Water Research Foundation
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guardians of drinking water quality

Effective Microbial Control Strategies for Main Breaks and Depressurization

Report #4307a

Subject Area: Water Quality

Effective Microbial Control Strategies for Main Breaks and Depressurization

About the Water Research Foundation

The Water Research Foundation (WRF) is a member-supported, international, 501(c)3 nonprofit organization that sponsors research that enables water utilities, public health agencies, and other professionals to provide safe and affordable drinking water to consumers.

WRF's mission is to advance the science of water to improve the quality of life. To achieve this mission, WRF sponsors studies on all aspects of drinking water, including resources, treatment, and distribution. Nearly 1,000 water utilities, consulting firms, and manufacturers in North America and abroad contribute subscription payments to support WRF's work. Additional funding comes from collaborative partnerships with other national and international organizations and the U.S. federal government, allowing for resources to be leveraged, expertise to be shared, and broad-based knowledge to be developed and disseminated.

From its headquarters in Denver, Colorado, WRF's staff directs and supports the efforts of more than 800 volunteers who serve on the board of trustees and various committees. These volunteers represent many facets of the water industry, and contribute their expertise to select and monitor research studies that benefit the entire drinking water community.

Research results are disseminated through a number of channels, including reports, the Website, Webcasts, workshops, and periodicals.

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Effective Microbial Control Strategies for Main Breaks and Depressurization

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FOREWORD

The Water Research Foundation (WRF) is a nonprofit corporation dedicated to the development and implementation of scientifically sound research designed to help drinking water utilities respond to regulatory requirements and address high-priority concerns. WRF’s research agenda is developed through a process of consultation with WRF subscribers and other drinking water professionals. WRF’s Board of Trustees and other professional volunteers help prioritize and select research projects for funding based upon current and future industry needs, applicability, and past work. WRF sponsors research projects through the Focus Area, Emerging Opportunities, and Tailored Collaboration programs, as well as various joint research efforts with organizations such as the U.S. Environmental Protection Agency and the U.S. Bureau of Reclamation.

This publication is a result of a research project fully funded or funded in part by WRF subscribers. WRF’s subscription program provides a cost-effective and collaborative method for funding research in the public interest. The research investment that underpins this report will intrinsically increase in value as the findings are applied in communities throughout the world. WRF research projects are managed closely from their inception to the final report by the staff and a large cadre of volunteers who willingly contribute their time and expertise. WRF provides planning, management, and technical oversight and awards contracts to other institutions such as water utilities, universities, and engineering firms to conduct the research.

A broad spectrum of water supply issues is addressed by WRF's research agenda, including resources, treatment and operations, distribution and storage, water quality and analysis, toxicology, economics, and management. The ultimate purpose of the coordinated effort is to assist water suppliers to provide a reliable supply of safe and affordable drinking water to consumers. The true benefits of WRF’s research are realized when the results are implemented at the utility level. WRF's staff and Board of Trustees are pleased to offer this publication as a contribution toward that end.

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Utilities Participating in Project Survey

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California American Water – Los Angeles
California American Water – Monterey Division
California American Water – Sacramento
California American Water – Thousand Oaks/Newbury Park
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City of Bellevue Utilities, WA
City of Bloomington, IL
City of Boulder, CO
City of Cocoa, FL
City of Fort Worth, TX
City of Greensboro, NC
City of Raleigh, NC
City of Tucson Water Department, AZ
District of Columbia Water and Sewer Authority, DC
Los Angeles Department of Water & Power, CA
Loudoun Water, VA
Manatee County Utilities, FL
Missouri American Water, MO
Moorhead Public Service, MN
New Jersey American Water, NJ
Philadelphia Water Department, PA
Seattle Public Utilities, WA
Spartanburg Water, SC
United Utilities, UK
WaterOne, KS
West Virginia American Water, WV

Featured Case Study Participating Utilities

Charlotte Mecklenburg Utilities, NC
City of Boulder, CO
Denver Water, CO
City of Fort Worth, TX
Los Angeles Department of Water & Power, CA
New Jersey American Water, NJ

Field Study Participating Utilities

Charlotte Mecklenburg Utilities, NC
City of Bellevue Utilities, WA
City of Boulder, CO
City of Fort Worth, TX

Other Contributors

The following individuals functioned as liaisons with AWWA with regards to updating the AWWA Standard 651 – Disinfecting Water Mains:

Gary Burlingame, Philadelphia Water Department, PA
Betsy Reilly, Massachusetts Water Resources Authority, MA

In addition, Dr. Grace Jang assisted our Team on many occasions as she functioned as WaterRF Project Officer. Her advice and support of the Project Advisory Committee, Jim Cherry, Virginia Beach Public Utilities; VA; Kenneth Mercer, American Water Works Association; Peter Marsden, Drinking Water Inspectorate, UK; and William Fromme, Greater Cincinnati Water Works, OH were instrumental in making this Project a success.

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EXECUTIVE SUMMARY

OBJECTIVES

The purpose of this project was to improve utility responses to main breaks and depressurization events to better protect public health. The specific project objectives included the following:

- Evaluate the effectiveness of disinfection and operational practices to mitigate microbial risks
- Identify parameters to quantify the level of control needed to mitigate the risks of microbial contamination from main breaks and depressurization events

BACKGROUND

By some estimates, there are over 700 water main breaks in the United States every day that require repair. This is in addition to the breaks and repairs that occur daily in other countries in North America, the United Kingdom, and other locations around the world. Some of these breaks are small, do not involve depressurization, and are fixed with a repair clamp, often maintaining some pressure in the pipe. For this type of main break, there is likely little chance of microbial contaminants entering the distribution piping network. At the other end of the spectrum, some breaks are much larger, with catastrophic events occurring on large transmission lines. These larger events may result in widespread depressurization for an extended period of time and may require removing and replacing sections of pipe and valves. This type of break could result in the entry of microbial and chemical contaminants both at the repair site and in the depressurized areas of the distribution system away from the break area.

