Purpose and Scope

Public health officials have long been concerned about cross-connections and backflow connections in plumbing systems and in public drinking water supply distribution systems. Such cross-connections, which make possible the contamination of potable water, are ever-present dangers. One example of what can happen is an epidemic that occurred in Chicago in 1933. Old, defective, and improperly designed plumbing and fixtures permitted the contamination of drinking water. As a result, 1,409 persons contracted amebic dysentery; there were 98 deaths. This epidemic, and others resulting from contamination introduced into a water supply through improper plumbing, made clear the responsibility of public health officials and water purveyors for exercising control over public water distribution systems and all plumbing systems connected to them. This responsibility includes advising and instructing plumbing installers in the recognition and elimination of cross-connections.

Cross-connections are the links through which it is possible for contaminating materials to enter a potable water supply. The contaminant enters the potable water system when the pressure of the polluted source exceeds the pressure of the potable source. The action may be called backsiphonage or backflow. Essentially it is reversal of the hydraulic gradient that can be produced by a variety of circumstances.

It might be assumed that steps for detecting and eliminating cross-connections would be elementary and obvious. Actually, cross-connections may appear in many subtle forms and in unsuspected places. Reversal of pressure in the water may be freakish and unpredictable. The probability of contamination of drinking water through a cross-connection occurring within a single plumbing system may seem remote; but, considering the multitude of similar systems, the probability is great.

Why do such cross-connections exist?

First, plumbing is frequently installed by persons who are unaware of the inherent dangers of cross-connections. Second, such connections are made as a simple matter of convenience without regard to the dangerous situation that might be created. And, third, they are made with reliance on inadequate protection such as a single valve or other mechanical device.

To combat the dangers of cross-connections and backflow connections, education in their recognition and prevention is needed. First, plumbing installers must know that hydraulic and pollution factors may combine to produce a sanitary hazard if a cross-connection is present. Second, they must realize that there are available reliable and simple standard backflow prevention devices and methods that may be substituted for the convenient but dangerous direct connection. And third, it should be made clear to all that the hazards resulting from direct connections greatly outweigh the convenience gained. This manual does not describe all the cross-connections possible in piping systems. It does attempt to reduce the subject to a statement of the principles involved and to make it clear to the reader that such installations are potentially dangerous. The primary purpose is to define, describe, and illustrate typical cross-connections and to suggest simple methods and devices by which they may be eliminated without interfering with the functions of plumbing or water supply distribution systems.
Human Blood in the Water System

Health Department officials cut off the water supply to a funeral home located in a large southern city, after it was determined that human blood had contaminated the fresh water supply. City water and plumbing officials said that they did not think that the blood contamination had spread beyond the building, however, inspectors were sent into the neighborhood to check for possible contamination. The chief plumbing inspector had received a telephone call advising that blood was coming from drinking fountains within the building. Plumbing and county health department inspectors went to the scene and found evidence that the blood had been circulating in the water system within the building. They immediately ordered the building cut off from the water system at the meter.

Investigation revealed that the funeral home had been using a hydraulic aspirator to drain fluids from the bodies of human "remains" as part of the embalming process. The aspirator directly connected to the water supply system at a faucet outlet located on a sink in the "preparation" (embalming) room. Water flow through the aspirator created suction that was utilized to draw body fluids through a hose and needle attached to the suction side of the aspirator.

The contamination of the funeral home potable water supply was caused by a combination of low water pressure in conjunction with the simultaneous use of the aspirator. Instead of the body fluids flowing into the sanitary drain, they were drawn in the opposite direction—into the potable water supply of the funeral home.

![Diagram](image-url)
Burned in the Shower

A resident of a small town in Alabama, jumped in the shower at 5 a.m. one morning in October, 1986, and when he got out his body was covered with tiny blisters. "The more I rubbed it, the worse it got," the 60 year old resident said. "It looked like someone took a blowtorch and singed me."

He and several other residents received medical treatment at the emergency room of the local hospital after the water system was contaminated with sodium hydroxide, a strong caustic solution.

Other residents claimed that, "It (the water) bubbled up and looked like Alka Seltzer. I stuck my hand under the faucet and some blisters came up."

One neighbor's head was covered with blisters after she washed her hair and others complained of burned throats or mouths after drinking the water.

The incident began after an 8-inch water main, that fed the town, broke and was repaired. While repairing the water main, one workman suffered leg burns from a chemical in the water and required medical treatment. Measurements of the pH of the water were as high as 13 in some sections of the pipe.

Investigation into the cause of the problem led to a possible source of the contamination from a nearby chemical company that distributes chemicals such as sodium hydroxide. The sodium hydroxide is brought to the plant in liquid form in bulk tanker trucks and is transferred to a holding tank and then pumped into 55 gallon drums. When the water main broke, a truck driver was adding the water from the bottom of the tank truck instead of the top, and sodium hydroxide backsiphoned into the water main.

Heating System Anti-Freeze into Potable Water

Bangor Maine Water Department employees discovered poisonous antifreeze in a homeowner's heating system and water supply in November, 1981. The incident occurred when they shut off the service line to the home to make repairs. With the flow of water to the house cut off, pressure in the lines in the house dropped and the antifreeze, placed in the heating system to prevent freeze-up of an unused hot water heating system, drained out of the heating system into house water lines, and flowed out to the street. If it had not been noticed, it would have entered the homeowner's drinking water when the water pressure was restored.
Salty Drinks

In January, 1981, a nationally known fast food restaurant located in southeastern United States, complained to the water department that all their soft drinks were being rejected by their customers as tasting "salty." This included soda fountain beverages, coffee, orange juice, etc. An investigation revealed that an adjacent water customer complained of salty water occurring simultaneously with the restaurant incident. This second complaint came from a water front ship repair facility that was also being served by the same water main lateral. The investigation centered on the ship repair facility and revealed the following:

- A backflow preventer that had been installed on the service line to the shipyard had frozen and had been replaced with a spool piece sleeve.
- The shipyard fire protection system utilized seawater that was pumped by both electric and diesel driven pumps.
- The pumps were primed by potable city water.

