2 incidents, respectively. In one 1976 incident in Chattanooga, TN, chlordane was being used for termite extermination and contaminated a three-block area of residential homes; 17 people reported they drank the suspect water. Reported symptoms by those people were nausea, abdominal pain, gastrointestinal problems, and neurological effects such as dizziness, blurred vision, irritability, headache, paresthesia, muscle weakness, and twitching (AWWA PNWS, 1995). In 1980, heptachlor and chlordane contaminated a portion of distribution system in Allegheny, PA that serviced approximately 300 people. A pesticide contractor created the cross-connection with a garden hose submerged in the chemical mixing tank. There were no reports of illness, however, residents were without water for 27 days (Watts, 1998). Another pesticide incident involved diazinon contamination in Tucson, AZ in 1989. Diazinon entered the system through a residential connection where a home-made pesticide pump system was hooked up to a garden hose. The combination of backpressure from the pump system and the water use by a next-door neighbor washing a car caused the pesticide to flow into the distribution system (Tucson Citizen, 1989). No illnesses were reported. In 1986, two employees of a Kansas grain mill became ill after drinking water contaminated with malathion that was backsiphoned into the plant’s water supply (AWWA PNWS, 1995). In 1988, a Florida man died of insecticide intoxication after he stepped off his mower, filled his water bottle, and drank from the bottle that was filled with contaminated water from a faucet at an airstrip. Officials suspected backflow as the cause of the water supply contamination (AWWA PNWS, 1995).

An example of a small amount of contamination resulting in a public health threat is a 1991 incident where 2.5 gallons of the herbicide TriMec backsiphoned into the Uintah Highlands water system in Utah affecting 2,000 homes (US EPA, 1989). Shortly thereafter, concentrations of the active ingredients, 2,4-D and Dicamba, at a consumer’s tap were measured at 638 and 64.8 parts per million (ppm), respectively. This incident also affected a nursing home and a day-care facility, both of which serve higher risk subpopulations. The health advisory level of both 2,4-D and Dicamba over a 10-day period is 0.3 ppm (US EPA, 2000a). Chronic health effects of 2,4-D and Dicamba include damage to the nervous system, kidney, and liver (US EPA, 2002a). However, only acute exposures were documented.

Metals

There are 73 reported backflow incidents with metal contaminants—55 with copper and 18 with hexavalent chromium. Copper contamination is most commonly associated with backflow incidents at restaurants, where carbonated water can dissolve portions of water or soft drink dispenser piping made of copper. In 1987, a child in Minnesota suffered acute copper toxicity when the backflow from a carbon dioxide machine contaminated a restaurant's potable system (AWWA PNWS, 1995). A similar incident at a fair in Springfield, MO, caused vomiting and abdominal pain in three people who drank soft drinks from a soft drink machine that had a faulty check valve (AWWA PNWS, 1995). Potential health effects due to copper poisoning include vomiting, nausea, and liver and kidney damage; refer to the Chemical Health Effects Table for other potential health effects (US EPA, 2002a). CDC reports that the observed acute health effects due to copper poisoning outbreaks are gastrointestinal illness (CDC, 1996).

Chromium is used as a corrosion inhibitor. In 1970, a cross-connection between a chromate-treated cooling system and the water supply at Skidmore College in New York, New York, caused five people to become nauseated (USC FCCCHR, 1993). In another incident in New Jersey in 1970, hexavalent chromium contamination occurred through a cross-connection of a building heating system and soft drink machine causing 11 people to become nauseated (USC FCCCHR, 1993). Potential chronic health effects are listed in the Chemical Health Effects Table (US EPA, 2002a).

Synthetic and volatile organic compounds

Synthetic and volatile organic compounds as a group are contaminants in 66 reported incidents, with the most frequent contaminants being ethylene glycol (used in antifreeze), propylene glycol (used in antifreeze and as a food additive), freon (refrigerant), and propane (fuel).

Ethylene and propylene glycol were contaminants in 16 and 5 reported incidents, respectively. Examples include one incident in 1982, when ethylene glycol backsiphoned from an air conditioning system's water holding tank into a group of dialysis machines contributing to the death of "several" patients in Illinois (AWWA PNWS, 1995). In 1985, backpressure from a hospital air conditioning system caused the introduction of ethylene glycol into the water system of a New York hospital. One woman died after being exposed while undergoing dialysis (CDC, 1987). In 1987, a cross-connection with a heating system contaminated the plumbing at a municipal building in North Dakota with ethylene glycol, causing acute illness in 29 people. Water from a spigot used to make flavored drinks contained 9 percent ethylene glycol. Reported health effects included excessive fatigue and dizziness, while two children experienced vomiting, excessive fatigue, and hematuria (CDC, 1987). Backflow of propylene glycol from a fire suppression system in 1993 into the potable water system of a park in Arizona occurred for at least 2 months before the point of entry was identified. Several employees reported nausea and intestinal upsets after drinking water during the period of contamination (Watts, 1998), which was discovered by taste and odor complaints.

Freon and propane were contaminants in four and three reported incidents, respectively. In 1989, backpressure from a propane tank car forced propane into the water supply of Fordyce, Arkansas. Three people in separate buildings were injured from explosions after flushing toilets, and two houses were destroyed and a business was damaged by explosions and subsequent fires (AWWA PNWS, 1995). Backpressure from an air conditioning unit caused freon to backflow into the distribution system in Franklin, NE. The contamination was detected when city residents complained of bad tasting water that caused a burning sensation in the mouth (AWWA PNWS, 1995).

Detergents were contaminants in nine reported incidents. Contamination of concentrated soap in 1995 from an incorrectly installed soap dispenser at a health care facility in Iowa affected 13 people was reported a burning sensation in their mouths and symptoms resembling the flu (CDC, 1998). In 1993 in Seattle, WA a temporary cross-connection at a car wash facility allowed soapy water in the distribution system, affecting an eight block area and causing two unconfirmed cases of illness (AWWA PNWS, 1992).

Nitrates and nitrites

Nitrates and nitrites were contaminants in four reported incidents. Nitrate is a common ion found in natural waters and is used in fertilizers. Nitrite is typically not observed at significant levels (AWWA, 2001), however nitrate reduces to nitrite in the human body. In one incident in the county courthouse building of Monterey, CA, sodium nitrate from the boiler and cooler system backflowed into the potable water supply through a faulty backflow prevention device. Nineteen people became sick and needed medical attention from drinking coffee from the courthouse snack bar (AWWA PNWS, 1995). An incident of nitrite contamination at a school in California caused illness in three people; a faulty double-check valve allowed chemicals from the chilling system to enter the school's potable water system (CDC, 1998). Another backflow incident through a cross-connection with a boiler and a faulty backflow prevention device occurred in New Jersey, causing six people to become ill with methemoglobinemia caused by nitrites (CDC, 1998). Potential health effects of nitrate consumption include diuresis and hemorrhaging of the spleen, among others (US EPA, 2002a).

5.2.2 Biological Contaminants

The risks posed by backflow of biological contaminants vary dramatically depending on the disease vector, the concentration and degree of infectivity of the pathogen, the level of disinfectant residual maintained by the water system, and the health of the individual exposed (Rusin et al., 1997). Infective dose studies of non-primary (opportunistic) pathogens on healthy individuals and animals, using the oral and intranasal route, demonstrate that very high doses (e.g., for bacteria, 10^6 -10^{10} cells) are needed for infection or disease (Rusin et al., 1997).

Pathogenic microorganisms (e.g., *Giardia*, some strains of *E. coli*) have contaminated potable water supplies through cross-connections with sewer lines, untreated surface water sources, reclaimed water supplies, equipment at medical facilities and mortuaries, and utility sinks, pools, and similar receptacles. In addition, drain lines, laboratories, and illegal connections of private wells and cisterns to public water supplies are primary sources of contamination (USC FCCCHR, 1993).

A majority of microbial incident reports (32 of 58) list the microbial contaminant as "sewage" or nonspecific microbes. In the summer of 1990, 1,100 guests of a country club in Tennessee suffered intestinal disorders in two mass incidents after consuming the club's contaminated water supplied from an auxiliary well that had become contaminated with sewage due to a cross-connection (AWWA PNWS, 1995). In February, 1990, a cross-connection between an auxiliary irrigation system supporting a golf course and country club and the Seattle Water Department's distribution system resulted in total and fecal coliform contamination that was detected by neighboring systems purchasing water (AWWA PNWS, 1995). The health effects from pathogens are often not specifically reported in the incident reports, making it more difficult to determine the type of microbial contaminant. The combination of these reporting issues leads to underreporting of contamination linked to a specific pathogen.

