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Distribution System Issue Paper

New or Repaired Water Mains

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Background and Disclaimer

The USEPA is revising the Total Coliform Rule (TCR) and is considering new possible distribution system requirements as part of these revisions. As part of this process, the USEPA is publishing a series of issue papers to present available information on topics relevant to possible TCR revisions. This paper was developed as part of that effort.

The objectives of the issue papers are to review the available data, information and research regarding the potential public health risks associated with the distribution system issues, and where relevant identify areas in which additional research may be warranted. The issue papers will serve as background material for EPA, expert and stakeholder discussions. The papers only present available information and do not represent Agency policy. Some of the papers were prepared by parties outside of EPA; EPA does not endorse those papers, but is providing them for information and review.

Additional Information

The paper is available at the TCR web site at:

http://www.epa.gov/safewater/disinfection/tcr/regulation_revisions.html

Questions or comments regarding this paper may be directed to **TCR@epa.gov.**

1.0 General Discussion of Topic

The construction, rehabilitation, and repair of water mains are extremely common activities that occur on a regular basis in all water systems. The relative frequency and nature of these activities represent a potential contamination risk to water distribution systems if proper procedures and existing standards are not followed. Installation and repair of water mains provides the potential for direct contamination of the distribution system.

The significance of the distribution system as a potential source of contamination of potable water can be illustrated by noting the magnitude of piping currently in service in the U.S. and the rate at which distribution pipes are replaced and installed. An estimated 880,000 miles (1.4 million km) of distribution piping are currently used in the U.S. to convey potable water to roughly 223 million people. Approximately 48% of existing piping is composed of unlined cast iron and 26% is judged to be in fair structural condition. Roughly 4,400 miles (7,080 km) of this pipe are replaced each year. In addition, an estimated 13,200 miles (21,240 km) of new pipe are installed each year, composed primarily of cement-lined ductile iron (48%), polyvinyl chloride (39%), and concrete pressure materials (12%) (Kirmeyer, Richards, and Smith, 1994).

Based on the Water Industry Data Base for all types of piping, there are 0.27 water main breaks per mile of pipe per year, which would equate to 237,600 water main breaks in the United States annually (Kirmeyer et al, 1994).

The AWWARF report *Pathogen Intrusion Into the Distribution System* (Kirmeyer et al., 2001), identified the following general pathways for microbial contamination of distribution systems, in order of relative risk level:

a. Water treatment contaminant breakthrough
b. Transitory contamination*
c. Cross-connections*
d. *Water main breaks and/or repairs***
e. Uncovered storage reservoirs
f. *New main installations***
g. Covered storage reservoirs
h. Purposeful contamination*

** Sources of contamination that are directly associated with the construction or repair of water mains.
* Sources of contamination that may be associated with water main construction or repair.

Three main points can be drawn from the above general list of contamination pathways.

1. Of the eight microbial contamination pathways identified in the AWWARF report, two of them are directly associated with main construction and repair.
2. Contamination via water main breaks and/or repairs generally carries a higher risk than contamination from new main installations.
3. Water main construction and repair activities can indirectly provide opportunities for contamination pathways, such as cross-connections.

2.0 Description of Potential Water Quality Problems

Table 1 lists the types of water quality problems that can occur as a result of construction and repair activities.

Table 1
Summary of Water Quality Issues Associated with Construction and Repair of Water Mains

Microbiological Issues	Physical Issues	Chemical Issues
Pathogen Contamination*	Turbidity	Harmful Chemical Contamination*
	Color	Exposure to Excess Chlorine*
		Loss of Disinfectant Residual
		Taste and Odor
		pH Stability

*Associated with the potential for direct public health impact.

Of these water quality problems, pathogen contamination, harmful chemical intrusion, and exposure to excess disinfectant residual can be linked to direct potential health risks and are addressed in this paper. Various potential health impacts have been associated with the chemical and biological issues identified in Table 1. The Chemical Health Effects Tables (U.S. Environmental Protection Agency, 2002a) provides a summary of potential adverse health effects from high/long-term exposure to hazardous chemicals in drinking water. The Microbial Health Effects Tables (U.S. Environmental Protection Agency, 2002b) provides a summary of potential health effects from exposure to waterborne pathogens.

In the event of contamination as a result of the construction or repair of water mains, the potential risk to public health is a function of:

- The type and amount of contaminant that actually enters the pipe(s),
- The type and amount of contaminant that may still enter the pipe(s) if the cause of contamination is not discovered and stopped, and
- Extent of the spread of the contaminants into the distribution system from the point(s) of intrusion.
- The disinfection and flushing measures taken prior to putting the pipe into service.