With the potable priming line left open and the pumps maintaining pressure in the fire lines, raw salt water was pumped through the priming lines, through the spool sleeve piece, to the ship repair facility and the restaurant.

Paraquat in the Water System

"Yellow gushy stuff" poured from some of the faucets in a small town in Maryland, and the State of Maryland placed a ban on drinking the water supply. Residents were warned not to use the water for cooking, bathing, drinking or any other purpose except for flushing toilets.

The incident drew widespread attention and made the local newspapers. In addition to being the lead story on the ABC news affiliate in Washington, D.C. and virtually all the Washington/Baltimore newspapers that evening. The news media contended that lethal pesticides may have contaminated the water supply and among the contaminants was paraquat, a powerful agricultural herbicide.

The investigation disclosed that the water pressure in the town water mains was temporarily reduced due to a water pump failure in the town water supply pumping system. Coincidentally, a gate valve between a herbicide chemical holding tank and the town water supply piping had been left open. A lethal cross-connection had been created that permitted the herbicide to flow into the potable water supply system. Upon restoration of water pressure, the herbicides flowed into the many faucets and outlets on the town water distribution system.

This cross-connection created a needless and costly event that fortunately did not result in serious illness or loss of life. Door-to-door public notification, extensive flushing, water sample analysis, emergency arrangements to provide temporary potable water from tanker trucks, all contributed to an expensive and unnecessary town burden.
Propane Gas in the Water Mains

Hundreds of people were evacuated from their homes and businesses on an August afternoon in a town in Connecticut in 1982 as a result of propane entering the city water supply system. Fires were reported in two homes and the town water supply was contaminated. One five-room residence was gutted by a blaze resulting from propane gas “bubbling and hissing” from a bathroom toilet and in another home a washing machine explosion blew a woman against a wall. Residents throughout the area reported hissing, bubbling noises, coming from washing machines, stoves and toilets. Faucets sputtered out small streams of water mixed with gas and residents in the area were asked to evacuate their homes.

This near-disaster occurred in one, 30,000 gallon capacity liquid propane tank when the gas company initiated immediate repair procedures. To start the repair, the tank was “purged” of residual propane by using water from one of two private fire hydrants located on the property. Water purging is the preferred method of purging over the use of carbon dioxide since it is more positive and will float out any sludge as well as any gas vapors. The “purging” consisted of hooking up a hose to one of the private fire hydrants located on the property and initiating flushing procedures.

Since the vapor pressure of the propane residual in the tank was 85 to 90 psi, and the water pressure was only 65 to 70 psi, propane gas backpressure backflowed into the water main. It was estimated that the gas flowed into the water mains for about 20 minutes and that about 2,000 cubic feet of gas was involved. This was approximately enough gas to fill one mile of an 8-inch water main.

Chlordane and Heptachlor at the Housing Authority

The services to seventy five apartments housing approximately three hundred people were contaminated with chlordane and heptachlor in a city in Pennsylvania, in December, 1980. The insecticides entered the water supply system while an exterminating company was applying them as a preventative measure against termites. While the pesticide contractor was mixing the chemicals in a tank truck with water from a garden hose coming from one of the apartments, a workman was cutting into a 6-inch main line to install a gate valve. The end of the garden hose was submerged in the tank containing the pesticides, and at the same time, the water to the area was shut off and the lines being drained prior to the installation of the gate valve. When the workman cut the 6-inch line, water started to drain out of the cut, thereby setting up a backsiphonage condition. As a result, the chemicals were siphoned out of the truck, through the garden hose, and into the system, contaminating the seventy five apartments.

Repeated efforts to clean and flush the lines were not satisfactory and it was finally decided to replace the water line and all the plumbing that was affected. There were no reports of illness, but residents of the housing authority were told not to use any tap water for any purpose and they were given water that was trucked into the area by volunteer fire department personnel. They were without their normal water supply for 27 days.
Boiler Water Enters High School Drinking Water

A high school in New Mexico was closed for several days in June 1984 when a home economics teacher noticed the water in the potable system was yellow. City chemists determined that samples taken contained levels of chromate as high as 700 parts per million, "astronomically higher than the accepted levels of .05 parts per million." The head chemist said that it was miraculous that no one was seriously injured or killed by the high levels of chromium. The chemical was identified as sodium dichromate, a toxic form of chromium used in heating system boilers to inhibit corrosion of the metal parts.

No students or faculty were known to have consumed any of the water; however, area physicians and hospitals advised that if anyone had consumed the high levels of chromium, the symptoms would be nausea, diarrhea, and burning of the mouth and throat. Fortunately, the home economics teacher, who first saw the discolored water before school started, immediately covered all water fountains with towels so that no one would drink the water.

Investigation disclosed that chromium used in the heating system boilers to inhibit corrosion of metal parts entered the potable water supply system as a result of backflow through leaking check valves on the boiler feed lines.

Pesticide in Drinking Water

A pesticide contaminated a North Carolina water system in April, 1986, prompting the town to warn residents of 23 households not to drink the water. The residents in the affected area were supplied drinking water from a tank truck parked in the parking lot of a downtown office building until the condition could be cleared up. Residents complained of foul smelling water but there were no reports of illness from ingesting the water that had been contaminated with a pesticide containing chlordane and heptachlor.

Authorities stated that the problem occurred when a water main broke at the same time that a pest control service was filling a pesticide truck with water. The reduction in pressure caused the pesticide from inside the tank to be sucked into the building's water main. The pesticide contaminated the potable water supply of the office building and neighborhood area.