The general health effects of most microbial pathogens include fever, nausea, and diarrhea, while some diseases have long-term and/or life-threatening effects. For example, the protozoan *Giardia* (a contaminant in 12 reported incidents) causes severe and potentially long-term diarrhea, accompanied by excessive gas, bloating, and weight loss. The Microbial Health Effects Table lists these general health effects and other potential diseases (US EPA, 2002b); however, the table is not all inclusive; additional potential health effects exist.

From backflow incident records collected by EPA, the most common microbial contaminants and their potential health effects are listed below with examples of backflow incidents.

Shigella

Shigella species are a cause of gastroenteritis, and are reported as contaminants in five incidents. The associated symptoms are vomiting, diarrhea, fever, and convulsions (US EPA, 2002b). All species of *Shigella* are highly infectious in humans and are spread through ingestion of fecal contamination (US FDA, 2001a). In one incident in 1977, a cross-connection led to four cases of shigellosis in an apartment house in Chicago, Illinois (USC FCCCHR, 1993). It is unknown whether the cross-connection spread *Shigella* into the distribution system.

E. coli

E. coli, a common biological contaminant (reported as a contaminant in two incidents) that is found in sewage, is normally a benign intestinal bacterium that is present in every human. However, some strains of *E. coli* are pathogenic, and can cause a variety of internal disorders. The most common effect is watery diarrhea, with some strains causing fever or dysentery. In rarer cases, some strains of *E. coli* can cause persistent diarrhea in young children, and have hemolytic properties. An infamous strain of *E. coli* is strain O157:H7, which, in addition to causing bloody diarrhea, can cause kidney failure (US EPA, 2002b). In 2000, two outbreaks of *E. coli* occurred in Medina County, OH, where approximately 30 became ill (Cleveland Plain Dealer, 2001).

Salmonella

Salmonella is one of the primary intestinal bacterial waterborne pathogens (reported as a contaminant in one incident). Depending on the strain, health effects can include typhoid fever, gastroenteritis (salmonellosis) (Benenson, 1995), and septicemia (US EPA, 2002b). In one incident, 750 people became ill with *Salmonella enteritidis* in Richland, Washington, in 1983. The incident involved new plumbing and contaminated ice (CDC, 1984). A person infected with the *Salmonella enteritidis* bacterium usually has fever, abdominal cramps, and diarrhea beginning 12 to 72 hours after consuming a contaminated food or beverage. The diarrhea can be severe, and the person may be ill enough to require hospitalization (CDC DBMD, 2001).

Campylobacter jejuni

Campylobacter jejuni is an avian gut bacteria that is the primary cause of bacterial diarrhea in the United States (CDC, 2002b). It is estimated that *Campylobacter* infects over two million people a year, and 10,000 cases are reported to the CDC annually, despite limited monitoring. Although *Campylobacter* is primarily a foodborne pathogen, it has been implicated in waterborne disease outbreaks in the past (CDC, 1996). This bacteria can cause gastroenteritis with symptoms including bloody diarrhea, fever, and abdominal cramping (US EPA, 2002b). In extreme cases, a *Campylobacter* infection may lead to Guillain-Barré syndrome where the immune system attacks part of the nervous system (CDC, 2002b). In 1986, 250 people became ill with diarrhea due to *Campylobacter* contamination in Noble, OK (CDC, 1996).

Cyanobacteria

Cyanobacteria are photosynthetic free-living bacteria. They produce algal blooms in fresh water, which can result in elevated toxin levels. Cyanobacterial toxins can produce acute neurotoxicity, hepatotoxicity, gastroenteritis, respiratory ailments, skin irritation, and allergic reactions through contact or ingestion (CDC, 2002c). In one incident in 1992, in Ritzville, Washington, backsiphonage from a drain sump near a new reservoir caused a reoccurring contamination of cyanobacteria (AWWA PNWS, 1995).

Norwalk and Norwalk-like viruses

The Norwalk family of viruses is a cause of viral gastroenteritis with symptoms of vomiting, diarrhea, upper respiratory problems, and fever (US EPA, 2002b). Although viral gastroenteritis is caused by a number of viruses, it is estimated that Norwalk or Norwalk-like viruses are responsible for about 1/3 of the cases of viral gastroenteritis not involving the 6-to-24-month age group (US FDA, 2001b). People often develop immunity to the Norwalk virus, however, it is not permanent and reinfection can occur (US FDA, 2001b). In developing countries the percentage of individuals who have developed immunity is very high at an early age. In the United States, the percentage increases gradually with age, reaching 50 percent in the part of the population over 18 years of age. Norwalk or Norwalk-like viruses were reported as a contaminant in two incidents. In one incident in 1980 in Lindale, Georgia, 1,500 people became ill with a Norwalk-like acute gastrointestinal illness as a result of a contamination incident for which the specific chemical or microbiological contaminant was never determined (CDC, 1982).

Giardia

Giardia was a contaminant in 12 reported incidents. *Giardia* are intestinal parasites that exist in natural waters in a nonreproductive stage (cysts). They can cause diarrhea, as well as vomiting, cramps, and bloating (US EPA, 2002b). The mode of infection is through ingestion of fecally contaminated food or water. The infections from these parasites are usually self-limiting, but among children, the elderly, and the immunocompromised, the infections can lead to chronic diarrhea, anemia, fever, and possibly death (Hoxie et al., 1997; US EPA, 1998; CDC, 2002a). In 1979, *Giardia* was responsible for 2,000 illnesses after backpressure effluent from a tree bubbler system in an Arizona State park (Lake Havasu) contaminated the potable water supply (USC FCCCHR, 1993). In 1994, dozens of people became ill from *Giardia* contamination through a cross-connection between a drain and an ice machine at a convention in Columbus, Ohio (AWWA PNWS, 1995).

Other contaminants

Biological contaminants that are nonmicrobial can also enter the distribution system. For example, due to a cross-connection at a funeral home, human blood and bodily fluids from the embalming process were backsiphoned into the distribution system, and blood flowed from water fountains and other water fixtures (US EPA, 1989). Human bodily fluids can be a vector for disease as well as being an aesthetic concern.

5.3 Data on Selected Backflow Incidents, 1970-1999

There are no reporting requirements nationally for backflow incidents, and no central repository for backflow incident information. Nonetheless, data on backflow incidents have been actively collected by several organizations, including the following:

- Centers for Disease Control (CDC), the federal agency that tracks epidemiology of illnesses as reported by doctors and health care providers.

- Cross-Connection Control Committee of the Pacific Northwest Section of the American Water Works Association (AWWA PNWS), a technical and educational association for the drinking water industry.

- University of Southern California's (USC's) Foundation for Cross-Connection Control and Hydraulic Research, a water engineering research and industry standards development organization.

- American Backflow Prevention Association (ABPA), a training and advocacy association for the water system industry.

Drawing from these and other sources, including EPA Regional Offices, the Florida Department of Environmental Protection, professional manuals on controlling cross-connections, and news reporting accounts, EPA compiled data on 459 backflow incidents that occurred in the United States between 1970 and 2001. Exhibit 5.1 summarizes the types of incidents reported at various sites and indicates the wide range of problems that can occur. Because backflow incidents are underreported, the data cannot support conclusions about the full magnitude of risk associated with backflow. And the exhibit summarizes only the reported acute health impacts, as surveillance programs do not capture impacts due to chronic exposures or chronic health effects.

Exhibit 5.1 Reported Backflow Incidents for Which EPA Has Compiled Data

Source of Contamination	Documented Incidents	Examples of Incidents
Residential Sites		
Homes With Individual Connections	55	• In 1991, an atmospheric vacuum breaker valve intended to protect a cross-connection between an irrigation system and the potable supply malfunctioned, allowing backflow of irrigation water into the public water system. The water system, located in Michigan, was contaminated with nematodes, rust, and debris (AWWA PNWS, 1995). • In 1997, recycled water reached approximately 1,600 California homes and businesses from a residential connection after a property owner illegally tapped into a reclaimed water line (California HHS Agency, 2001).
Apartment Buildings or Condominiums	27	• In 1981, chlordane and heptachlor were backsiphoned through a garden hose submerged in a termite exterminator's tank truck in Pennsylvania. An undisclosed number of illnesses occurred, and 75 apartment units were affected (NAPHCC, 1996). • In 1985, hexavalent chromium backflowed from a Boston, Massachusetts condominium's cooling tower into the potable water system (NAPHCC, 1996).
Mobile Homes or Mobile Home Parks	1	• In 1984, a leak developed in a wall separating solar water heater heat transfer medium from a residential water supply. The water supply of a mobile home in Oregon was contaminated with dichlorofluoromethane (AWWA PNWS, 1995).
Neighborhood	3	• In 1995, a business tapped into an irrigation line containing untreated water in Yakima, Washington, without installing a backflow prevention device. This allowed *Giardia* to contaminate area residences, resulting in 11 cases of giardiasis. (AWWA PNWS, 1995). • In 1997, a fire truck pump created backpressure on a fire hydrant before the valve was closed, forcing over 60 gallons of aqueous fire-fighting foam into an estimated 40,000 neighborhood taps in Charlotte-Mecklenburg, North Carolina (ABPA, 1999).