APPROACH

The study, which was co-funded by the Water Research Foundation and the Drinking Water Inspectorate, included the following sequence of activities:

Step 1: Define Terminology and Establish the Baseline of Practice

This step developed a common understanding of the issues (both in the United States and the United Kingdom), provided a framework for evaluating risks, and identified the current practices in use today.

Step 2: Conduct Laboratory and Pilot Studies and Risk Modeling

This step formed the scientific basis for evaluating risks and their respective response measures. To model the risk of contamination during a main break, four factors were considered:

- The disinfectant demand of the contaminant
- The inactivation kinetics of microbial contaminants
- The effectiveness of contaminant removal by flushing

- The risk of the material remaining after disinfection and/or flushing

Step 3: Identify/Pilot Test Field and Monitoring Activities

Step 3 translated the science from the laboratory into the real world, ultimately including the beta testing of actual risk mitigation procedures. This step was based on existing and potential field practices that could be used by utilities to mitigate the risks of microbial contamination during a main break repair. There are three main aspects of Step 3:

- Identify field risk reduction strategies
- Develop a monitoring program to confirm disinfectant efficacy
- Beta-test sanitation control strategies

Step 4: Develop Tiered Risk Management Strategy Including Multiple Barriers

Step 4 synthesized the results of the study and developed a tiered risk management strategy. This step included a workshop with utility and regulatory representatives to balance risk management with practical methodologies to form the basis for appropriate response to main breaks.

Step 5: Prepare Work Products and Final Report

The study concluded with a final report and related outreach materials developed to inform drinking water practitioners about the identified best management practices to reduce the risks of microbial contamination from main breaks and depressurization. In addition, a Pocket Guide with sanitation procedures was developed as an add-on to this project.

RESULTS/CONCLUSIONS

As part of the Risk Management strategy, four categories of breaks and responses were developed and summarized:

- Type 1 — Positive pressure maintained during excavation and repair
- Type 2 — Positive pressure maintained during excavation, followed by controlled shut down for repair
- Type 3 — Loss of pressure at break site/possible local depressurization
- Type 4 — Catastrophic failure, loss of pressure at break site, and widespread depressurization

Table ES.1 was developed to help guide the process of categorizing and responding to main breaks.

Table ES.1
Main Break Types and Responses

Type 1 Break	Type 2 Break	Type 3 Break	Type 4 Break
Positive pressure maintained during break	Positive pressure maintained during break	Loss of pressure at break site/ possible local depressurization adjacent to the break	Loss of pressure at break site/ widespread depressurization in the system
Pressure maintained during repair	Pressure maintained until controlled shutdown	Partial or un-controlled shutdown	Catastrophic event/failure
No signs of contamination intrusion	No signs of contamination intrusion	Possible contamination intrusion	Possible/ actual contamination intrusion
Procedures	Procedures	Procedures	Procedures
Excavate to below break	Excavate to below break	Uncontrolled shutdown	Catastrophic failure response
Maintain pit water level below break	Maintain pit water level below break	Document possible contamination	Document possible contamination
Repair under pressure	Controlled shutdown	Disinfect repair parts	Shut-off customer services in affected area
Disinfect repair parts	Disinfect repair parts	Conduct scour flush (3 ft/sec for 3 pipe volumes)	Disinfect repair parts
Check residual disinfectant level in distribution system	Conduct low velocity flush (flush 3 pipe volume)	Conduct slug chlorination (CT of 100 mg/L-min[3])	Conduct scour flush (3 ft/sec for 3 pipe volumes)
No Boil Water Advisory (BWA)	Check residual disinfectant level in distribution system	Check residual disinfectant level in distribution system and ensure it is adequate	Conduct slug chlorination (CT of 100 mg/L-min[3])
No bacteriological samples	No Boil Water Advisory (BWA)	Instruct customers to flush premise plumbing upon return to service	Instruct customers to flush premise plumbing upon return to service
	No bacteriological samples	BWA – TBD; based on depressurization extent and presence of contamination[1,2]	Check residual disinfectant level in distribution system and ensure it is adequate
		Bacteriological samples - TBD; based on depressurization extent and presence of contamination[1,2]	Issue BWA/ Boil Water Notice or “Do Not Drink” Order
			Bacteriological sampling required

Notes:

1. TBD – To be Determined
2. If depressurization is limited to the pipe section, or area flushed or disinfected, then a boil water advisory and/or bacteriological testing are not needed. However, if the area of depressurization is larger than the treated area, then a precautionary boil water advisory and/or bacteriological testing should be considered.
3. In highly tuberculated pipes, a higher CT should be considered to compensate for possible lower flushing efficiency.

There is an increasing risk of intrusion and contamination associated with the types of breaks proceeding from Type 1 (Minimal Risk) to Type 4 (Highest Risk). Likewise, the suggested mitigation responses are tailored to increase in intensity and effectiveness with each type of break from 1 to 4. The report also contains a Main Break Risk Triage Flowchart which can be used by utilities to respond to main breaks in effective and efficient ways.