The extent and seriousness of a contamination event is dependent upon several factors, including:

- How quickly the contamination is discovered;
- The immediate response actions after discovery, such as physical isolation of the area to prevent contaminant spread and physical removal of contaminated materials; and
- The degree of success of the mitigation measures employed, such as flushing, inactivation/destruction, and identification and correction of other conditions that may contribute to the contamination problem.

2.1 Pathogen Contamination

According to Craun and Calderon (2001), from 1971 to 1998, 619 waterborne disease outbreaks were reported in community and non-community water systems. Of these, 113 outbreaks (18.3%) and an associated 21,000+ cases of illness were caused by chemical and microbial contaminants entering the distribution system or water that was corrosive to plumbing systems within building or homes. Of the 113 outbreaks attributed to distribution system deficiencies, only 6 cases (5.3%) were the result of contamination of water mains during construction or repair activities. Of the 12 *largest* outbreaks caused by distribution system contamination during the 1971-1998 period, two (16.6%) were associated with contamination of mains during storage and contamination of a broken main. 1,400 cases of acute gastroenteritis illness were associated with contamination of mains during storage, and 1,272 cases of *Giardia* were associated with the contamination of a broken main.

According to Kirmeyer et al (2000), there were 35 reported cases of waterborne disease outbreaks associated with contamination of water mains over the period 1920-1984. The report did not specify whether contamination was associated with main failure, cross connection, construction or repair work, or a combination of causes. The illnesses associated with these outbreaks included: gastroenteritis of unknown etiology (19 cases), typhoid fever (6), hepatitis A (4), shigellosis (1), giardiasis (2), salmonellosis (1), viral gastroenteritis (1), and amoebiasis (1).

An outbreak of hemorrhagic *E. coli* serotype 0157:H7 occurred in Cabool, MO during December 1989 and January 1990 and resulted in 240 cases of diarrhea and 4 deaths (Geldreich 1996). It was concluded that the illness was caused by waterborne contaminants that entered the distribution system through two major pipe breaks and 43 service meter failures that occurred during unusually cold weather. Haas et al. (1998) point out that the water utility did not practice disinfection following main repairs, relying instead on flushing the repaired main with finished water. Clark et al. (1991) used a water quality model to study contaminant propagation through the Cabool distribution system. The model results indicate that the contaminant was possibly introduced from sewer overflows that occurred at the same time as the two major water main breaks.

Five waterborne disease outbreaks in the United Kingdom were linked to microbiological contamination of water mains (Galbraith, Barrett, and Stanwell-Smith 1992). In 1946, sewage entered a defective water pipe, causing 22 cases of typhoid fever at the Royal Air Force Station, Biggleswade, Bedfordshire. In 1959, 50 typhoid fever cases in North Kerry, Northern Ireland were linked to fecal pollution from a carrier entering a rising main. In 1983 in Sussex, a leaking water pipe near a defective sewer resulted in about 145 cases of *Campylobacter* enteritis. In 1986 in Hertfordshire, a *Campylobacter* enteritis outbreak affected 257 people and appeared to have resulted from rehabilitation work on a water main.

2.2 Harmful Chemical Contamination

Documented waterborne disease outbreaks associated with harmful chemicals entering water mains are much fewer than those attributed to pathogenic microbes. Craun et al. (2001) lists a total of 35 outbreaks in U.S. community water systems from 1971 through 1998 that were attributed to harmful chemicals. None of the incidents were reported to be a direct result of construction or repair activities. No other references to chemical contamination as a result of water main construction or repair were found in the literature.

2.3 Exposure to Excess Chlorine

The conventional practice in water main disinfection is summarized in ANSI/AWWA Standard C651-92. Three different disinfection methods are recommended, each of which can result in potentially large volumes of highly chlorinated water that must be disposed of. There are several issues of potential concern associated with exposure to excess chlorine including damage to the environment, damage to distribution system facilities, worker safety, and possible back flow during hydrostatic pressure testing, disinfection, and flushing.

ANSI/AWWA Standard C651-92 suggests a temporary flushing/testing connection that includes an appropriate cross-connection control device consistent with the degree of hazard. However, backflow protection during main disinfection is optional, unless specifically identified in the purchaser's specifications.