Exhibit 5.1 Reported Backflow Incidents for Which EPA Has Compiled Data

Source of Contamination	Documented Incidents	Examples of Incidents
Government and Institutional Sites		
Medical Sites (Hospital, Dental, Nursing Sites, Blood Banks, etc.)	27	• In 1982 in Illinois, ethylene glycol backsiphoned from an air conditioning system's water holding tank into a group of dialysis machines, contributing to the death of "several" (number not given) patients (AWWA PNWS, 1995). • During shut-down of a water main to repair a valve in 1984, the backflow of water from a nursing home's boiler caused burns to a water department employee's hands in Washington State (AWWA PNWS, 1995). • In 1994, during repairs to a nursing home air conditioning unit in Franklin, Nebraska, a hole left in the cooling coils allowed freon to backflow into the city water main, affecting the city's 1,100 residents. Customers complained about the taste of the water, but no illnesses were reported (AWWA PNWS, 1995).
Schools, Universities, and Children's Camps	31	• In 1990, six staff members of an Indiana middle school reported becoming ill after drinking water containing ethylene glycol that backflowed from the school's cooling system into the potable water system (AWWA PNWS, 1995). • In 1987, copper sediment contamination in a beverage mixing tank resulted in four cases of illness in a residence hall at Michigan university (AWWA PNWS, 1995). • In 1995, three people became ill at a California school after drinking water from a system with a double-check backflow prevention valve that did not meet industry standards and had badly deteriorated rubber gaskets (Craun and Calderon, 2001).
Public Water Systems	15	• In 1984, creosote was backsiphoned through a three-quarter inch hose used to prime a pump, contaminating a section of a Georgia community water system. No illnesses were reported (AWWA PNWS, 1995). • In 1970 in Mattoon, Illinois, hot wash water from an asphalt plant backpressured into mains during flow testing of fire hydrants (USC FCCCHR, 1993).

Exhibit 5.1 Reported Backflow Incidents for Which EPA Has Compiled Data

Source of Contamination	Documented Incidents	Examples of Incidents
Other Government/ Institutional Sites (e.g., public buildings, churches)	24	• In 1976, water fountains at the State Capitol building in Salem, Oregon, were contaminated with freon gas from a ruptured heat exchanger. The gas combined with the fluoride in the water supply, forming an acid compound that caused a bitter, burning taste (AWWA PNWS, 1995). • In 1991, two check valves froze open at a Texas Air Force base, resulting in a backflow from a water chiller; pathogenic bacteria were detected in the water. The specific contaminant was not identified. Approximately 22,000 workers and residents were without water during system flushing (AWWA PNWS, 1995). • In 1994, the water system at a Tennessee prison was cross-contaminated by the facility's wastewater pump station, resulting in 304 cases of giardiasis (Craun and Calderon, 2001). • Purified drinking water lines at the Oak Ridge Reservation's K-25 atomic bomb fuel plant were interconnected for an unknown length of time (possibly on the order of decades) with lines carrying impure creek water. The creek water contained poisons generated from nuclear fuel production, possibly including contaminants such as strontium-90 and arsenic (Nashville Tennessean, 2000).
Commercial Sites		
Restaurants	28	• In 1979, two high school students in Seattle, WA, became ill, showing symptoms of copper poisoning after drinking soft drinks from a dispensing machine in a restaurant. The backflow of carbon dioxide from the soft drink dispensing machine was considered the likely cause of the copper release (AWWA PNWS, 1995). • In 1987, a child in Minnesota suffered acute copper toxicity when backflow from a carbon dioxide machine contaminated a restaurant's potable system (AWWA PNWS, 1995).
Office Buildings	18	• In 1989, a backflow event at an Ohio government office building occurred after crews worked on the air conditioning system. Twelve individuals became ill after ingesting water that had been contaminated with Acid Blue 9, an algae-retarding chemical (AWWA PNWS, 1995). • In 1991, trichloroethane entered the distribution system of a city in Missouri from a newspaper office. Uncoordinated flushing by the water system caused the contaminant to spread throughout the system, with concentrations as high as 420 micrograms/L (AWWA PNWS, 1995).

Exhibit 5.1 Reported Backflow Incidents for Which EPA Has Compiled Data

Source of Contamination	Documented Incidents	Examples of Incidents
Other Commercial Sites	66	• In 1974, backsiphonage of a chromium compound from the chiller water of an air conditioning system contaminated the drinking water system in the auditorium hosting the 94th annual AWWA conference and exhibition in Massachusetts, involving thousands of people (AWWA PNWS, 1995). • In 1990, 1,100 guests of a Tennessee racquet and country club became ill with an intestinal disorder after consuming the club's contaminated water supplied from an unauthorized and unprotected auxiliary well in close proximity to a malfunctioning sewage pumping station (AWWA PNWS, 1995). • In 1994, a number of individuals attending an Ohio convention got sick with giardiasis, spread by an ice machine contaminated by a cross-connection to a sewage drain (AWWA PNWS, 1995).
Miscellaneous Sites		
Agricultural Sites	6	• In 1991, an antibiotic solution used at a commercial chicken house entered an Arkansas public water system as a result of a cross-connection between an auxiliary well connected to the chicken house plumbing (AWWA PNWS, 1995). • In 1995, pesticides (paraquat and atrazine) were backsiphoned into a distribution system when an accidental water main cut occurred while a Louisiana farmer was diluting herbicides in a tank. Some people reported nausea, stomach burns and pains, profuse sweating, diarrhea, and shortness of breath. The incident was the subject of a class-action lawsuit (AWWA PNWS, 1995).
Recreational Sites	10	• In 1986 in Springfield, MO, failure of a single check valve on a soft drink dispensing machine at a local fair resulted in the backflow of carbon dioxide that created levels of 2.7 mg/L of copper and 2.2 mg/L of zinc. Three people experienced vomiting and abdominal pain (AWWA PNWS, 1995). • In 2000, contaminated water lines at an Ohio fairground resulted in an outbreak of *E. coli*, resulting in 30 cases of illness (Cleveland Plain Dealer, 2001).

Exhibit 5.1 Reported Backflow Incidents for Which EPA Has Compiled Data

Source of Contamination	Documented Incidents	Examples of Incidents
Industrial Sites	40	• In 1989, backpressure from a propane tank car forced propane into the water supply of Fordyce, Arkansas. Three people in separate buildings were injured from explosions after flushing toilets, and two houses were destroyed and a business was damaged by explosions and subsequent fires (AWWA PNWS, 1995). • In 1990, at least two individuals became ill after an unknown quantity of industrial chemicals backflowed into the public water supply via an unprotected auxiliary line illegally tapped to a hose connected to the plant's flushing system. The incident occurred at a New Mexico facility that transforms wheat and barley into ethanol (AWWA PNWS, 1995).
Other Sites/Site Type Unknown	108	• In 1980, a cross-connection aboard an Alaskan crab processing ship resulted in backflow of sewage (including *Giardia*), causing 189 employees to become ill and endangering about $35 million worth of processed king crab (USC FCCCHR, 1993; CDC, 1982).
Total	459	

Source: CDC, AWWA PNWS, ABPA, EPA, USC FCCCHR, FDEP, and Newspapers

5.4 Occurrence of Cross-Connections and Backflow

From a 1999 American Backflow Prevention Association (ABPA) survey, ABPA estimated that 42 percent of cross-connection surveys conducted (by 135 respondents, representing 30 states) identified a cross-connection. The most common cross-connections reported were from irrigation (62 percent of respondents identified an irrigation cross-connection), fire systems (43 percent), garden/washdown hoses (43 percent), and boilers (38 percent). A total of 233 backflow incidents were reported by 51 percent of respondents, or 1.7 incidents per system (ABPA, 1999). These numbers only reflect those backflow incidents detected; many go undetected because it is not practical for systems to continuously monitor their distribution systems for changes in pressure or the presence of contaminants. In addition, ABPA conducted a survey in 2000, which included a question on the occurrence of low pressure events which may lead to backflow where unprotected. A survey of 70 systems responding to the survey reported 11,186 pressure reduction incidents in the previous year; 34.8% of the incidents were from routine flushing, 19.2% were due to main breaks, and 16.2% of the incidents were due to service line breaks (ABPA, 2000).