APPLICATIONS AND RECOMMENDATIONS

The following groups can immediately benefit from the results of this project:

- AWWA: updating the AWWA Standards to improve clarity
- Water Utilities: revising existing water utility guidelines and practices to improve sanitation during main break repair
- Regulatory Agencies: revising regulatory requirements to better match the Risk with the Response framework proposed by this report

Regarding AWWA Standards, Standard 651, *Disinfecting Water Mains*, has already benefited from the research and findings of this study. Project staff has shared findings with AWWA staff and volunteer committees and changes to the Standard are underway. The Technical Guidance Notes used in the United Kingdom already advocate a tiered risk-based approach; any revision of the Notes may want to consider the findings of this project as well.

Regarding water utility practices, the summary tables and Main Break Triage Flowchart developed in the report provide a basis for updating utility main break repair practices to more effectively address sanitation and customer issues. Four practices are described in detail to help operations and maintenance staff address the multitude of issues faced during a break and repair: monitoring disinfectant residuals, attaining scour flushing velocities, implementing slug disinfection, and maintaining positive pressure. To help field crews who are doing repairs to remember and implement good practices during repair of water main breaks, a Field Pocket Guide listing good practices was developed as part of this project. The Field Pocket Guide, titled, *Good Practices for Preventing Microbial Contamination of Water Mains*, may also be useful in utility training programs for crews involved in these activities.

Concerning regulatory agencies, the laboratory research conducted on disinfection and flushing provides a sound technical basis for public health protection and mitigation measures related to main breaks. The use of water pressure and presence or absence of contamination to trigger boil water advisories and notices will hopefully clarify the risk associated with the four types of main breaks and help regulators and utilities focus their efforts and manage customer notifications in the most efficient way possible.

PROJECT DELIVERABLES

All the project deliverables can be downloaded from the 4307 project page. Printed copies of the final report and Field Pocket Guide can be ordered as 4307a. Additionally, the Field Pocket Guide can be ordered separately as 4307b. The Appendices from the report are posted separately on the WRF Website. Lastly, a Fact Sheet was developed to highlight the key findings.

RESEARCH PARTNER

Drinking Water Inspectorate

CHAPTER 1: INTRODUCTION AND APPROACH

BACKGROUND

By some estimates, there are over 700 water main breaks and repairs in the United States every day. This is in addition to the breaks and repairs that occur daily in other countries in North America, the United Kingdom, and other locations around the world. Some of these breaks are small, do not involve depressurization, and are repaired with a repair clamp, often maintaining some pressure in the pipe. For this type of main break, there is likely little chance for microbial contaminants to enter the distribution piping network. At the other end of the spectrum, some breaks are much larger, even catastrophic events occurring on large transmission lines. These larger events may result in widespread, extended duration depressurization and involve removing and replacing sections of pipe and valves. This type of break has the potential for entry of microbial (and chemical) contamination both at the repair site and potentially in the depressurized areas of the distribution system away from the break area.

This distribution system contamination concern is not just recent as indicated by the following reference and quote:

> *"In 1895 Brouardel and Thoinot wrote…'Another type of contamination is that which occurs not at the spring itself, but rather within the course of a distribution system: there is nothing more common than for the water supply in a town to be pure at the point of emergence, but for the distribution system within the town to be severed or ruptured, thus draining the contaminated urban soil' " (Goubert 1986).*

More recently, concerns have been raised regarding the integrity of water distribution systems as the final barrier to provide safe drinking water. The proportion of reported waterborne disease outbreaks due to distribution system deficiencies has increased from about 12% up to 39% in recent decades (Craun et al. 2006; Liang et al. 2006; and Blackburn et al. 2004). Considering only outbreaks in community water systems, of the 30 reported during 2001-2004, 77% were related to deficiencies in water distribution systems. In a June 2000 survey (Pierson et al. 2001) of Philadelphia water distribution system staff, 56% indicated that loss of positive pressure before securing a main break was a "common occurrence", while 44% indicated it occurred "sometimes". None of the respondents indicated that loss of positive pressure before securing a main was a "rare occurrence" or "never occurred". In recent years, the U.S. Environmental Protection Agency (EPA) has indicated it is interested in additional study of water distribution systems and has identified water main breaks and repairs as an increased area of interest (EPA 2010). The pathogen risks to be considered during a main break and repair include protozoa, bacteria, and viruses, and these potential contaminants may or may not be associated with particles in the surrounding soil and within the pipe itself.

There are several interrelated issues that come into play when addressing risks associated with water main breaks and repair practices:

- Definitions of various types of main breaks (or bursts as termed in the UK) are lacking or not consistent;

- Site conditions and repair practices vary widely across the industry including pipe material, age of infrastructure, rural versus inner city, weather, soils, depth of cover, and groundwater, just to name a few;
- A Risk Management Structure to assess the risk of contamination associated with main break and depressurization events does not exist;
- Assessment methods to determine the effectiveness of mitigation measures such as flushing procedure is underdeveloped;
- The time required for bacteriological analysis to develop results from monitoring at main breaks is lengthy;
- AWWA Standard C651, Disinfecting Water Mains (AWWA 2005), is often referenced by regulatory agencies in emergency repair of water main breaks; however, this standard is mostly applicable for new installations;
- States or regulatory agencies want to encourage better sanitary procedures for main break repairs but do not have a good reference or standard protocol to require; and
- There is inconsistency of U.S. regulator concern about the issue – some states require boil water advisories for even small breaks, whereas other states have other higher priorities.