The National Pollution Discharge Elimination System is a Federal program established under the Clean Water Act and is aimed at protecting the nation's waterways from point and non-point sources of pollution. Under this program, dechlorination is required prior to discharge to the environment. Chlorine residual limitations vary depending on receiving water characteristics (use classification, water quality standards, flow characteristics) and discharge characteristics (flow, duration, frequency). ANSI/AWWA Standard C651-92 lists the amounts of chemicals required to neutralize various residual chlorine concentrations.

3.0 Sources of Contamination

There are three phases associated with water main construction or repair activities where contamination may occur: 1) prior to construction/repair, 2) during construction/repair, and 3) after construction/repair. The conditions and contributing factors for potential microbial or chemical contamination associated with each phase are discussed below.

3.1 Contamination Sources Prior to Construction or Repair

Exposure of piping materials to contaminants can begin at the point of manufacture. Subsequent handling and storage also present opportunities for exposure. According to Pierson et al (2001) sources of contamination may include:

- Accumulation of soils, sediments, and trash which can carry and/or harbor microbial contaminants.
- Exposure to storm water runoff and other waters that can carry microbial and chemical contaminants.
- Exposure to harmful chemicals.
- Exposure to chemically contaminated soils and sediments.
- Exposure to animals and humans and their wastes.

Haas et al. (1998) document a case study from Philadelphia that illustrates the potential for microbial contamination of pipes prior to installation. A 12-inch pipe was placed on the curbside of a street for two days with no protection. Swabs were taken of the pipe's internal surface and analyzed for bacteria. Seventy-five percent of the swabs were positive for non-coliform bacterial growth on membrane filters. The Philadelphia Water Department uses the presence of non-coliform growth as an indicator for contamination.

ANSI/NSF 61 – "Drinking Water Systems Components – Health Effects" and the AWWA/ANSI standards for pipe, pipe linings/coatings, and fittings essentially establish requirements for the quality of materials and workmanship. ANSI/AWWA Standard C600-93 states that the interior of all pipe, fittings, and other appurtenances shall be kept free from dirt or foreign matter at all times. While the current ANSI/NSF 61 standard does not provide specific requirements for the sanitary conditions of piping materials that are intended for use in drinking water systems, other manuals of practice, such as AWWA Manual 20 – Water Chlorination Principles and Practices (1973), recommend precautionary measures like the use of watertight plugs at all times when construction is not actually in progress.

3.2 Contamination Sources during Construction or Repair

Water main construction or repairs are most commonly done in open trenches or excavations, during which the interiors of pipes and fittings can come into contact with soil and water in the trench. The chance of soil and water contacting piping materials during construction or repair activities is potentially much greater than it is during storage and handling prior to construction/repair. AWWA Standard C-651-99 has been developed to address potential microbial contamination during main construction or repair.

3.2.1 Contamination from Soil and Trenchwater Exposure

Kirmeyer et al. (2000) evaluated 66 water and soil samples from water main repair sites to identify and characterize potential pathogen routes of entry. The samples were analyzed for enteric viruses, total and fecal coliform bacteria, coliphage, *Clostridium perfringens* and *Bacillus subtilis*. A summary of positive samples is provided Table 2. Actual microbe concentrations are presented in the Intrusion White Paper.

Table 2 Summary of Microbial Occurrences at Main Repair Sites		
Microbe	**Presence in Trench Water Samples**	**Presence in Soil Samples**
Total Coliform	18 of 31 samples	23 of 33 samples
Fecal Coliform	12 of 18 samples	15 of 30 samples
Clostridium perfringens	9 of 30 samples	8 of 32 samples
Bacillus subtilis	24 of 30 samples	31 of 32 samples

(Adapted from: Kirmeyer et al, 2000)

These results indicate that pathogens and fecal indicator species are present at detectable levels in the soil and standing water at main break repair sites.

As reported in Haas et al. (1998), Harris (1959) investigated the bacterial loading of trenches and found that the largest bacterial densities in trench bottoms occurred next to existing pipe. Moisture content increased bacterial counts substantially (up to 100-fold). Thus, the authors concluded that the damp soil of a main repair trench is a potential source of bacterial contamination during repairs (Haas et al. 1998).

3.2.2 Cross-Connections

Another potential contamination source that can occur during or immediately after main installations or repairs are cross-connections. Health impacts associated with cross connections are described in a separate White Paper. Examples of potential cross-connections that may be associated with main construction or repair include backflow from a contaminated service connection, connection of a contaminated flushing point to the new/repaired section of main, and flow of contaminated water across a leaking or improperly seated isolation valve.