Car Wash Water in the Water Main Street

This car wash cross-connection and back-pressure incident, which occurred in February, 1979, in the state of Washington, resulted in backflow chemical contamination of approximately 100 square blocks of water mains. Prompt response by the water department prevented a potentially hazardous water quality degradation problem without a recorded case of illness.

Numerous complaints of grey-green and "slippery" water were received by the water department coming from the same general area of town. A sample brought to the water department by a customer confirmed the reported problem and preliminary analysis indicated contamination with what appeared to be a detergent solution. While emergency crews initiated flushing operations, further investigation within the contaminated area signaled the problem was probably caused by a car wash.
or laundry, based upon the soapy nature of the contaminant. The source was quickly narrowed down to a car wash and the proprietor was extremely cooperative in admitting to the problem and explaining how it had occurred. The circumstances leading up to the incident were as follows:

- On Saturday, February 10, 1979, a high pressure pump broke down at the car wash. This pump recycled reclaimed wash and rinse water and pumped it to the initial scrubbers of the car wash. No potable plumbing connection is normally made to the car wash's scrubber system.

- After the pump broke down, the car wash owner was able to continue operation by connecting a 2-inch hose section temporarily between the potable supply within the car wash, and the scrubber cycle piping.

- On Monday, February 12, 1979, the owner repaired the high pressure pump and resumed normal car wash operations. The 2-inch hose connection (cross-connection) was not removed!

- Because of the cross-connection, the newly repaired high pressure pump promptly pumped a large quantity of the reclaimed wash/rinse water out of the car wash and into a 12-inch water main in the street. This in turn was delivered to the many residences and commercial establishments connected to the water main.

Within 24 hours of the incident, the owner of the car wash had installed a 2-inch reduced pressure principle backflow preventer on his water service and all car wash establishments in Seattle that used a wash water reclaim system were notified of the state requirement for backflow prevention.

Water fountains at an East Coast Shipyards were posted “No Drinking” as workers flushed the water lines to eliminate raw river water that had entered the shipyard following contamination from incorrectly connected water lines between ships at the pier and the shipyard. Some third shift employees drank the water before the pollution was discovered and later complained of stomach cramps and diarrhea.

The cause of the problem was a direct cross-connection between the on-board salt water fire protection water system and the fresh water connected to one of the ships at the dock. While the shipyard had been aware of the need for backflow protection at the dockside tie up area, the device had not been delivered and installed prior to the time of the incident. As a result, the salt water on-board fire protection system, being at a greater pressure than the potable supply, forced the salt water, through backpressure, into the shipyard potable supply.

Fortunately, a small demand for potable water at the time of the incident prevented widespread pollution in the shipyard and the surrounding areas.
Chlordane in the Water Main

In October, 1979, approximately three gallons of chlordane, a highly toxic insecticide, was sucked back (back-siphoned) into the water system of a residential area of a good sized eastern city. Residents complained that the water “looked milky, felt greasy, foamed and smelled,” and as one woman put it, “It was similar to a combination of kerosene and Black Flag pesticide.”

The problem developed while water department personnel were repairing a water main. A professional exterminator, meanwhile, was treating a nearby home with chlordane for termite elimination. The workman for the exterminator company left one end of a garden hose that was connected to an outside hose bibb tap in a barrel of diluted pesticide. During the water service interruption, the chlordane solution was back-siphoned from the barrel through the house and into the water mains.

Following numerous complaints, the water department undertook an extensive program of flushing the water mains and hand delivered letters telling residents to flush their lines for four hours before using the water. Until the water lines were clear of the contaminant, water was hand-hauled into homes, and people went out of their homes for showers, meals and every other activity involving potable water.

Fortunately, due to the obvious bad taste, odor and color of the contaminated water, no one consumed a sufficient quantity to endanger health.

Hexavalent Chromium in Drinking Water

In July, 1982, a well meaning maintenance mechanic, in attempting to correct a fogging lens in an overcooled laser machine, installed a tempering valve in the laser cooling line, and inadvertently set the stage for a backpressure backflow incident that resulted in hexavalent chromium contaminating the potable water of a large electronic manufacturing company in Massachusetts employing 9,000 people. Quantities of 50 parts per million hexavalent chromium were found in the drinking water which is sufficient to cause severe vomiting, diarrhea, and intestinal sickness. Maintenance crews working during the plant shutdown were able to eliminate the cross-connection and thoroughly flush the potable water system, thereby preventing a serious health hazard from occurring.

The incident occurred as follows:

- Laser machine lenses were kept cool by circulating chilled water that came from a large refrigeration chiller. The water used in the chiller was treated with hexavalent chromium, a chemical additive used as an anticorrosive agent and an algicide. As a result, the chilled water presented a toxic, non-potable substance unfit for human consumption but very...
Employee Health Problems due to Cross-Connection

A cross-connection incident occurring in a modern seven-story office building located in a large city in New Hampshire, in March, 1980, resulted in numerous cases of nausea, diarrhea, loss of time and employee complaints as to the poor quality of the water.

On Saturday, March 1, 1980, a large fire occurred two blocks away from a seven-story office building in this large New Hampshire city. On Sunday, March 2, 1980, the maintenance crew of the office building arrived to perform the weekly cleaning, and after drinking the water from the drinking fountains, and sampling the coffee from the coffee machines, noticed that the water smelled rubbery and had a strong bitter taste. Upon notifying the Manchester Water Company, water samples were taken and preliminary analysis disclosed that the contaminants found were not the typical contaminants associated with fire line disturbances. Investigating teams suspected that either the nearby fire could have siphoned contaminants from adjacent buildings into the water mains, or the contamination could have been caused by a plumbing deficiency occurring within the seven story building itself.