Water RF and the Drinking Water Inspectorate recognized these important issues and developed a request for a solicited proposal to address the important water industry needs. This study is not intended to address all of these issues in detail but will likely touch each one in some manner. Water RF Project 4307, Effective Microbial Control Strategies for Main Breaks and Depressurization is referred to as the "Project" in this report.

PROJECT PURPOSE AND APPROACH

The purpose of this Project is to improve utility responses to main breaks and depressurization events to better protect public health. The specific project objectives include the following:

- Evaluate the effectiveness of disinfection and operational practices to mitigate risks; and
- Identify parameters to quantify the level of control achieved.

The Project team's technical approach aimed to meet the Project objectives and provide an opportunity for information exchange with utilities on the public health risks associated with main breaks. The study included the following sequence of activities:

Step 1: Define Terminology and Establish the Baseline of Practice

This step developed a common understanding of the issues (both in the US and the UK), provided a framework for evaluating risks, and identified the current practices in use today. The scope of Step 1 included a questionnaire/survey of key utilities, and the formation of a compact technical team of practitioners to meet, use the technical data gathered, and propose definitions and break/repair categories as a basis for mitigation strategies. (Terms and Definitions have been defined in Appendix A.)

Step 2: Conduct Laboratory and Pilot Studies and Risk Modeling

This step formed the scientific basis for evaluating risks and their respective response measures. To model the risk of contamination of a main break, four pieces of information were collected and determined:

- The disinfectant demand of the contaminating material
- The inactivation kinetics of microbial contaminants
- The effectiveness of removal of contamination by flushing
- The risk of the material remaining after disinfection and/or flushing

Since the amount of contamination can vary in any situation, it was necessary to model a range of contamination scenarios and determine protocols that were: 1) universally applicable, or 2) applicable to a set of clearly defined conditions. Although it may be advantageous to have a universal solution (provided it was feasible), it was determined to be more practical to explore a range of protocols that could be used under their respective defined conditions.

Step 3: Identify/Pilot Test Field and Monitoring Activities

Step 3 translated the science from the laboratory into practical application, ultimately including the beta testing of actual risk mitigation procedures. This step was based on field practices that are being or could be used by utilities to mitigate the risks of microbial contamination during a main break repair. There are three main aspects of Step 3:

- Identify field risk reduction strategies
- Develop monitoring program to confirm disinfectant efficacy
- Beta-test sanitation control strategies

For a field procedure to become widely used in practice, it needed to be effective, practical, economical, and acceptable to regulatory agencies. Potential effectiveness was largely evaluated during Step 2. The practical aspects of the procedures were evaluated during Step 3 by working with the utility partners to identify what is achievable in the field, developing a monitoring program to demonstrate how well the laboratory results translate to the field, and beta-testing the recommended procedures in a field setting.

Step 4: Develop Tiered Risk Management Strategy Including Multiple Barriers

Step 4 synthesized the results of the study and culminated in the development of a tiered risk management strategy. This step included a workshop with utility and regulatory representatives to balance risk management with practical methodologies to form the basis for appropriate response to main breaks. There are three aspects of Step 4 as follows:

- Conduct a Risk Management Workshop
- Develop a Tiered Risk Management Strategy
- Document the Best Management Practices

Step 5: Prepare Work Products and Final Report

The study concluded with a final report and related outreach materials developed to inform drinking water practitioners about the identified best management practices to reduce the risks of microbial contamination from main breaks and depressurization. In addition, a previously developed Pocket Guide with Sanitation Procedures was updated as part of an add-on to this Project.

CHAPTER 2:
CURRENT STATUS OF SANITATION PROCEDURES DURING MAIN BREAK REPAIR

OVERVIEW

Good practices by operators generally reduce the risk of microbial contamination from the onset of the break through to repair and restoration of service. Main breaks are identified in one of two ways, through physical evidence, usually water flowing at the ground surface, or acoustically through listening on pipelines for the sound made by water escaping pressurized pipe. The physical display of a water main leak often requires an initial assessment to determine if the break is creating an immediate problem by virtue of significant flow (loss of pressure implied), damage, or safety risk. Many leaks have apparent low flow and are not causing immediate significant damage or hazard. These modest leaks, like most acoustically detected leaks, require identification of the leak and scheduling of a repair crew but without urgency. For discussion purposes, leaks and their repair are divided into two pressure categories. The first is the leak where there is no apparent or likelihood of loss of pressure to customers and the second is one where there is a likely loss of pressure.

Breaks without Loss of Pressure

Without loss of pressure, water service is not interrupted to maintain pressure to customers and aid in pinpointing the leak location. It is common good practice to dig around the pipe and below the pipe to create a repair work area. Depending on the nature of the leak, water flow may be reduced by partially closing valves as work continues. Before water is completely shut off, the work pit is dug and a sump pump is effectively controlling water levels below the pipe level. As positive pressure is maintained, effectively no contaminated water external to the pipe is allowed to enter the pipe. In some cases pressure is maintained throughout the repair as a repair clamp is secured to the defective pipe location. It is important to note that the majority of leaks that are located proactively and repaired can fall under this category. With good practices such as maintaining pressure until pit water levels in the work area are below the pipe and proper flushing, microbial risk from infiltration is minimized.