5.5 Difficulties in Detecting Backflow Incidents and Associated Outbreaks

Contamination due to backflow incidents may not be detected or reported for several reasons:

- Bacterial contamination tends to be transient and highly localized (ABPA, 1999).

- Water system operators monitor routinely for coliform bacteria, however, most often that is the only microbial monitoring conducted (US EPA, 2001). While these bacteria are important indicators of distribution system problems, some microbial contaminants may go undetected. The limited nature of biological monitoring, especially in smaller systems (as infrequent as once per year), makes it unlikely that contamination will be detected in a timely manner. Operators monitor for a limited number of chemicals (US EPA, 2001), but not routinely or often enough to identify most backflow incidents.

- Most backflow incidents are generally detected and reported to the local authority only if customers detect an irregularity in their water supply. Not all contamination that produces illness and disease can be detected by taste, color, or odor (Hoxie et al., 1997). For many highly toxic substances, including benzene, vinyl chloride, and dichloromethane, the taste and odor threshold is well above the drinking water maximum contaminant level (MCL) (DWI0441, 1992; Glaza and Park, 1992).

- Even if an irregularity is detected, it may not be reported by the consumer.

- When water system operators suspect backflow incidents, they have a disincentive to document and report them because of concerns about legal liability and loss of consumer confidence, as noted by an EPA Office of the Inspector General report (US EPA, 1995). (Fortunately, these same concerns provide the utility with an incentive to protect the distribution system.)

- The difference between epidemic and endemic transmission is obscured by limitations in recognizing when an outbreak occurs (Frost et al., 1996). A study of waterborne cryptosporidiosis estimates that out of every 10,000 infections by *Cryptosporidium* only 3 would be reported, and concludes that surveillance for detected cases of a reportable illness may substantially underestimate rates of infection and morbidity (Perz et al., 1998).

- Some contaminants that enter the distribution system through cross-connections and backflow may not be reportable.

- The incidents of reduced pressure and some cross-connections are often transient in nature. Pressure changes may not be detected by conventional pressure monitoring equipment. Reduced pressures may also affect only a portion of the distribution system, a specific pressure zone, or only piping beyond the service connection.

State officials offer perspective on the estimated extent of underreporting. One State official suspects that there may be 10 times as many as incidents as are reported (Fauver, 2002). Another State official estimates approximately 1,200 backflow incidents occur per year, assuming that all water main breaks will cause a backflow incident (and each of 600 public water systems in the State average 2 water main breaks a year). Yet only 15 backflow incidents have been documented in the State since 1970 (Koenig, 2002).

Outbreaks of illness associated with backflow incidents also are underreported, for the following reasons:

- Outbreaks of illness may not be linked to an incident of backflow contamination (Craun and Calderon, 2001). Documented effects of contamination are usually acute and result from short-term exposures; whether mild or severe, the effect appears soon after exposure. Effects that are long-lasting or only appear after some time (chronic effects) are difficult to ascribe to a single event or associate with a waterborne source. Cross-connections combined with uncorrected backflow situations that cause continuous or intermittent exposure over a long time and result in chronic illness would be less likely to be linked to backflow contamination.

- Contamination may not affect enough people to attract the attention of public health officials (Craun and Calderon, 2001).

- Information that could tie an incident to an outbreak of illness or disease, such as where and when a contaminant entered the system, is often missing.

Even when incidents are detected and voluntarily reported, inconsistent reporting and documentation procedures make it hard to assess the full scope of the problem. Some organizations that record incidents will accept reports only if they have documentation that meets their standards. The USC FCCCHR prepared a *Summary of Case Histories* (USC FCCCHR, 1993) that covers 397 incidents from 1903 to 1993. The Chief Engineer of the Foundation estimated that more than 90 percent of the backflow incidents known to water system administrators were not documented enough to be included in the case histories (CCC WS, 1999). Inadequate documentation can result from the fact that where backflow is suspected, in most instances it is difficult if not impossible to trace the origin of contamination (BMI, 1999).

6.0 Costs of Backflow Contamination Incidents

The costs associated with backflow incidents depend on the nature and scope of the incident and the nature and extent of the response. Depending on these factors, costs could be incurred for public notification; the repair of damage to water distribution system infrastructure; investigation, sampling, and laboratory analysis; clean-up of structures and equipment; purchases of bottled water; responding to consumer complaints; lawsuits (both legal fees and judgments); the repair of property damage; replacement of spoiled food; missed work and school; loss of production; and medical expenses. Beyond actual costs, other losses could include leisure time and even mortality.

The ABPA 1999 survey gathered information to estimate the costs water systems may incur to mitigate a backflow incident. The survey collected data from 25 water systems serving fewer than 10,000 people and from 103 systems serving 10,000 people or more. Survey results show that for the 92 systems that responded, water system operators expended an average of 494 hours per event mitigating backflow incidents. At $30 per hour (the average rate of technical labor reported by the Bureau of Labor Statistics (2000)), that averages $14,800 per event. Eleven of these were significantly more time consuming than the others, averaging 3,683 hours and about $110,500 (at $30 per hour) per incident. Excluding these 11 most time-consuming incidents, operators expended an average of 60.8 hours per incident and $1,820 per incident. Utility-level costs such as these do not include costs for all of the possible elements described earlier, especially those for health-related effects.

Other backflow incidents reported monetary losses due to food spoilage, property damage, and lawsuits. Examples include a backflow of wastewater through a cross-connection created with the water supply and the wastewater line when a new well was installed; the wastewater contaminated pork valued at approximately $2 million (NAPHCC, 1996). A lawsuit for $21 million was filed against a pest control company that contaminated the water supply to 63 homes and businesses with pesticide; the money was compensation for physical distress, inconvenience (the homes and businesses were without water for several days), and loss of property value (AWWA PNWS, 1992).

7.0 Other Problems Associated with Backflow Incidents

This section discusses other negative effects associated with cross-connections and backflow that, although not a direct threat to health, can cause other undesired effects such as negative publicity, consumer complaints, damage to the water system, and impediments to system operation. Negative effects discussed are: 1.) corrosion; 2.) microbial growth; and 3.) taste, odor, and color problems.

Corrosion

Many contaminants, such as acids and carbon dioxide, can corrode pipes and other distribution system materials. Many incidents of corrosion induced by carbon dioxide backflow have released toxic amounts of copper into drinking water systems (AWWA PNWS, 1995). Many of these incidents were reported because the corrosion was rapid enough and large enough in extent to produce concentrations of corroded metal high enough to be toxic or to lead to complaints about taste and odor.

Corrosion in iron pipes is much less likely to be noticed because iron is not as toxic as copper, and corrosion of iron and steel is relatively slow, leading to lower concentrations. But slow corrosion is a problem: corroded iron pipes can lead to discolored water, stained laundry, and taste complaints (McNeil and Edwards, 2001). Corrosion can also weaken the integrity of pipes, causing leaks that can allow contaminants in through intrusion or catastrophic breaks, which can in turn cause reduced pressure (McNeil and Edwards, 2001). Corrosion of iron pipes can also form tubercles that can shelter microbes (including pathogens) from disinfection (US EPA, 1992).

Microbial growth

When backflow through cross-connections introduces microbes into the distribution system, these organisms can attach to pipe walls in places where the disinfectant residual may be inadequate to inactivate the microbes, such as in dead ends. Such organisms, even if they are not pathogenic themselves, can be a concern because they can colonize on the pipe walls, forming biofilms (US EPA, 1992) that trap and concentrate nutrients, promoting growth of pathogens (Costerton and Lappin-Scott, 1989). The biofilm can lead to total coliform violations, even in the absence of contamination events. Biofilm can also cause complaints about taste and odor and harbor potentially pathogenic organisms from disinfection (Characklis, 1988). Backflow through cross-connections can also introduce nutrients that support the growth of pre-existing biofilms.