Water pH levels of the building water indicated that an injection of chemicals had probably taken place within the seven-story building. Tracing of the water lines within the building pinpointed a 10,000 gallon hot-water storage tank that was used for heat storage in the solar heating system. It did not have any backflow protection on the make-up supply line! As the storage tank pressure increased above the supply pressure, as a result of thermal expansion, the potential for backpressure backflow was present. Normally, this would not occur because a boost pump in the supply line would keep the supply pressure to the storage tank always greater than the highest tank pressure. The addition of rust inhibiting chemicals to this tank greatly increased the degree of hazard of the liquid. Unfortunately, at the same time that the fire took place, the pressure in the water mains was reduced to a dangerously low pressure and the low pressure cutoff switches simultaneously shut off the storage tank booster pumps. This combination allowed the boiler water, together with its chemical contaminants, the opportunity to enter the potable water supply within the building. When normal pressure was reestablished in the water mains, the booster pumps kicked in, and the contaminated water was delivered throughout the building.
Dialysis Machine Contamination

Ethylene glycol, an antifreeze additive to air conditioning cooling tower water, inadvertently entered the potable water supply system in a medical center in Illinois in September, 1982, and two of six dialysis patients succumbed as a direct or indirect result of the contamination.

The glycol was added to the air conditioning water, and the glycol/water mix was stored in a holding tank that was an integral part of the medical center’s air conditioning cooling system. Pressurized make-up water to the holding tank was supplied by a medical center potable supply line and fed through a manually operated control valve. With this valve open, or partially open, potable make-up water flowed slowly into the glycol/water mixture in the holding tank until it filled to the point where the pressure in the closed tank equaled the pressure in the potable water supply feed line. As long as the potable feed line pressure was at least equal to, or greater than, the holding tank pressure, no backflow could occur. The stage was set for disaster, however.

It was theorized that someone in the medical center flushed a toilet or turned on a faucet, which in turn dropped the pressure in the potable supply line to the air conditioning holding tank. Since the manually operated fill valve was partially open, this allowed the glycol/water mixture to enter the medical center potable pipelines and flow into the dialysis equipment. The dialysis filtration system takes out trace chemicals such as those used in the city water treatment plant, but the system could not handle the heavy load of chemicals that it was suddenly subjected to.

The effect upon the dialysis patients was dramatic: patients became drowsy, confused and fell unconscious, and were promptly removed to intensive care where blood samples were taken. The blood samples revealed a build-up of acid and the medical director stated that, “Something has happened in dialysis.” Dialysis was repeated on the patients a second and third time.

Tests of the water supply to the filtration system quickly determined the presence of “an undesirable chemical in the water purification system.” The partially open fill valve was then found that it had permitted the glycol water mix to drain from the air conditioning holding tank into the medical center’s potable supply lines and then into the dialysis filtration system equipment.

Creosote in the Water Mains

Creosote entered the water distribution system of a southeastern county water authority in Georgia, in November, 1984, as a result of cross-connection between a ¾-inch hose that was being used as a priming line between a fire service connection and the suction side of a creosote pump. The hose continually supplied water to the pump to ensure the pump was primed at all times. However, while repairs were being made to a private fire hydrant, the creosote back-siphoned into the water mains and contaminated a section of the water distribution system.

Detailed investigation of the cause of the incident disclosed that the wood preservative company, as part of their operation, pumped creosote from collective pits to the other parts of their operation. The creosote pump would automatically shut off when the creosote in the pit was lowered to a predetermined level. After the creosote returned to a higher level, the pump would restart. This pump would lose its prime quite often prior to the pit refilling, and to prevent the loss of prime, the wood preservative company would connect a hose from a ¾-inch hose bibb, located on the fire service line, to the suction side of the pump. The hose bibb remained open at all times in an effort to continuously keep the pump primed.
Kool-Aid Laced With Chlordane

In August, 1978, a professional exterminator was treating a church located in a small town in South Carolina, for termite and pest control. The highly toxic insecticide chlordane was being mixed with water in small buckets, and garden hoses were left submerged in the buckets while the mixing was being accomplished. At the same time, water department personnel came by to disconnect the parsonage's water line from the church to install a separate water meter for the parsonage. In the process, the water was shut off in the area of the church building. Since the church was located on a steep hill, and as the remaining water in the lines was used by residents in the area, the church was among the first places to experience a negative pressure.

The chlordane was quickly siphoned into the water lines within the church and became mixed with the Kool-Aid being prepared by women for the vacation bible school. Approximately a dozen children and three adults experienced dizziness and nausea. Fortunately, none required hospitalization or medical attention.

Repairs were necessary to one of the private fire hydrants on the wood preservative company property, necessitating the shutting down of one of two service lines and removal of the damaged fire hydrant for repair. Since the hydrant was at a significantly lower level than the creosote pit, the creosote back-siphoned through a 

After the repairs were made to the hydrant, and the water service restored, the creosote, now in the fire lines, was forced into the main water distribution system.
Theory of Backflow and Backsiphonage

A cross-connection is the link or channel connecting a source of pollution with a potable water supply. The polluting substance, in most cases a liquid, tends to enter the potable supply if the net force acting upon the liquid acts in the direction of the potable supply. Two factors are therefore essential for backflow. First, there must be a link between the two systems. Second, the resultant force must be towards the potable supply.

An understanding of the principles of backflow and backsiphonage requires an understanding of the terms frequently used in their discussion. Force, unless completely resisted, will produce motion. Weight is a type of force resulting from the earth’s gravitational attraction.

Pressure (P) is a force per unit area, such as pounds per square inch (psi). Atmospheric pressure is the pressure exerted by the weight of the atmosphere above the earth.