Breaks with Loss of Pressure

In other circumstances, such as where a defective pipe needs to be removed and replaced, the pipe is fully depressurized by shutting down valves near to the work site. In this case, disinfection procedures are followed including placement of chlorine into the pipe and swabbing of the area. The depressurized area may be limited to a single block of customers; however, depending on valve operability and placement, the depressurized area may be larger. Restoration of the main to full service then requires flushing and removal of air from the pipe which is typically accomplished by directing flow to a nearby hydrant or blowoff as valves are opened. The hydrant provides some visual evidence of water condition as air is removed and any turbidity clears. Good practice includes checking the hydrant flow for a measurable chlorine residual. If chlorine has been placed in the pipe at the repair, it is also prudent to check that any excessive chlorine has been removed.

With loss of pressure before repairs are even initiated, water flow is generally reduced quickly to reduce water loss, damage, and safety hazards. Severe, uncontrolled flow may extend the loss of pressure well beyond the immediate area of the break. In areas with significant topography changes, a leak in a valley can cause loss of pressure at the top of a hill nearby. If a major transmission pipe has burst, the supply to an area may be jeopardized with resulting depressurization to a large area. Managing contamination risks for breaks in this category must take into consideration the potential of contamination from offsite backsiphonage from undetected pipe leaks or reverse flow from customer services.

This type of break requires a shutdown or causes depressurization before the repair area is isolated from the environment. Following the water line shutdown, there is obvious potential for saturated soil near the pipe to deliver contaminated water back into the pipeline. In addition to addressing breaks where pressure is maintained, the analysis in subsequent chapters deals with worst case scenarios, which is prudent when dealing with human health issues.

AWWA STANDARD 651- DISINFECTING WATER MAINS (AWWA 2005)

This standard, or portions of the standard, are routinely used by water agencies and public health officials to provide guidance on procedures to disinfect new water mains and breaks on existing system components. It was last updated in 2005 and is being revised at the time this report was developed. The standard defines the minimum requirements for disinfection of water mains including the preparation of water mains, application of chlorine, and sampling and testing for the presence of coliform bacteria. It describes the forms of chlorine that can be used; procedures to be used when mains are wholly and partially dewatered; trench treatment; swabbing of pipe; flushing; slug disinfection; bacteriological sampling procedures; records for compliance; and requirements for re-disinfection. Many of the requirements in the current Standard 651 appear to be more applicable to new main installation as opposed to repair of broken water mains. The new standard is targeted to be issued in 2014 and will likely use some of the information and findings from this Water RF Project.

PROJECT SURVEY RESULTS

A survey questionnaire was prepared and distributed to 34 North American utilities, and one United Kingdom (UK) utility. The final results of the utility questionnaire are summarized below in two parts: 1) compiled results from the 27 North American utilities that returned the survey and 2) results from the single UK utility participant for comparison. The full survey results are contained in Appendix B with key findings summarized below.

North American Utilities

Figure 2.1 presents the results for total main breaks per year per utility ranging from less than 1 to more than 3000 main breaks per year. In Figure 2.2, the main break data is normalized by dividing the total main breaks per year by the length of pipelines in each system. The majority of the utilities that responded to the questionnaire have less than 0.30 main breaks per mile of pipeline per year, with a median value of about 0.18. These results are comparable to prior work which reports a national average of 0.27 main breaks per mile per year (Kirmeyer et al. 1994).