3.2.3 Contamination from Leaching

The application of linings and coatings is a common rehabilitation technique used to prevent internal corrosion and restore pipe smoothness. This process can be conducted at the point of manufacture or through an *in situ* process known as cured in place (CIP). As discussed in the Permeation and Leaching White Paper, the type of coating and curing methodology can impact the chemical stability of cementitious and organic constituents in the lining and application resin. Proper application and curing is necessary to prevent accelerated chemical leaching. Curing times are specific to the pipe type and size, resin or solvent type, and curing temperature, but are typically in the range 12 to 48 hours.

3.3 Contamination Sources after Construction or Repair

According to Pierson et al (2001), contamination of water mains after their construction or repair has been completed can occur through these pathways:

- Leaking pipe joints

- Stagnant, unsanitary water from adjacent piping sections
- Cross-connections
- Transitory pressures

ANSI/AWWA Standards 600-606 provide recommendations for pressure and leakage testing. Problems that can occur if the new or repaired pipe section is not adequately pressure tested include:

- Deflection of flexible couplings greater than that acceptable for the type of coupling may lead to leaks and subsequent contaminant intrusions.
- Pipe joints are designed to seal under high internal pressure conditions but may leak if the external pressure is higher than the internal pressure (e.g., a low-pressure pipe where there is a high groundwater level).
- Adapters may leak if not installed properly.

Haas et al. (1998) report another potential source of contamination from stagnant water created by closed valves directly adjacent to the area of main construction or repair. Distribution system water that lies stagnant for extended periods in dead end sections around the area of construction or repair can have no disinfectant residual and low dissolved oxygen, conditions which may promote the growth of bacteria. Potential issues associated with microbial growth are presented in a separate White Paper. When the construction or repair is completed, this stagnant water can then re-enter the distribution system if the area adjacent to the repair site is not properly flushed.

4.0 Prevention/Mitigation Methods

4.1 Design Practices

Water mains should be designed to provide adequate separation from potential sources of contamination such as pipes carrying sewage, storm water, or reclaimed wastewater. The selection of adequate separation is based on factors such as pipe material and joint type, soil conditions, and space for repair. The Great Lakes Upper Mississippi River Board of State Public Health and Environmental Mangers (1997) recommend the following minimum separation distances:

- 10-foot horizontal separation between water mains and sanitary sewer force mains or sewers installed in parallel;
- 18-inch vertical separation for water main crossing above or below a sewer or force main.

In practice, separation distances vary at the local level. Best management practices for pipeline design are outlined in Pierson et al (2001). These include (but are not limited to):

- Adequate numbers and types of hydrants, blow-offs, and valves
- Ability of valves to provide for complete isolation
- Minimization of number and length of tie-ins

- Minimization of distance between flushing point and valve that terminates the new main
- Simple installation configurations to enable unidirectional flow

Design practices should facilitate the effective and sanitary repair or installation, and should facilitate contamination removal through flushing.

4.2 Conditions of Piping Materials

According to Geldrich (1994), the key to prevention of contamination is physical cleanliness of new sections being installed so that there will be opportunity for successful disinfection. According to Burlingame et al (1993), the sanitary handling and storage of materials is perhaps the most critical step in protecting against microbial contamination during water main construction. The ANSI/AWWA C600-99 standard provides guidelines on pipe storage and handling procedures, but not on sanitary protection of materials and tools used in main work. In addition to storing materials at the site prior to construction, many utilities stockpile pipe materials for future use at their utility yard.

According to Pierson et al (2001), protection from contamination is equally important for stockpiled pipes. The use of pipe caps and wraps can secure new mains and prevent contamination prior to installation. The literature cites examples where pipe caps are recommended during the curing of cement mortar linings, both at the factory (North American Society for Trenchless Technology, 1999) and *in situ* (CSIRO, N.d.). In these instances, pipe end caps prevent the circulation of air that could otherwise accelerate drying and lead to cracking of the cement lining. The application of epoxy linings *in situ* typically involves use of a thermosetting resin that requires maintenance of an elevated temperature within the pipeline. This is generally accomplished by providing a recirculating system where fluid is heated and passed through the in-place liner. Because of the need to recirculate fluid, pipe end caps are typically not employed. Pipe caps can be used to conduct a static cure; however, the fluid temperature should remain above the recommended level throughout the test.