Taste, odor, and color problems

Some contaminants introduced through cross-connections and backflow may not cause illness but may result in consumer complaints about the tastes, odors, or color of the water (e.g., seawater and dyes (AWWA PNWS, 1995)). Such incidents can lower consumer confidence in the water system, require water and employee time to flush the system to remove the offending contaminant, and initiate an investigation to identify and correct the cross-connection.

8.0 Suitable Measures for Preventing and Correcting Problems Caused by Cross-Connections and Backflow

This section reviews existing research, data, and available information regarding the prevention of cross-connections and backflow incidents, as well as mitigation measures systems use following a backflow incident.

8.1 Preventive Measures

Backflow into the public water distribution system can be prevented by eliminating cross-connections or protecting the potable water supply using backflow prevention devices and assemblies. Some systems educate the public to prevent cross-connections, and maintain and inspect the distribution system to correct those found. However, because situations frequently arise where new cross-connections occur before they are detected and corrected, it is helpful to build in to the distribution system physical impediments to backflow, including mechanical backflow prevention devices and assemblies. Systems look to minimize the risk posed to their distribution systems from a customer's plumbing system, and therefore conduct hazard assessments in order to determine the level of protection needed and what approach should be taken. The appropriate type of protection depends on the physical characteristics of the cross-connection (e.g., whether there is a potential for backpressure in addition to backsiphonage) and the degree of the potential hazard. The degree of hazard is a function of both the probability that backflow may occur and the toxicity or pathogenicity of the contaminant involved. A high hazard can be defined as,

> "a condition, device, or practice which is conducive to the introduction of waterborne disease organisms, or harmful chemical, physical, or radioactive substances into a public water system, and which presents an unreasonable risk to health" (BMI, 1996).

Low hazard can be defined as,

> "a hazard that could cause aesthetic problems or have a detrimental secondary effect on the quality of the public potable water supply" (BMI, 1996).

Another reason for conducting risk assessments is to determine and help manage legal liability due to public health risk; therefore, these definitions of high and low hazard are ultimately subjective and depend upon the risk aversion of the water system, appropriate local regulations, and the particular risk assessment conducted by the system.

8.1.1 Physical Separation

Air gaps, if designed and maintained properly, make backflow physically impossible as they ensure that there is no connection between the supply main and the nonpotable source. An effective air gap is a physical separation of a supply pipe from the overflow rim of a receiving receptacle, by at least twice the diameter (minimum of one inch) of the incoming supply pipe (USC FCCCHR, 1993; BMI, 1996). The distance between the end of a faucet and the overflow of a utility sink is an example of an air gap. While air gaps provide physical assurances against backflow, they are often tampered with as people extend the end of the pipe to prevent splashing and thus potentially create a cross-connection. By the AWWA standard, air gaps are acceptable in lieu of mechanical backflow prevention assemblies beyond the service connection only if installed and maintained by the local cross-connection control program enforcement agency (AWWA, 1999).

8.1.2 Backflow Prevention Devices and Assemblies

Mechanical backflow prevention devices and assemblies offer protection of the potable water system if other protective approaches fail. Backflow prevention devices and assemblies may be installed at the service connection to a facility (effectively "containing" a potential contaminant within a customer's plumbing system and preventing it from entering the distribution system). Alternatively, devices and assemblies can also be installed at high and low hazard cross-connections inside the facility, including all outlets where cross-connections could potentially be created (this type of approach is called "isolation" or "fixture outlet protection"). Some drinking water authorities prefer isolation to containment because personnel working beyond the service connection are protected and, in most cases, the assembly can be sized smaller because of smaller piping beyond the service connection. However, backflow devices and assemblies used for isolation could be bypassed through changes to internal plumbing, inadvertently creating an unprotected cross-connection.

There are two types of mechanical protection available to systems: backflow prevention "devices" and backflow prevention "assemblies". Backflow prevention devices function by stopping the reversal of flow, but are not testable once installed because they do not have inlet and outlet shut-off valves or test cocks (USC FCCCHR, 1993). Backflow prevention assemblies, by contrast, include an inlet and outlet shut-off valve and test cocks to facilitate testing of the assembly while it is in its functional environment (in-line) (USC FCCCHR, 1993).

Backflow prevention assemblies include pressure vacuum breakers (PVBs), spill resistant vacuum breakers (SVBs), double check valve assemblies (DCVAs), and reduced pressure principle backflow assemblies (RPs) (USC FCCCHR, 1993) (BMI, 1996). PVBs are vertically positioned assemblies that include spring-loaded check valves designed to close when flow stops (USC FCCCHR, 1993). They also have an air inlet valve that is designed to open when the internal pressure is lower than the atmospheric pressure, preventing backsiphonage but not backpressure. PVBs must be a minimum of 12 inches above all downstream piping and the flood level rim of a receptor to function properly. PVBs are designed to protect against low- or high-hazard situations.

SVBs are similar in design to PVBs with the addition of a diaphragm seal that stops water from spilling out the air inlet whenever the assembly is pressurized. As with PVBs, they protect against backsiphonage only (BMI, 1996).

A DCVA consists of two internally loaded, independently operating check valves together with tightly closing resilient seated shut-off valves upstream and downstream from the check valves (USC FCCCHR, 1993). These assemblies require a minimum of 1 foot of clearance at the bottom for maintenance purposes to allow for the worker to get to the assembly. These assemblies are used for protection against either backsiphonage or backpressure, but only for situations of low hazard.

RPs consist of two internally loaded, independently operating check valves and a mechanically independent, hydraulically dependent relief valve located between the check valves (USC FCCCHR, 1993). The relief valve maintains a zone of reduced pressure between the two check valves. The RP also has tightly closing, resilient seated shut-off valves upstream and downstream of the water supply. RPs must have a minimum of 1 foot clearance at the bottom of the assembly for maintenance purposes. RPs protect against backsiphonage or backpressure in low- or high-hazard situations.

One common backflow prevention device is an atmospheric vacuum breaker (AVB). AVBs rely on atmospheric instead of water pressure to work, and are installed downstream from all shut-off valves.

AVBs contain an air inlet valve that closes when the water flows in the normal direction. But, as water ceases to flow, the air inlet valve opens and prevents backsiphonage. AVBs must be a minimum of 6 inches above all downstream piping and the flood level rim of a receptor to function properly (USC FCCCHR, 1993). Household hose bib vacuum breakers and frost-proof wall hydrant faucets are examples of AVBs. According to some, AVBs do not protect against backpressure and are used in situations of low hazard (BMI, 1999); however, some plumbing codes recognize AVBs as high hazard assemblies.

The selection of any particular assembly or device is a function of the hazard assessment that balances the likelihood of backpressure and backsiphonage and the potential contaminants involved. The total cost of installing and maintaining a particular device or assembly can also be a factor for some water systems. In cases of low hazard and backsiphonage only, systems typically install less expensive AVBs or PVBs. If backpressure is a concern, many systems use double check valve assemblies, and if the degree of hazard is high, many systems install a reduced pressure principle backflow assembly.

The cost of backflow preventers has been reported by industry experts to be a deterrent in starting and maintaining and backflow prevention program (CCC WS, 1999). The cost of backflow preventers can range from $18 to over $22,000 (Watts, 2002), depending on the size and preventer type. Installation costs are typically borne by the water system and passed along to consumers, or are borne directly by consumers (ABPA, 2000).

8.1.3 Cross-Connection Control and Backflow Prevention Programs

Many states and local jurisdictions require cross-connection control and backflow prevention programs. However, many utilities do not have programs, or have programs that are insufficient to provide reasonable protection from cross-connections (ABPA, 1999). The program requirements vary widely between states: they may be part one or more of various regulations, including the drinking water regulations, health code, plumbing code, policy decision of the utility itself and building codes. A 1993 U.S. General Accounting Office report on the review of 200 sanitary surveys and a nationwide questionnaire of states identified inadequate cross-connection control programs as the most common deficiency (US GAO, 1993).

Programs and their level of effort are often tailored to the perceived risk of backflow and the types of hazards that can be introduced into the distribution system (USC FCCCHR, 1993). These factors may contribute to determining whether a containment or isolation program is implemented locally, as well as what types of backflow preventers are required. The need for backflow prevention in a water system is determined through a variety of means, including: surveys of new sites; retrofit programs; and change of occupancy inspections. Some programs inspect a site upon request. In many of these cases, identification of hazards determines the need for backflow prevention. For example, Kansas City, Missouri's program does informal, informational checks and passes the data to the plumbing authority (Nelson, 1999). The cross-connection control programs of Boston and Cambridge, Massachusetts, check connections to the last free-flowing tap (Hendrickson, 1999). Other programs, such as the one for Gatlinburg, Tennessee, identify additional requirements as a function of the risk of the facility (City of Gatlinburg, 2001). The water system in Price, Utah, performs about 20-30 inspections each year, about half of which go beyond containment to focus on potential cross-connection hazards. Staff focus primarily on high-hazard sites, but inspect other types of sites after installations or upgrades (Price, 1999).