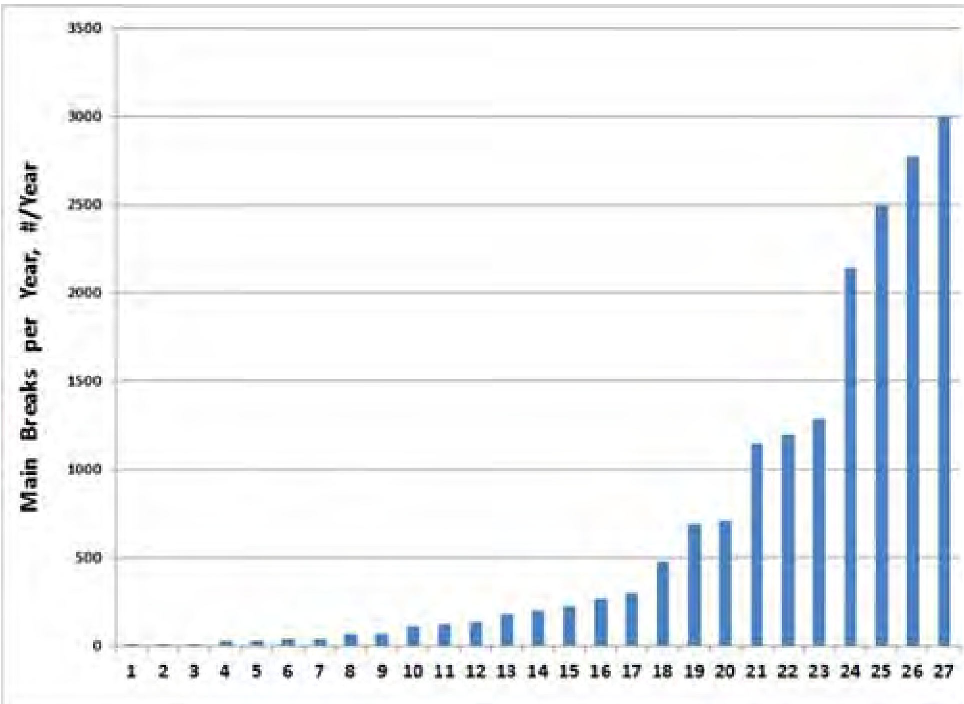

Figure 2.1 Main Breaks per Year, Total per North American Utility Participant

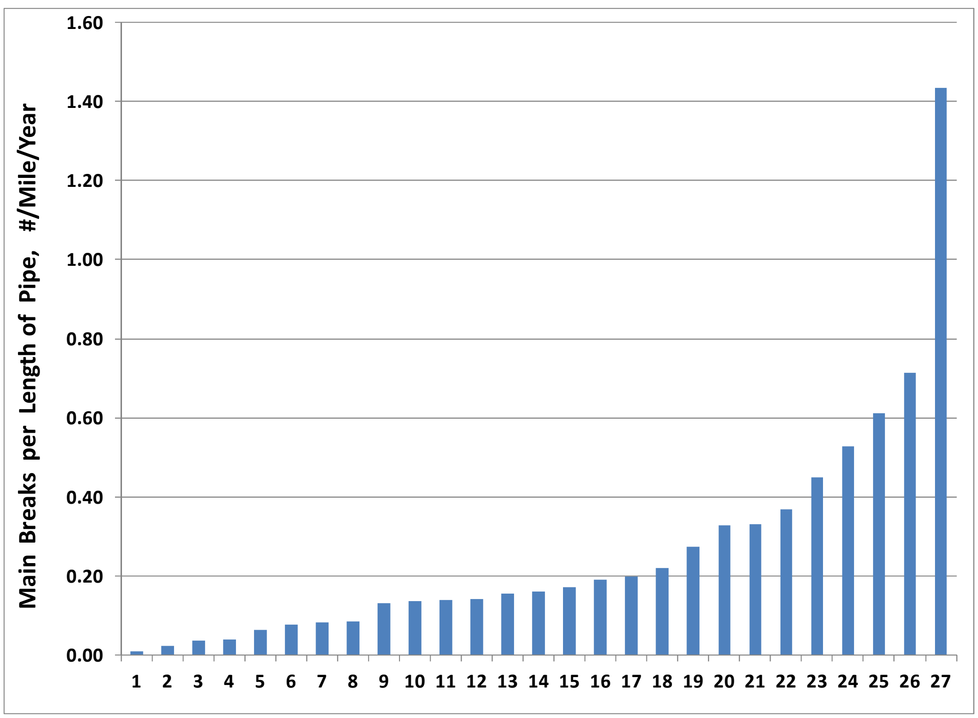

Figure 2.2 Main Breaks per Mile of Pipe per Year, North American Utility Participants

Table 2.1 presents results for whether there was a seasonal component to main breaks in each system. About 70% of the utilities indicated that there is a seasonal component to main breaks, with the winter season having the highest incidence due to issues related to cold weather conditions. On average, 38% of main breaks occurred in the winter season, with one utility reporting that almost 80% of main breaks occurred in the winter. Another time of high break failures documented in the southern US is the impact of drought, usually in summer that dries clayey soils and causes high incidence of failures. Note high rates of breaks in a compressed time frame can lead to less experienced or contracted crews being relied upon to handle the increased work-load of main break repairs during the winter season or crews working in great haste to keep up with failures. This presents a challenge for the utility to maintain consistency in its response procedures.

Table 2.1
Seasonal occurrence of main breaks

Season	Min.	Max.	Average
Winter	18%	79%	38.2%
Spring	4%	25%	14.5%
Summer	5%	39%	22.5%
Fall	7%	38%	24.9%

Responses to questions on how utilities respond to main breaks include:

- 67% of respondents have written procedures for the repair of main breaks
- A wide variety of repair procedures was noted
- 96% of utilities provide training on sanitary practices during water main break repairs, with the majority of training being conducted informally
- 89% reported that they follow portions of AWWA Standard C651, Disinfecting Water Mains
- All respondents indicated that flushing is performed as part of the main break repair return-to-service (which is a part of AWWA Standard C651)
- About 50% of utilities require water quality sampling before a return-to-service

The survey questionnaire requested information on Boil Water Advisory (BWA) occurrence. As shown on Table 2.2, most utilities included in the questionnaire have BWA's very rarely or never. There are several that do have BWA's every one to five years or even one or more per year.

Table 2.2
Frequency of boil water advisories

Boil Water Advisory Frequency	Utilities
1 or More per Year	5
Every 1 to 5 Years	3
Very Rare	11
Never	7

The survey questionnaire requested information on the types of customer interactions each utility has with customers in response to main break repairs. As shown on Table 2.3, most provide notification at a minimum, with many providing instructions to customers to flush their premise plumbing upon return-to-service.

Table 2.3
Customer interactions related to main break repairs

Types of Customer Contacts	Utilities
Instructions to Flush Premise Plumbing on Return to Service	8
Notification Only	11
Instructions to Flush Premise Plumbing and/or Notification	4
None	4

United Kingdom Participant

Results for the participating utility from the UK are summarized in this section. It should be noted that the one participant from the UK represents a substantial portion of the country. Demographics of the UK participant include:

- Estimated Population Served – 7,200,000
- Number of Service Connections – 2,500,000
- Length of Pipeline – 25,000 Miles

The UK utility reported a main break frequency of 0.06 main breaks per mile of pipeline per year. By comparison, this is toward the low end of the data collected from the North American utilities. The seasonal component to the break frequency was reported as follows:

- Winter 40%
- Spring 20%

- Summer 20%
- Fall 20%

Note that the winter frequency of 40% is nearly equivalent to the overall average frequency of winter main breaks reported for the North American utilities.