Pressure may be referred to using an absolute scale, pounds per square inch absolute (psia), or gage scale, pounds per square inch gage (psig). Absolute pressure and gage pressure are related. Absolute pressure is equal to the gage pressure plus the atmospheric pressure. At sea level the atmospheric pressure is 14.7 psia. Thus,

\[ P_{\text{absolute}} = P_{\text{gage}} + 14.7 \text{psi} \]
or

\[ P_{\text{gage}} = P_{\text{absolute}} - 14.7 \text{ psi} \]

In essence then, absolute pressure is the total pressure. Gage pressure is simply the pressure read on a gage. If there is no pressure on the gage other than atmospheric, the gage would read zero. Then the absolute pressure would be equal to 14.7 psi which is the atmospheric pressure.

The term vacuum indicates that the absolute pressure is less than the atmospheric pressure and that the gage pressure is negative. A complete or total vacuum would mean a pressure of 0 psia or -14.7 psig. Since it is impossible to produce a total vacuum, the term vacuum, as used in the text, will mean all degrees of partial vacuum. In a partial vacuum, the pressure would range from slightly less than 14.7 psia (0 psig) to slightly greater than 0 psia (-14.7 psig).

Backsiphonage results in fluid flow in an undesirable or reverse direction. It is caused by atmospheric pressure exerted on a pollutant liquid forcing it toward a potable water supply system that is under a vacuum. Backflow, although literally meaning any type of reversed flow, refers to the flow produced by the differential pressure existing between two systems both of which are at pressures greater than atmospheric.

Water Pressure

For an understanding of the nature of pressure and its relationship to water depth, consider the pressure exerted on the base of a cubic foot of water at sea level. (See Fig. 1.) The average weight of a cubic foot of water is 62.4 pounds per square foot gage. The base may be subdivided into 144-square inches with each subdivision being subjected to a pressure of 0.433 psig.

Suppose another cubic foot of water were placed directly on top of the first (See Fig. 2). The pressure on the top surface of the first cube which was originally atmospheric, or 0 psig, would now be 0.433 psig as a result of the superimposed cubic foot of water. The pressure of the base of the first cube would also be increased by the same amount of 0.866 psig, or two times the original pressure.

FIGURE 1.
Pressure exerted by 1 foot of water at sea level.

1See formal definition in the glossary of the appendix.
If this process were repeated with a third cubic foot of water, the pressures at the base of each cube would be 1,299 psig, 0.866 psig, and 0.433 psig, respectively. It is evident that pressure varies with depth below a free water surface; in general each foot of elevation change, within a liquid, changes the pressure by an amount equal to the weight-per-unit area of 1 foot of the liquid. The rate of increase for water is 0.433 psi per foot of depth.

Frequently water pressure is referred to using the terms “pressure head” or just “head,” and is expressed in units of feet of water. One foot of head would be equivalent to the pressure produced at the base of a column of water 1 foot in depth. One foot of head or 1 foot of water is equal to 0.433 psig. One hundred feet of head is equal to 43.3 psig.

![Figure 2. Pressure exerted by 2 feet of water at sea level.]

**Siphon Theory**

Figure 3 depicts the atmospheric pressure on a water surface at sea level. An open tube is inserted vertically into the water; atmospheric pressure, which is 14.7 psia, acts equally on the surface of the water within the tube and on the outside of the tube.

![Figure 3. Pressure on the free surface of a liquid at sea level.]

**Figure 3.**

**Pressure on the free surface of a liquid at sea level.**

If, as shown in Figure 4, the tube is slightly capped and a vacuum pump is used to evacuate all the air from the sealed tube, a vacuum with a pressure of 0 psia is created within the tube. Because the pressure at any point in a static fluid is dependent upon the height of that point above a reference line, such as sea level, it follows that the pressure within the tube at sea level must still be 14.7 psia. This is equivalent to the pressure at the base of a column of water 33.9 feet high and with the column open at the base, water would rise to fill the column to a depth of 33.9 feet. In other words, the weight of the atmosphere at sea level exactly balances the weight of a column of water 33.9 feet in height. The absolute pressure within the column of water in Figure 4 at a height of 11.5 feet is equal to 9.7 psia. This is a partial vacuum with an equivalent gage pressure of -5.0 psig.

As a practical example, assume the water pressure at a closed faucet on the top of a 100-foot high building to be 20 psig; the pressure on the ground floor would then be 63.3 psig. If the pressure at the ground were to drop suddenly due to a heavy fire demand in the area to 33.3 psig, the pressure at the top would be reduced to -10 psig. If the building water system were airtight, the water would remain at the level of the faucet because of the partial vacuum created by the drop in pressure. If the faucet were opened, however, the vacuum would be broken and the water level would drop to a height of 77 feet above the ground. Thus, the atmosphere was supporting a column of water 23 feet high.

Figure 5 is a diagram of an inverted U-tube that has been filled with water and placed in two open containers at sea level.

If the open containers are placed so that the liquid levels in each container are at the same height, a static state will exist; and the pressure at any specified level in either leg of the U-tube will be the same.

The equilibrium condition is altered by raising one of the containers so that the liquid level in one container is 5 feet

![Figure 4. Effect of evacuating air from a column.]

![Figure 5. Pressure relationships in a continuous fluid system at the same elevation.]

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1 See formal definition in the glossary of the appendix
above the level of the other. (See Fig. 6.) Since both containers are open to the atmosphere, the pressure on the liquid surfaces in each container will remain at 14.7 psia.

If it is assumed that a static state exists, momentarily, within the system shown in Figure 6, the pressure in the left tube at any height above the free surface in the left container can be calculated. The pressure at the corresponding level in the right tube above the free surface in the right container may also be calculated.