In an effort to evaluate the measures states take to address cross-connections and backflow, EPA analyzed existing state requirements (Exhibit 8.1). The analysis reviewed regulations of all states pertaining to drinking water, clean water, and plumbing and building codes. Additionally, information from the following surveys was used as supplementary information for the analysis: the EPA Office of Inspector General Report (The Survey Report on the Cross-Connection Control Program, 1995); the Florida Report (The State of Florida's Evaluation of Cross-Connection Control Rules/Regulations in the 50 States, FDEP, 1996); Governmental Affairs Committee (GAC) Follow-up Survey (Summary of the Cross-Connection Control Requirements-Nationally, 1997); the American Backflow Prevention Association (ABPA) Survey, 1999; the Association of State Drinking Water Administrators (ASDWA) Survey, 1999; and the Van Loon Survey, 1999.

Exhibit 8.1. State Cross-Connection Control Requirements

Requirement	Number of States With Requirement
Does the State have a requirement for the control of cross-connections and/or backflow prevention?	50
Is it specified in the requirement that the system must implement or develop a cross-connection control and/or backflow prevention program?	32
Does the State require authority to implement a local ordinance or rule for cross-connection control and/or backflow prevention?	33
- Must the authority cover testing of backflow prevention assemblies?	27
- Must the authority cover the use of only licensed or certified backflow assembly testers?	16
- Must the authority cover the entry of the premises for the sake of inspecting the premises?	14
- Must the authority cover the entry of the premises for the sake of inspecting and/or installing backflow prevention assemblies?	15
Does the State require training, licensing, or certification of backflow prevention assembly testers?	26
Does the State require training, licensing, or certification of backflow prevention assembly and/or device installers?	6
Does the State require training, licensing, or certification of backflow prevention assembly and/or device repairers?	10
Does the State require training, licensing, or certification of cross-connection control inspectors?	19
Does the State require inspection of backflow prevention devices and/or testing of backflow prevention assemblies?	37
Does the State require the system to include record keeping as part of cross-connection control?	34
Does the requirement include keeping records of hazard assessment surveys?	11
Does the State require the system to notify the public following the occurrence of a backflow event?	3
Does the state require the local rule or ordinance to allow the system to take enforcement action against customers that do not comply with the cross-connection control and backflow prevention requirements?	23
Does the State conduct periodic reviews of cross-connection control programs?	3
Does the State regulation or plumbing code require public education regarding cross-connection control and/or backflow prevention?	7

Source: Derived from state drinking water and clean water regulations and state plumbing and building codes.

Considerable variability exists in state statutes, regulations, and policies related to cross-connection control and backflow prevention. In some cases where states do not require programs, some water systems within the state have implemented comprehensive and active programs in absence of a state requirement to do so.

According to input from a Cross-Connection Control Expert Meeting in September, 1999, a program is considered active and comprehensive if it contained regulations with these requirements: 1) require adoption of some form of legal authority (ordinance, by-law, code) for establishing and maintaining a cross-connection control program at the local level; 2) require training and certification specifications; 3) require record keeping and reporting; 4) provides public education; and 5) define enforcement responsibility and penalties. Many state programs that require cross-connection control and backflow prevention programs share these elements (ASDWA, 1999; USC FCCCHR, 1993). As noted in Exhibit 8.1, several states have these requirements, although a majority do not have all five of the recommended minimum elements.

Authority

Experts agreed that a cross-connection control program should have the authority to effectively enforce its ordinances and requirements (CCC WS, 1999). It is recommended by groups such as the AWWA (AWWA, 1999) that local cross-connection control programs have the legal authority in place to carry out basic program requirements, such as: 1) enter premises and inspect facilities to determine the degree of hazard and the presence of cross-connections; 2) to install, repair, and test backflow devices; 3) license employees or contractors engaged in testing of assemblies to ensure competency; and 4) terminate water service in case of noncompliance. Not all states require authority to effectively enforce the ordinances and requirements—33 states require local authorities to implement cross-connection control ordinances. Of those states, only 14 states require authority to enter premises for inspection purposes, and 15 states require authority to enter premises to inspect or install backflow prevention devices (Exhibit 8.1).

Different local authorities may have pre-existing responsibilities that would be overlapped by a cross-connection control program. Water utilities typically have the responsibility to protect the distribution system up to a customer's meter. In some cases, they fulfill this responsibility by placing backflow assemblies at the meter (USC FCCCHR, 1993). Plumbing authorities are often responsible for all potable water connections downstream of the meter (USC FCCCHR, 1993). Engineers and building authorities have inspection and compliance responsibilities which, in some cases, overlap with plumbing authorities. Additional overlap of authority occurs with regard to fire lines. While fire lines can use potable water and are frequently interconnected with the potable system (AWWA, 1999), they are usually unmetered and typically not considered part of the drinking water supply, and therefore are not subject to plumbing codes. Having backflow assemblies on fire lines (e.g., the Boston, Massachusetts, program involving the fire authorities) requires the cooperation of fire departments. In addition, many programs require customers to understand the dangers of backflow and take effective measures to eliminate, fix, and isolate cross-connections.

Training and certification

Training and certification is considered an important element of a cross-connection control and backflow prevention program (CCC WS, 1999). The training and certification can cover administering a program, conducting site surveys, installing and testing approved backflow assemblies, as well as for maintaining and repairing backflow assemblies. The testing of backflow prevention assemblies by a certified tester works to ensure that the assembly is functioning properly and will prevent backflow.

Twenty-six states require certification of backflow assembly testers (Exhibit 8.1). In some states, backflow assembly testers also install and repair the backflow preventers, however only 6 states require training, licensing, or certification of backflow installers (Exhibit 8.1). A small number of states expand their training requirements to program managers, installers, and/or repairers. Nineteen states require certification of survey inspectors (Exhibit 8.1).

Having trained and certified testers may contribute to effective cross-connection control and backflow prevention. For example, in 1998, a 42-inch water main broke in close proximity to the Boston Public Library, causing a dramatic drop in pressure in a large portion of the city for a short period; however, there were no reported backflow incidents (Hendrickson, 1999). The key elements of the Boston, Massachusetts, cross-connection control and backflow prevention program include 11 full-time cross-connection control staff employees, all of whom are certified testers licensed by the State of Massachusetts (Hendrickson, 1999).

Public education

There have been incidents of water system customers installing inadvertent cross-connections leading to backflow incidents. Education of the public may reduce the number of cross-connections created on the customer side, and is therefore a critical element in the implementation and success of a cross-connection control and backflow prevention program (CCC WS, 1999). Seven states required public education regarding cross-connection and/or backflow control and prevention (Exhibit 8.1). Public education is usually a function of the local water purveyor. Also, states sometimes provide materials for distribution, and maintain Internet sites that include information about state water quality programs to educate consumers about CCC programs and the role they play in protecting their drinking water. The Michigan Backflow Prevention Association has developed a video used for training utility personnel on educating the public (MBPA, 1997).

Educational tools used by local programs are: meetings, brochures, and seminars. Las Vegas, Nevada, has run multiple seminars to explain the program since they serve two jurisdictions (Blish, 1999). They have been so successful that some of the large casinos now have their own on-site trained and certified cross-connection control personnel. Tucson, Arizona distributes backflow prevention brochures to customers, and in the past has used public access television to promote the program. They also distribute backflow prevention brochures to existing customers during inspections (Adams, 1999). Other programs distribute fliers and bill inserts. The public awareness program of Sandy City, Utah, consists of fact sheets, manufacturer's information on backflow prevention, newspaper articles and newsletters, public meetings with customers, and backflow information provided to people requesting information on sprinkler systems (Oakeson, 1999).

Reporting and record keeping

A requirement to report backflow incidents is important for detection and correction of cross-connections (CCC WS, 1999). Although many backflow incidents are believed to occur undetected, those that are detected can provide valuable information on other potential cross-connections in the distribution system. Three states require reporting of backflow incidents to the public, while eight states require systems to notify state authorities (Exhibit 8.1).