The UK participant does have written procedures for the repair of main breaks. These procedures do not reference AWWA C651; rather, they are in compliance with the UK's Principles of Water Supply Hygiene and Associated Technical Guidance Notes (http://www.water.org.uk/) (Water UK 2011) (Also, see Appendix E). Note that the UK Principles of Water Supply Hygiene and Associated Technical Notes include the same five procedures that are outlined in AWWA C651 as follows: Trench Treatment; Swabbing of Pipe; Flushing; Disinfection Operation; and Biological Tests. The UK utility does have occasional Boil Water Advisories that occur every one to five years.

U.S. ENVIRONMENTAL PROTECTION AGENCY

The Total Coliform Rule was being revised during the same time frame that this WRF Project on main break sanitation was being conducted. As part of the development of the Revised Total Coliform Rule, the EPA formed a Total Coliform Rule/Distribution System Advisory Committee (TCRDSAC) and charged them with developing an Agreement-in-Principle that would form the basis for rulemaking and future actions. The Agreement-in-Principle provided recommendations related to revising the Total Coliform Rule and what information about distribution systems was needed to better understand and address possible public health impacts from potential degradation of drinking water quality in distribution systems. The TCRDSAC identified seven distribution system areas and divided them into two tiers, with Tier One containing the following four issues (EPA 2010):

1. Cross connections and backflow of contaminated water
2. Contamination due to storage facility design, operation and maintenance
3. Contamination due to main installation, repair or rehabilitation
4. Contamination due to pressure conditions and physical gaps in the distribution infrastructure

Issues 3 and 4 relate directly to this Water RF Project on main break sanitation. EPA indicates that main breaks cause flooding and potential pathways for contaminants to enter the distribution system or be mobilized from internal distribution system surfaces. Main breaks may also lead to low pressure situations in other parts of the distribution system that can result in backflow events or otherwise affect the quality of water delivered to customers. Therefore, ensuring the integrity and effective operation of the distribution systems are critical for public health protection. It is apparent that regulations designed to avoid contamination risk are likely to be developed in the future.

CHAPTER 3:
CASE STUDY EXAMPLES OF GOOD PRACTICES FOR MAIN BREAK RESPONSE

OVERVIEW

A series of case studies was developed to highlight "Featured Programs" for main break responses. These featured programs contain one or more of the best management practices of what could be considered a model utility main break response program. These best management practices address the following aspects of response to water main breaks:

- Risk assessment
- Main break notification
- Main break/leak investigation and isolation
- Pollution prevention
- Responses to unauthorized discharge of potable water
- Main break repair
- Release-to-service criteria after main break, and
- Boil water advisory

The individual utilities across the US and UK that responded to the survey questionnaire typically do not practice every best management practice for main break repair. However, when reviewed collectively, the participating utilities offer a wide spectrum of practices that can serve as models for others in the water supply industry. The following utilities were selected to serve as featured programs:

CASE STUDIES

City of Fort Worth, TX

The Fort Worth program includes complete descriptions for many responses to main breaks including emergency response, leak detection procedures, excavation pit procedures, responses tied to type of break, and a flow chart for Boil Water Advisory (BWA) actions. Contact: Ray G. Moreno, Water Systems Superintendent; email: Ray.Moreno@fortworthgov.org.

Los Angeles Department of Water and Power (LADWP), CA

The Los Angeles program offers complete procedures on pollution prevention, disinfection and dechlorination, training materials with quizzes, flushing protocols, and safety consideration. Contact: Charles Sparks, Water-Education-Safety-Training; email: charles.sparks@ladwp.com.

New Jersey American Water (NJAW), NJ

New Jersey American provides a comprehensive Boil Water Advisory (BWA) Guideline. Contact: Scott Baxter-Green / Water Quality Manager; email: scott.baxter-green@amwater.com.

City of Boulder, CO

Boulder's program developed protocols for main break notification and communication. Contact: Ken Clark, Regulatory Compliance Specialist; email: clarkke@bouldercolorado.gov.

Charlotte-Mecklenburg Utilities Department (CMUD), NC

The CMUD program includes comprehensive training materials and performance evaluation forms for their main break repair procedures. Contact: Angela Lee, Field Operations Division Manager; email: alee@ci.charlotte.nc.us.

Denver Water (DW), CO

The Denver Water program centers on a flowchart for risk assessment that helps guide main break response activities. Contact: Stephen Lohman, Laboratory Director; email: Steve.Lohman@denverwater.org

The full featured program descriptions (Appendix C) contain language taken directly from the specific program written materials or were paraphrased by the study team for brevity.

CHAPTER 4:
LABORATORY AND PILOT TESTING RESULTS

OVERVIEW AND PURPOSE

Detailed laboratory and pilot tests were conducted in the American Water facilities in New Jersey with the complete data and information contained in Appendix D. The testing included disinfectant demands, inactivation experiments with both suspended and attached microbes, and flushing studies for particle removal. The purpose of these experiments and studies was to provide a scientific basis for understanding the microbial risks associated with main breaks and repairs, depressurization in the distribution system, and the potential effectiveness of mitigation measures.