4.3 Construction and Repair Practices

ANSI/AWWA Standards 600-606 address pipe installation procedures, as well as guidelines on inspection, trench construction, pipe installation, joint assembly, flushing, pressure and leakage testing. Best management practices during the construction or repair of water mains are provided in Pierson et al (2001). Topics of interest include:

- Maintenance of pipe caps, plugs, or other protective coverings until pipes are joined.
- Provision positive flow shutoff.
- Protection of existing mains and service connections with watertight caps or covers.
- Completion of all pipe and fitting joints in the trench before work is stopped.
- Use of recommended packing and sealing materials.
- Gasket cleaning.

- Disinfection of fittings, joints, valves, and exposed existing connections with swab or spray technique.
- Disinfection of hand tools, tapping machines, and other equipment that come in contact with pipes and fittings.

Main breaks are a pervasive problem for many utilities. The cause for breaks are varied, however, according to Deb et al (2000), one of the primary causes of main breaks in otherwise structurally sound water mains is improper installations. Broken mains may become depressurized due to water loss or service shutdown.

According to AWWA Manual M20 – Water Chlorination Principles and Practices (1973), contractors and worker should be thoroughly familiar with all pertinent state and local requirements governing installations of mains. The Manual recommends the use of watertight plugs at all times when construction is not actually in progress.

According to Pierson et al (2001), trenchless technologies have gained increasing popularity over the past several years because they reduce disruption and can be cost efficient. Pierson et al (2001) discuss contamination control methods for trenchless rehabilitation and replacement techniques including pit excavation, pit dewatering, storing and handling of new liners, coupling methods, extraction of bentonite slurry, lubricant use, flushing, and chlorination. The AWWARF Manual *Demonstration of Innovative Water Main Renewal Techniques* (Deb et al, 1999) demonstrates and evaluates various trenchless technologies and identifies conditions under which each technology can be best applied.

4.4 Trench Work

As described previously, trench water has a high potential for contaminating water mains during installation and repair. Dewatering the trench to a level below the pipe invert may be necessary to avoid contamination. Pierson et al (2001) suggest using submersible pumps and fittings used for clean water work only to avoid cross-contamination from sewage water applications.

4.5 Preparing for Service

The elements for contamination control associated with preparing a new, rehabilitated, or repaired main for service include hydrostatic testing, flushing and cleaning, disinfection, and water quality testing. ANSI/AWWA Standards 600-606 address these issues.

In North America, disinfection is typically performed in accordance with AWWA Standard C651-99. Based on a survey of 250 utilities, Haas et al. (1998) found that 75% of respondents reference the AWWA Standard C651 in their construction documents. The AWWARF report *Development of Disinfection Guidelines for the Installation and Replacement of Water Mains* (Haas et al., 1998) documents the results of actual field evaluations to test the adequacy of AWWA Standard C651 for Disinfecting Water Mains. The researchers concluded that the AWWA standard provides adequate disinfection: the AWWA-recommended disinfection dose of 25 mg/L for a 24-hour contact time provides more than a 4-log (99.99%) inactivation of HPC organisms. It was also found that approximately 10 mg/L free chlorine reduces HPC bacteria to less than 100 colony-forming units per milliliter (cfu/mL).

The AWWARF report Practices *to Prevent Microbiological Contamination of Water Mains* (Pierson et al, 2001) provides examples of water main release-to-service data developed by individual utilities. Figure 1 shows guidance developed by the Texas Natural Resource Conservation Commission related to public water supplier response to loss of pressure to all or parts of the distribution system and release-to-service criteria.