Lack of records or poorly organized records can inhibit corrective measures. Thirty-four states require some sort of record keeping as part of their cross-connection control and backflow prevention program (Exhibit 8.1). As part of its cross-connection control program, Tucson, Arizona, has a data management system that tracks each assembly's compliance status (Adams, 1999). The Charlotte-

Mecklenburg incident involving firefighting foam, which took 39 hours and 100 city employees to remedy, prompted the state to require a comprehensive evaluation of the Charlotte-Mecklenburg Utility Department's backflow prevention program by an outside consultant. One of the key findings resulting from the evaluation was that the program did not have a formal retrofit program for existing connections and devoted excessive resources to record keeping; the resources spent on record keeping were used inefficiently. Since then, the utility has implemented a new data management system to reduce the record keeping burden and plans to hire an additional staff member to focus on developing a program for retrofitted equipment (ABPA, 1999).

Testing and repair

Many systems that have cross-connection control and backflow prevention programs require testing to ensure that backflow preventers are working correctly. As in any mechanical device, backflow assemblies can deteriorate and fail as they get older. Testing intervals typically are annual, semi-annual, or risk-based (USC FCCCHR, 1993).

Many states require in regulation or code specific components that make up a testing program. A testing program frequently identifies the appropriate standards that a backflow prevention device or assembly must meet (e.g., standards set by the USC FCCCHR, AWWA, or in the Uniform Plumbing Code (UPC)), as well as specifies a routine testing frequency to ensure adequate performance of the devices. In many cases, assemblies are then tested by a certified backflow assembly tester. Approximately 37 states require inspection and/or testing of various backflow assemblies in their regulations (Exhibit 8.1).

In Boston, Massachusetts, as required by the state, reduced pressure backflow assemblies are tested twice a year; double-check valve assemblies are tested once per year (Hendrickson, 1999). The program performs 11,000 site inspections per year. All surveys go to the last free-flowing outlet regardless of whether the facility is considered high- or low-hazard, as required by state cross-connection control regulations. Under this program, 100 percent of all high-hazard sites have installed protection. This high level of testing has prevented any cross-connection incident since 1984, and no boil-water notices have been necessary (Hendrickson, 1999).

Enforcement

AWWA recommends that cross-connection control program authority should include clearly defined enforcement procedures such as provisions to shut off water service if devices are not installed or tested, entry to property is not allowed, devices and assemblies are not installed properly, devices are not tested, and testing payments are not received (AWWA, 1999). According to the 1995 EPA Office of Inspector General report, state officials indicated that they adopted a regulation prohibiting cross-connections and required the local water suppliers to establish a program with the responsibility to administer and enforce the program at the local level (US EPA, 1995). State officials indicated, however, that there is little follow-up or enforcement at the state level (US EPA, 1995). In addition, several states do not require systems to develop programs to implement or enforce the requirements, through additional drinking water regulations, plumbing codes, or health codes. For example, only 23 states require enforcement action against noncomplying customers (Exhibit 8.1). In Denver, Colorado, enforcement consists of notifying customers that backflow assemblies must be installed. Customers are then given 90 days to comply, followed by a second notice, 30 days of grace, and then third notice. Failure to comply may lead to suspension of water service. Inspections are done by request and number approximately 25 per month (Stevens, 1999). Thirty-two states require water systems to have a CCC program, but only three states conduct periodic reviews of cross-connection control programs, and these reviews are conducted annually (Exhibit 8.1).

8.1.4 Disinfectant Residual

While not able to prevent cross-connections or backflow from occurring, the use of disinfectant residuals (i.e., free chlorine or chloramines) can provide a measure of protection against waterborne disease through the inactivation of some microbial or oxidation of some chemical contaminants. Although contamination from cross-connections and backflow may be controlled by a disinfectant residual (Snead et al., 1980), some water supply professionals believe a disinfectant residual is not effective when cross-connections result in massive contamination (LeChevallier, 1999). In some cases, reductions in a disinfectant residual can signify the existence of a contamination problem in the distribution system, including those resulting from cross-connections and backflow (Haas, 1999). However, some disinfectant residual sampling strategies (e.g., grab samples), may not be able to detect a reduction in disinfectant residual concentrations for transient events, such as many backflow incidents.

8.1.5 Pressure Stabilization and Maintenance of Positive Pressure

Since backsiphonage and possibly backpressure are induced by drops in distribution system pressure, maintaining positive and stable pressure reduces the risk of backflow. Minimizing pressure spikes through use of variable speed pumps and proper valve opening and closing procedures may reduce the frequency of main breaks that cause backsiphonage (Kirmeyer et al, 2001), and thus be a preventive measure. Maintaining positive pressure through changes in pumping patterns and adding additional pump power can minimize backsiphonage and may reduce the occurrence of backpressure events (Kirmeyer et al, 2001). Pressure stabilization and pressure maintenance may be difficult for systems with multiple entry points and those with large variances in elevation or daily demand. Main breaks, firefighting demands, or other unusual demands that cannot be predicted will also hinder a system's ability to maintain pressure.

The initial design of a distribution system can minimize possible cross-connection and backflow opportunities by avoiding low pressure areas and ensuring positive pressure throughout the system. Water systems that are aware of pressure drops within their distribution systems can conduct additional water quality testing to determine if a backflow incident has occurred, thus detecting incidents that may have gone undetected. Systems that have records of pressure over a period of time have the ability to identify chronic trouble spots, and the records can provide information to devise a strategy to fix them (LeChevallier et al, 2001). Studying and correcting low pressure zones in existing systems, either continual or transient, can reduce the number of backflow incidents (LeChevallier et al., 2001).

8.1.6 Pipeline Maintenance and Inspection

Regular inspection of pipelines may identify conditions that could lead to main breaks such as frozen valves, advanced corrosion, and small leaks, and allow them to be repaired before they lead to main breaks, which can lead to backsiphonage. Regularly cleaning and flushing pipelines may also reduce buildup and growth of biofilms that may promote corrosive conditions that can cause pipeline leaks and eventually breaks (Shindala and Chisolm, 1970; Norris and Ryker, 1987).

8.1.7 Sanitary Surveys

Through the course of conducting sanitary surveys on elements related to the distribution system, likely cross-connections may be identified and corrected by the water system (US EPA, 1999). Sanitary surveys may also find evidence of corroding pipelines, frozen valves, and other situations that could lead to pressure maintenance problems.

8.1.8 Standards and Codes

The plumbing codes adopted by states are represented in Exhibit 8.2. In addition to the plumbing codes listed in the exhibit, AWWA also provides guidelines and standards (AWWA, 1999). Some areas of the country use plumbing codes to set standards, as well as cross-connection control and backflow prevention programs. The plumbing standards used by many localities can be found in the Uniform Plumbing Code, the International Plumbing Code, the Building Officials and Code Administration, and the Southern Building Code Congress International. However, plumbing codes are often only enforceable against plumbers and property owners, and not public water systems themselves.

Exhibit 8.2 Plumbing Codes Adopted by States

Plumbing Code	Number of States Adopting
Statewide Code	47
No Statewide Code	3
Statewide Codes Adopted	
Uniform Plumbing Code	14
State Code	7
International Plumbing Code	5
National Standard Plumbing Code	4
Southern Building Code Congress International	4
Other	13

Source: NAPHCC Survey (1999), IAPMO Plumbing Code Adoption Map (2001)

8.2 Corrective Measures

This section describes methods used by water systems to correct contamination from cross-connection and backflow incidents once they have been detected, as well as minimize resulting problems. Corrective actions that systems conduct following detection of an incident include: 1) isolation of the contaminated area; 2) public notification; 3) flushing and cleaning the system; and 4) pipeline replacement.

8.2.1 Isolation of the Contaminated Area

If preventive measures fail and a backflow contamination event occurs, systems frequently respond by trying to limit the damage and remove the contaminant from the system. When a system learns of a contamination event, many systems isolate the portion of the system that was contaminated to prevent the contamination from spreading. The response to a 1982 propane gas leak in a town in Connecticut was to first evacuate residents and seal off the affected area (AWWA PNWS, 1995). This is achieved by shutting off valves surrounding the contaminated area. Crews generally start at the point where the contamination was reported and work their way out until they find the edge of the contamination. Contaminants that are not detectable through sight or smell may be difficult to track and contain if field testing techniques for the contaminant are not available. Because a stuck valve can prevent an area from being isolated and lead to the spread of contamination, valve exercising programs can be important in isolating contamination events. In 1988, in response to a backflow incident at a paint factory in Edgewater, Florida, the factory manager isolated the factory water system from the city water system prior to flushing out the contaminants (USC FCCCHR, 1993). An example of not being able to isolate the area is the Charlotte-Mecklenburg incident (Exhibit 5.1), which required 90 million gallons to flush the distribution system (ABPA, 1999).