As shown in Figure 6, the pressure at all levels in the left tube would be less than at corresponding levels in the right tube. In this case, a static condition cannot exist because fluid will flow from the higher pressure to the lower pressure; the flow would be from the right tank to the left tank. This arrangement will be recognized as a siphon. The crest of a siphon cannot be higher than 33.9 feet above the upper liquid level, since atmosphere cannot support a column of water greater in height than 33.9 feet.

Figure 7 illustrates how this siphon principle can be hazardous in a plumbing system. If the supply valve is closed, the pressure in the line supplying the faucet is less than the pressure in the supply line to the bathtub. Flow will occur, therefore, through siphonage, from the bathtub to the open faucet.

![Figure 7. Backsiphonage in a plumbing system.](image)

The siphon actions cited have been produced by reduced pressures resulting from a difference in the water levels at two separated points within a continuous fluid system.

Reduced pressure may also be created within a fluid system as a result of fluid motion. One of the basic principles of fluid mechanics is the principle of conservation of energy. Based upon this principle, it may be shown that as a fluid accelerates, as shown in Figure 8, the pressure is reduced. As water flows through a constriction such as a converging section of pipe, the velocity of the water increases; as a result, the pressure is reduced. Under such conditions, negative pressures may be developed in a pipe. The simple aspirator is based upon this principle. If this point of reduced pressure is linked to a source of pollution, backsiphonage of the pollutant can occur.

![Figure 8. Negative pressure created by constricted flow.](image)

One of the common occurrences of dynamically reduced pipe pressures is found on the suction side of a pump. In many cases similar to the one illustrated in Figure 9, the line supplying the booster pump is undersized or does not have sufficient pressure to deliver water at the rate at which the pump normally operates. The rate of flow in the pipe may be increased by a further reduction in pressure at the pump intake. This often results in the creation of negative pressure at the pump intake. This often results in the creation of negative pressure. This negative pressure may become low enough in some cases to cause vaporization of the water in the line. Actually, in the illustration shown, flow from the source of pollution would occur when pressure on the suction side of the pump is less than pressure of the pollution source; but this is backflow, which will be discussed below.

The preceding discussion has described some of the means by which negative pressures may be created and which frequently occur to produce backsiphonage. In addition to the negative pressure or reversed force necessary to cause backsiphonage and backflow, there must also be the cross-connection or connecting link between the potable water supply and the source of pollution. Two basic types of connections may be created in piping systems. These are the solid pipe with valved connection and the submerged inlet.
Figures 10 and 11 illustrate solid connections. This type of connection is often installed where it is necessary to supply an auxiliary piping system from the potable source. It is a direct connection of one pipe to another pipe or receptacle.

Solid pipe connections are often made to continuous or intermittent waste lines where it is assumed that the flow will be in one direction only. An example of this would be used cooling water from a water jacket or condenser as shown in Figure 11. This type of connection is usually detectable but creating a concern on the part of the installer about the possibility of reversed flow is often more difficult. Upon questioning, however, many installers will agree that the solid connection was made because the sewer is occasionally subjected to backpressure.

Submerged inlets are found on many common plumbing fixtures and are sometimes necessary features of the fixtures if they are to function properly. Examples of this type of design are siphon-jet urinals or water closets, flushing rim slop sinks, and dental cuspidors. Oldstyle bathtubs and lavatories had supply inlets below the flood level rims, but modern sanitary design has minimized or eliminated this hazard in new fixtures. Chemical and industrial process vats sometimes have submerged inlets where the water pressure is used as an aid in diffusion, dispersion and agitation of the vat contents. Even though the supply pipe may come from the floor above the vat, backspillage can occur as it has been shown that the siphon action can raise a liquid such as water almost 34 feet. Some submerged inlets difficult to control are those which are not apparent until a significant change in water level occurs or where a supply may be conveniently extended below the liquid surface by means of a hose or auxiliary piping. A submerged inlet may be created in numerous ways, and its detection in some of these subtle forms may be difficult.

The illustrations included in part B of the appendix are intended to describe typical examples of backspillage, showing in each case the nature of the link or cross-connection, and the cause of the negative pressure.

**Backflow**

Backflow, as described in this manual, refers to reversed flow due to backpressure other than siphonic action. Any interconnected fluid systems in which the pressure of one exceeds the pressure of the other may have flow from one to the other as a result of the pressure differential. The flow will occur from the zone of higher pressure to the zone of lower pressure. This type of backflow is of concern in buildings where two or more piping systems are maintained. The potable water supply is usually under pressure directly from the city water main. Occasionally, a booster pump is used. The auxiliary system is often pressurized by a centrifugal pump, although backpressure may be caused by gas or steam pressure from a boiler. A reversal in differential pressure may occur when pressure in the potable system drops, for some reason, to a pressure lower than that in the system to which the potable water is connected.

The most positive method of avoiding this type of backflow is the total or complete separation of the two systems. Other methods used involve the installation of mechanical devices. All methods require routine inspection and maintenance.

Dual piping systems are often installed for extra protection in the event of an emergency or possible mechanical failure of one of the systems. Fire protection systems are an example. Another example is the use of dual water connections to boilers. These installations are sometimes interconnected, thus creating a health hazard.

The illustrations in part C of the appendix depict installations where backflow under pressure can occur, describing the cross-connection and the cause of the reversed flow.

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1 See formal definition in the glossary of the appendix
Methods and Devices for the Prevention of Backflow and Back-Siphonage

A wide choice of devices exists that can be used to prevent back-siphonage and back pressure from adding contaminated fluids or gases into a potable water supply system. Generally, the selection of the proper device to use is based upon the degree of hazard posed by the cross-connection. Additional considerations are based upon piping size, location, and the potential need to periodically test the devices to ensure proper operation.