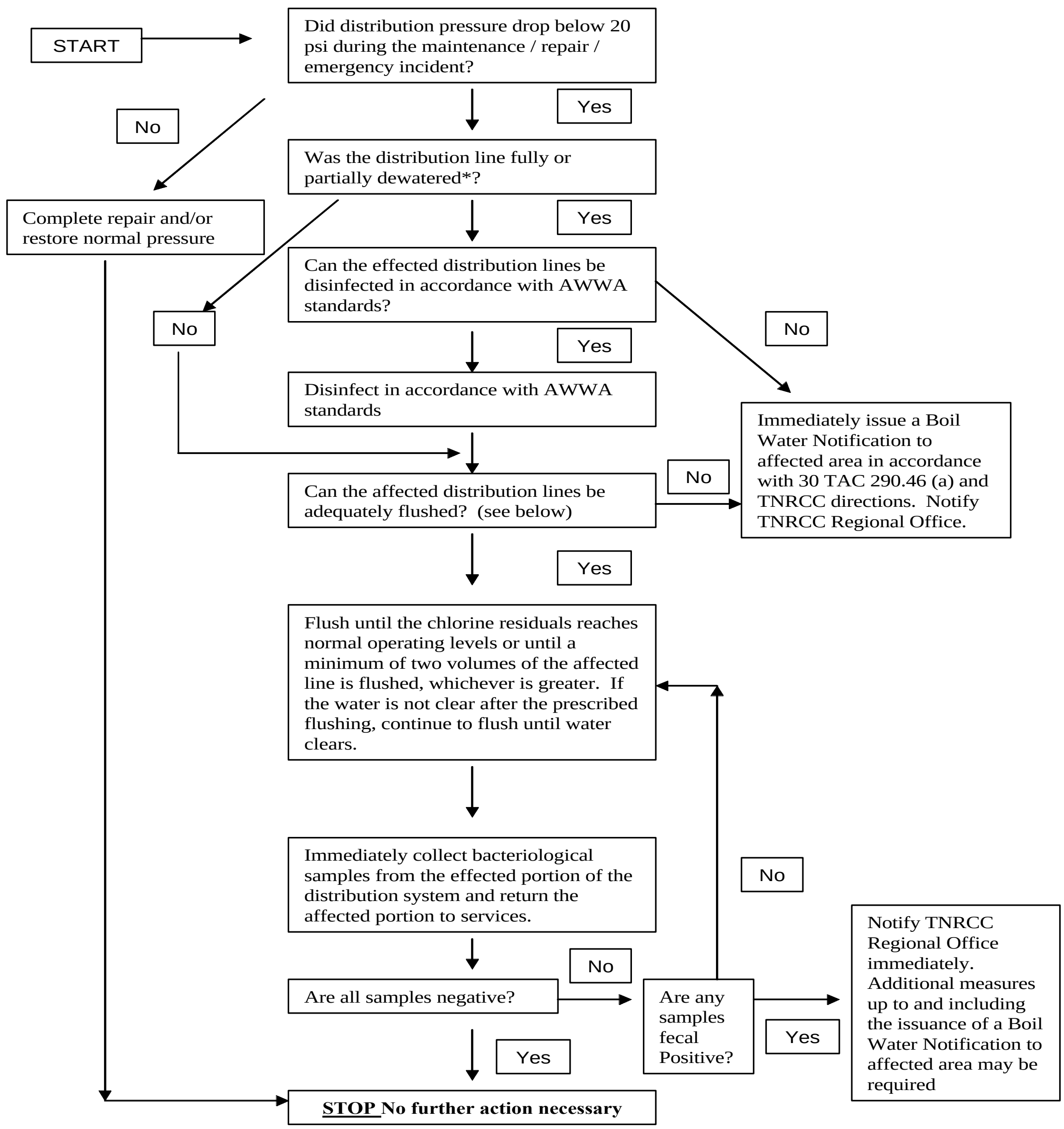

Figure 1
Public Water Supplier Response to Loss of Pressure to All or Parts of the Distribution System
(Source: Texas Natural Resource Conservation Commission)

Figure 1. Public Water Supplier Response to Loss of Pressure to All or Parts of the Distribution System (Source: Texas Natural Resource Conservation Commission)

5.0 Summary

Installation and repair of water mains provides a direct opportunity for contamination of the distributed water. Roughly 4,400 miles (7,080 km) of cast iron pipe are replaced each year, and an estimated 13,200 miles (21,240 km) of new pipe are installed each year. Of the 12 largest waterborne disease outbreaks reported between 1971 and 1998, two were associated with main construction and repair activities. 1,400 cases of acute gastroenteritis illness were associated with contamination of mains during storage, and 1,272 cases of *Giardia* were associated with the contamination of a broken main. Public health issues associated with Cross Connections and Pathogen Intrusion are addressed in separate White Papers. Contamination can occur before, during, and after construction or repair if existing AWWA standards are not followed. ANSI/AWWA Standards 600-606 address pipe installation procedures, as well as guidelines on inspection, trench construction, joint assembly, flushing, pressure and leakage testing. Best management practices during the construction or repair of water mains are provided in AWWA M20 and Pierson et al (2001). Specific sanitary criteria in AWWA standards for the storage and handling of water mains focus on preventing gross contamination.

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