8.2.2 Public Notification

If a contamination event has occurred and the contamination was unable to be isolated before reaching customers, all customers served by the system must be notified (65 FR 25982). The type of notification depends on the contaminant and the size of the area contaminated (65 FR 25982). If the contaminant has acute health effects notification must be as quick as possible, either through broadcast media or through system employees or public safety officials going door-to-door depending on the size of the area. For contaminants without immediate or short-term health effects, the public can be notified by other methods such as letters placed in mail boxes or print media (65 FR 25982). Notification of the public can prevent health effects by minimizing possible contact with contaminated water until other immediate corrective measures have been completed. During the Charlotte-Mecklenburg incident (Exhibit 5.1), the city coordinated an emergency response and notified 40,000 affected customers. In a 25-block radius from the incident, door-to-door notifications were made instructing customers not to use their water. An extended area beyond the door-to-door radius was notified through media reports not to use their water (ABPA, 1999).

8.2.3 System Flushing and Cleaning

Once a contamination event has been detected and isolated, usually water system authorities flush the system as a first attempt to remove the contaminant. Flushing is done by opening up hydrants and expelling water from the system using a wide open valve approach until the contaminant can no longer be detected. If a large area has been affected several hydrants may need to be opened in succession to clean the system. Flushing generally moves from the source of contamination in the downstream direction. If the source of contamination is not found and fixed there is a possibility of a repeat incident. In 1986, after sodium hydroxide contaminated the distribution system of Lacey's Chapel, Alabama, water mains and affected plumbing were flushed after containment (Watts, 1998). Valves are then slowly opened before the hydrant is turned off. This allows for the removal of any contamination that was undetected during system isolation and may have moved beyond the valves used for isolation (Yoke and Gittelman, 1986). Out of 28 backflow incidents on which EPA has information and where a response was reported, 12 reported flushing the affected portion of the distribution system.

Some contaminants may not be adequately removed by flushing. Microbial contaminants may concentrate in biofilms that may not be easily dislodged by flushing alone. The water system serving Muncie, Indiana, drained its entire distribution system over a weekend in an unsuccessful effort to remove the biofilm (Geldreich, 1996). Other contaminants may adsorb to biofilm layers or corroded pipe materials and be released slowly to water in the pipe and, therefore, may take an unreasonable amount of time to flush from the system (US EPA, 1992). In these cases, water systems may opt to physically clean the pipelines. Pigging and rodding are cleaning methods where a device is introduced into the pipe that physically scrapes biofilm and corrosion layers from the sides of the pipe (Kirmeyer et al, 2001). Jetting and sandblasting can also be used to remove such layers. Typically pipes are disinfected and flushed after a physical cleaning by one of the above methods.

8.2.4 Pipeline Replacement

Some contaminants may not be removed by physical cleaning. Examples include the pesticide chlordane, which can adsorb to even clean pipe material and is released into solution only at slow rates. In 1987, following contamination of drinking water lines in Fairlawn and Hawthorn, New Jersey, with the pesticides chlordane and heptachlor, the affected lines were removed and replaced (AWWA PNWS, 1995). Radioactive materials are also difficult to remove physically as they can irradiate pipe materials. Other contaminants such as highly corrosive or explosive contaminants may cause damage to the system. In these cases, systems may choose to replace the contaminated piping and other appurtenances.

9.0 Possible Indicators of a Backflow Incident

This section discusses events, occurrences, or signals that help indicate to a water system or regulatory authority that a backflow incident is occurring or has occurred. A problem for water systems in detecting cross-connections is that there is little immediate warning that a backflow incident is occurring. In some cases it is not known for some time after an incident, and in other cases it is never discovered. With an active monitoring program, cross-connections may be detected by routine inspection, and deficiencies in the distribution system that could lead to backflow could be corrected. However, the efficacy of a cross-connection control program might only be known to the extent that new backflow incidents are not detected. Possible indicators of backflow include: 1) customer complaints of water quality; 2) drops in operating pressure; 3) drops in disinfectant residual; 4) water meters running in reverse; and 5) coliform detections. It is also possible that cross-connections and contamination due to backflow events can occur in the absence of these indicators.

Customer complaints

From the backflow incident data collected (Exhibit 5.1), the primary indicator of backflow has been customer complaints of odor, discoloration of the water, or direct physical harm from contact with the water. Generally, it is unknown how long a backflow incident may have occurred before it is detected through aesthetic or health concerns.

Drops in operating pressure

Continual monitoring for reduced pressure can give immediate warning of a potential backflow incident. It may also identify the area where a pressure drop may have originated, and thus help isolate areas affected by backflow. A drop in operating pressure can only indicate that a backflow event may have already occurred; it cannot stop an event in progress or prevent an incident, unless the root cause is corrected.

Drops in Disinfectant Residual

A drop in the disinfectant residual of a distribution system can be an indicator of a backflow event. Many factors influence the concentration of the disinfectant residual in the distribution system, including the assimilable organic carbon level, the type and concentration of disinfectant, water temperature, and system hydraulics (Trussell, 1999). Entry of foreign material into the distribution system from backflow (or other events) may alter these factors and contribute to a loss of residual.

Water meters running in reverse

During periods of reversed water flow, water meters can reverse their counters. When investigating a water quality complaint at a restaurant in Kennewick, WA, a cross-connection specialist found the meter at the site running backwards; the dual check valves for the carbon dioxide tanks were impaired, allowing the pressurized carbon dioxide to backflow into the water supply line (AWWA PNWS, 1995). Based on a survey of water systems, many have the ability to detect meters running backwards and have detected this occurrence on several occasions (Schwartz, 2002).

Total coliform detections and heterotrophic plate count changes

A sudden spike in total coliform detections, or a sudden change in heterotrophic bacterial densities (measured by heterotrophic plate count) is an indication that contaminants could have entered the distribution system (40 CFR 141). Persistent coliform contamination may indicate a long-standing cross-connection. Monitoring for coliform and other microbial indicators of contamination, as well as more extensive monitoring, may help identify instances of backflow contamination.

10.0 Research Opportunities

This document identifies what we know regarding the potential health risks associated with cross-connections and backflow incidents in drinking water distribution systems based on available literature, research, and information. However, as with most areas, further opportunities exist for research to result in greater certainty of the health impacts associated with drinking water distribution systems. Some specific research opportunities, among others, related to cross-connections and backflow are: further analysis of how surges contribute to occurrence of backflow; the degree of underreporting of backflow incidents across the country; what constitutes an effective cross-connection control and backflow prevention program; and what the effectiveness of disinfectant residual is for protecting against microbial contamination from backflow. It is not feasible to list all specific data needs for cross-connection control and backflow prevention, but two reports being prepared for EPA as part of its Comprehensive Drinking Water Research Strategy and the Microbial/Disinfection Byproducts (M/DBP) Research Council outline additional research opportunities.

11.0 Summary

Cross-connections and backflow represent a significant public health risk (US EPA, 2000b) by allowing chemical and biological contaminants into the potable water supply (a conclusion of the Microbial/Disinfection Byproducts Federal Advisory Committee (M/DBP FACA)). Of the 459 backflow incidents from 1970-2001 on which EPA has information, an estimated 12,093 cases of illness resulted. Fifty-seven of these cross-connection-related waterborne disease outbreaks were reported to CDC from 1981-1998, and resulted in at least 9,734 cases of illness. A wide number and range of chemical and biological contaminants have been reported to enter the distribution system through cross-connections and backflow. Pesticides, sewage, antifreeze, coolants, and detergents were the most frequent types of contaminants reported. Although a wide range of contaminants have been reported, the number on contamination incidents is considered a likely underestimate due to problems in detecting, reporting, and documenting incidents. These problems include: an inability to detect incidents without health effects; incidents with health effects that are unreported because affected individuals do not realize a connection between their illness and the drinking water; no requirement on either health officials or water system officials to report detected backflow incidents; and no central repository for reported illness. Where undetected, cross-connections may also expose consumers to contaminants from backflow long-term. Cross-connections can be prevented through mechanical means and through programs administered by local or state officials to specifically locate and eliminate cross-connections and prevent backflow. Officials can also take measures to correct deficiencies that either have the potential to lead to backflow incidents or have already caused a backflow incident, and they can increase monitoring for indicators of potential problems to improve reaction time to future incidents.

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