There are six basic types of devices that can be used to correct cross-connections: air gaps, barometric loops, vacuum breakers—both atmospheric and pressure type, double check with intermediate atmospheric vent, double check valve assemblies, and reduced pressure principle devices. In general, all manufacturers of these devices, with the exception of the barometric loop, produce them to one or more of three basic standards, thus insuring the public that dependable devices are being utilized and marketed. The major standards in the industry are: American Society of Sanitary Engineers ASSE, American Water Works Association (AWWA), and the University of California Foundation for Cross-Connection Control and Hydraulic Research.

Air Gap

Air gaps are non-mechanical backflow preventers that are very effective devices to be used where either back-siphonage or back pressure conditions may exist. Their use is as old as piping and plumbing itself, but only relatively recently have standards been issued that standardize their design. In general, the air gap must be twice the supply pipe diameter but never less than one inch. See Figure 12.

(2) The air gap may be easily defeated in the event that the "2D" requirement was purposely or inadvertently compromised. Excessive splash may be encountered in the event that higher than anticipated pressures or flows occur. The splash may be a cosmetic or true potential hazard—the simple solution being to reduce the "2D" dimension by thrusting the supply pipe into the receiving funnel. By so doing, the air gap is defeated.

(3) At an air gap, we expose the water to the surrounding air with its inherent bacteria, dust particles, and other airborne pollutants or contaminants. In addition, the aspiration effect of the flowing water can drag down surrounding pollutants into the reservoir or holding tank.

(4) Free chlorine can come out of treated water as a result of the air gap and the resulting splash and churning effect as the water enters the holding tanks. This reduces the ability of the water to withstand bacteria contamination during long term storage.

(5) For the above reasons, air gaps must be inspected as frequently as mechanical backflow preventers. They are not exempt from an in-depth cross-connection control program requiring periodic inspection of all backflow devices.

Air gaps may be fabricated from commercially available plumbing components or purchased as separate units and integrated into plumbing and piping systems. An example of the use of an air gap is shown in Figure 13.

FIGURE 12. Air gap.
Barometric Loop

The barometric loop consists of a continuous section of supply piping that abruptly rises to a height of approximately 35 feet and then returns back down to the originating level. It is a loop in the piping system that effectively protects against backsiphonage. It may not be used to protect against backpressure.

Its operation, in the protection against backsiphonage, is based upon the principle that a water column, at sea level pressure, will not rise above 33.9 feet (Ref. Chapter 3, Fig. 4 Page 13).

In general, barometric loops are locally fabricated, and are 35 feet high.

Atmospheric Vacuum Breaker

These devices are among the simplest and least expensive mechanical types of backflow preventers and, when installed properly, can provide excellent protection against backsiphonage. They must not be utilized to protect against backpressure conditions.

Construction consists usually of a polyethylene float which is free to travel on a shaft and seal in the uppermost position against atmosphere with an elastomeric disc. Water flow lifts the float, which then causes the disc to seal. Water pressure keeps the float in the upward sealed position. Termination of the water supply will cause the disc to drop down venting the unit to atmosphere and thereby opening downstream piping to atmospheric pressure, thus preventing backsiphonage. Figure 15 shows a typical atmospheric breaker.

In general, these devices are available in ½-inch through 3-inch size and must be installed vertically, must not have shutoffs downstream, and must be installed at least 6-inches higher than the final outlet. They cannot be tested once they are installed in the plumbing system, but are, for the most part, dependable, trouble-free devices for backsiphonage protection.

Figure 16 shows the generally accepted installation requirements—note that no shutoff valve is downstream of the device that would otherwise keep the atmospheric vacuum breaker under constant pressure.

Figure 17 shows a typical installation of an atmospheric vacuum breaker in a plumbing supply system.
Hose Bibb Vacuum Breakers

These small devices are a specialized application of the atmospheric vacuum breaker. They are generally attached to sill cocks and in turn are connected to hose supplied outlets such as garden hoses, slab sink hoses, spray outlets, etc. They consist of a spring loaded check valve that seals against an atmospheric outlet when water supply pressure is turned on. Typical construction is shown in Figure 18.

When the water supply is turned off, the device vents to atmosphere, thus protecting against backsiphonage conditions. They should not be used as backpressure devices. Manual drain options are available, together with tamper-proof versions. A typical installation is shown in Figure 19.

Pressure Vacuum Breakers

This device is an outgrowth of the atmospheric vacuum breaker and evolved in response to a need to have an atmospheric vacuum breaker that could be utilized under constant pressure and that could be tested in line. A spring on top of the disc and float assembly, two added gate valves, test cocks, and an additional first check, provided the answer to achieve this device. See Figure 20.

These units are available in the general configurations as shown in Figure 20 in sizes ½-inch through 10-inch and have broad usage in the agriculture and irrigation market. Typical agricultural and industrial applications are shown in Figure 21.

Again, these devices may be used under constant pressure but do not protect against backpressure conditions. As a result, installation must be at least 6- to 12-inches higher than the existing outlet.

A spill resistant pressure vacuum breaker (SVB) is available that is a modification to the standard pressure vacuum breaker but specifically designed to minimize water spillage. Installation and hydraulic requirements are similar to the standard pressure vacuum breaker and the devices are recommended for internal use.
Double Check with Intermediate Atmospheric Vent

The need to provide a compact device in ½-inch and ¾-inch pipe sizes that protects against moderate hazards, is capable of being used under constant pressure and that protects against backpressure, resulted in this unique backflow preventer. Construction is basically a double check valve having an atmospheric vent located between the two checks (See Figure 22). Line pressure keeps the vent closed, but zero supply pressure or backsiphonage will open the inner chamber to atmosphere. With this device, extra protection is obtained through the atmospheric vent capability. Figure 23 shows a typical use of the device on a residential boiler supply line.

Double Check Valve

A double check valve is essentially two single check valves coupled within one body and furnished with test cocks and two tightly closing gate valves (See Figure 24).

The test capability feature gives this device a big advantage over the use of two independent check valves in that it can be readily tested to determine if either or both check valves are inoperative or fouled by debris. Each check is spring loaded closed and requires approximately a pound of pressure to open.

This spring loading provides the ability to "bite" through small debris and still seal—a protection feature not prevalent in unloaded swing check valves. Figure 24 shows a cross section of double check valve complete with test cocks. Double checks are commonly used to protect against low to medium hazard installations such as food processing steam kettles and apartment projects. They may be used under continuous pressure and protect against both backsiphonage and backpressure conditions.
Double Check Detector Check

This device is an outgrowth of the double check valve and is primarily utilized in fire line installations. Its purpose is to protect the potable supply line from possible contamination or pollution from fire line chemical additives, booster pump fire line backpressure, stagnant “black water” that sits in fire lines over extended periods of time, the addition of “raw” water through outside fire pumper connections (Siamese outlets), and the detection of any water movement in the fire line water due to fire line leakage or deliberate water theft. It consists of two, spring loaded check valves, a bypass assembly with water meter and double check valve, and two tightly closing gate valves. See Figure 25. The addition of test cocks makes the device testable to insure proper operation of both the primary checks and the bypass check valve. In the event of very low fire line water usage, (theft of water) the low pressure drop inherent in the bypass system permits the low flow of water to be metered through the bypass system. In a high flow demand, associated with deluge fire capability, the main check valves open, permitting high volume, low restricted flow, through the two large spring loaded check valves.

Residential Dual Check

The need to furnish reliable and inexpensive backsiphonage and backpressure protection for individual residences resulted in the debut of the residential dual check. Protection of the main potable supply from household hazards such as home photograph chemicals, toxic insect and garden sprays, termite control pesticides used by exterminators, etc., reinforced, a true need for such a device. Figure 26 shows a cutaway of the device.

It is sized for ½″, ¾″, and 1-inch service lines and is installed immediately downstream of the water meter. The use of plastic check modules and elimination of test cocks and gate valves keeps the cost reasonable while providing good, dependable protection. Typical installations are shown in Figures 27 and 28.
Reduced Pressure Principle Backflow Preventer

Maximum protection is achieved against backsiphonage and backpressure conditions utilizing reduced pressure principle backflow preventers. These devices are essentially modified double check valves with an atmospheric vent capability placed between the two checks and designed such that this “zone” between the two checks is always kept at least two pounds less than the supply pressure. With this design criteria, the reduced pressure principle backflow preventer can provide protection against backsiphonage and backpressure when both the first and second checks become fouled. They can be used under constant pressure and at high hazard installations. They are furnished with test cocks and gate valves to enable testing and are available in sizes ¼-inch through 10 inch.

Figure 29A shows typical devices representative of ¼-inch through 2-inch size and Figure 29B shows typical devices representative of 2½-inch through 10-inch sizes.
The principles of operation of a reduced pressure principle backflow preventer are as follows:

Flow from the left enters the central chamber against the pressure exerted by the loaded check valve 1. The supply pressure is reduced thereupon by a predetermined amount. The pressure in the central chamber is maintained lower than the incoming supply pressure through the operation of the relief valve 3, which discharges to the atmosphere whenever the central chamber pressure approaches within a few pounds of the inlet pressure. Check valve 2 is lightly loaded to open with a pressure drop of 1 psi in the direction of flow and is independent of the pressure required to open the relief valve. In the event that the pressure increases downstream from the device, tending to reverse the direction of flow, check valve 2 closes, preventing backflow. Because all valves may leak as a result of wear or obstruction, the protection provided by the check valves is not considered sufficient. If some obstruction prevents check valve 2 from closing tightly, the leakage back into the central chamber would increase the pressure in this zone, the relief valve would open, and flow would be discharged to the atmosphere.

When the supply pressure drops to the minimum differential required to operate the relief valve, the pressure in the central chamber should be atmospheric. If the inlet pressure should become less than atmospheric pressure, relief valve 3 should remain fully open to the atmosphere to discharge any water which may be caused to backflow as a result of backpressure and leakage of check valve 2.

Malfunctioning of one or both of the check valves or relief valve should always be indicated by a discharge of water from the relief port. Under no circumstances should plugging of the relief port be permitted because the device depends upon an open port for safe operation. The pressure loss through the device may be expected to average between 10 and 20 psi within the normal range of operation, depending upon the size and flow rate of the device.

Reduced pressure principle backflow preventers are commonly installed on high hazard installations such as plating plants, where they would protect against primarily backsiphonage potential, car washes where they would protect against backpressure conditions, and funeral parlors, hospital autopsy rooms, etc. The reduced pressure principle backflow preventer forms the backbone of cross-connection control programs. Since it is utilized to protect against high hazard installations, and since high hazard installations are the first consideration in protecting public health and safety, these devices are installed in large quantities over a broad range of plumbing and water works installations. Figures 31 and 32 show typical installations of these devices on high hazard installations.
FiguRE 33.  Typical bypass configuration reduced pressure principle devices

FiguRE 34.  Typical installation reduced pressure principle device horizontal illustration.

Note: Device to be set 12" minimum from wall.

FiguRE 35.  Typical installation reduced pressure principle device vertical illustration.

Note: (1) Refer to manufacturers installation data for vertical mount.
(2) Unit to be set at a height to permit ready access for testing and service.
(3) Vertical installation only to be used if horizontal installation cannot be achieved.
FIGURE 36.
Typical installation double check valve horizontal and vertical installation.

FIGURE 37.
Typical installation residential dual check with straight set and copperhorn.

Note: Vertical installation only to be used if horizontal installation cannot be achieved.