MAIN BREAK RISK MODELING

A previously developed risk modeling approach – Quantitative Microbial Risk Assessment (QMRA) was used to estimate risks associated with main breaks, repair and mitigation measures and set the stage for laboratory and pilot studies. Key steps of a typical QMRA approach include hazard identification, exposure assessment, dose- response assessment, and risk characterization. For this Project, the specific steps in the risk assessment were as follows:

1. Estimate pathogen levels near water mains by meta-analysis of pathogen occurrence levels collected from literature
2. Determine pathogen levels that occur in the distribution system after intrusion and dilution
3. Repair the break and place back into service with or without disinfection and/or flushing
4. Estimate the level of individual water intake
5. Apply dose response models for virus, bacteria and protozoa collected from literature
6. Characterize the risk of infection using Monte-Carlo simulations programmed in Mathematica 8.0 (Wolfram Research Inc., Champaign, IL, USA)
7. Estimate risk reduction with mitigation approaches - disinfection and flushing based on laboratory and pilot tests

Based on this model approach and literature, preliminary assumptions and findings were identified as follows:

- Pathogens are present in the soil and water outside the pipe including bacteria, virus, and Protozoa. The specific organisms of interest include: *E coli* O157:H7, Norovirus, and *Cryptosporidium*.
- Dilution of an intrusion was assumed to be 0.1 to 1.0 % within the distribution system.
- The amount of unheated tap water consumed daily by an individual was approximated by a lognormal distribution with a median water consumption of 0.18 liter.
- The EPA risk of less than $1x10^{-4}$ per person per year was used for risk control purposes (1 in 10,000).

- With dilution only within the piping system, risk levels for Norovirus, *E. coli* O157, and *Cryptosporidium* all exceeded the risk level of 1 in 10,000 (2-3 logs of magnitude higher). The risk model indicated 7-log reduction of virus levels is needed to achieve the acceptable risk levels via a combination of effective flushing (2-3 logs of particle removal) and disinfection (4-5 log inactivation of virus).
- Flushing of water appeared to reduce particles if a threshold velocity was reached. Threshold velocities could be attained in smaller diameter mains fairly easily but reaching that threshold would likely be a problem in larger mains (>16-inch diameter).
- Disinfection efficiency would depend on the target organism, water quality conditions, presence and type of particulate matter, form and level of disinfectant, and time of exposure. Specifically, disinfectants are limited in the ability to control *Cryptosporidium*, *where* flushing is the primary control for that pathogen.

Based on this initial screening and evaluation, laboratory and pilots tests were conducted with a focus on disinfection and flushing as mitigating measures to pathogen entry at the break site and at depressurized locations.

DISINFECTION STUDIES

Chlorine/Chloramines Decay Experiment

This experiment was conducted to test if background disinfectant residuals could persist after contaminants intruded during main breaks. A total of 105 disinfectant decay tests were conducted: 59 tests for free chlorine and 46 tests for chloramines. The contaminants introduced included various sources- raw sewage, meter, pit, or valve box water and ranged from a dilution of 0.01 % to 1.00%. Initial chlorine demands were mostly 0.0 to 2.0 mg/L and wastewater intrusion resulted in up to 6.6 mg/L of initial chlorine demand. By comparison, initial chloramine demands were mostly less than 1.0 mg/L. These tests suggest that initial free chlorine residual could be overcome by water contamination during depressurization while chloramine residual would remain largely unchanged.

Inactivation Experiment of Suspended Microbes

To evaluate the inactivation of viral, bacterial, and protozoan pathogens, surrogate organisms were used including MS-2 bacteriophage, *E. coli*, and *Bacillus* spores, respectively. The findings were consistent with those reported in previous literature studies:

- MS-2 Inactivation. Chlorine was effective in inactivating MS2 (>5 log inactivation with a Concentration X Time (CT) of 15 -20 mg/L Cl_2-min)
- *Bacillus* Inactivation. No significant inactivation was observed with chlorine or chloramine within the tested CT ranges
- *E. coli* Inactivation. Both chlorine and chloramines were effective in inactivating *E. Coli* during the 180 contact period (mostly >5 to 6 log inactivation within 5 minutes).

Inactivation Experiment of Particle-Attached Microbes

Inactivation of particle associated microbes is more complex because of the nature of the particulate material (organic or inorganic) and the microbial interaction (simply attached or enmeshed in a biofilm). It was assumed that the particles entering a distribution system were soils and that they could be classified according to the Unified Soil Classification System as 1. Coarse grained soils (sands and gravels); 2. Fine grained soils (silts and clays) and 3. Highly organic soils (referred to as "peat"). The risk model indicates that 7-log reduction of virus levels needed to be achieved to reach a risk level of 1 in 10,000. Assuming a 3-log reduction by flushing, the remaining 4-log virus reduction would be needed from disinfection. The findings resulting from these experiments are as follows:

- Results suggest that either sand or clay could provide some protection against disinfection for virus and that for free chlorine, a CT level of 92 mg/L Cl_2-min was required for 4-log inactivation.
- Peat particles appeared to provide the most protection compared with clay and sand particles. Neither a background disinfectant residual nor the disinfectant levels required to control sand- or clay-associated microbes appear adequate to disinfect peat-associated microbes. The risk controlling CT value is 1,500 mg/L Cl_2-min for 4 log inactivation of peat associated virus (e.g. 25 mg/L Cl_2 for 60 minutes).

FLUSHING STUDIES

Experimental Set-up

The pilot scale pipe loop system at the New Jersey American Water Company Delaware River Treatment Plant was used in this flushing study (See Figure 4.1). The pipe loop is approximately 200 feet in length and consists of a combination of 4 inch PVC pipe and 4 inch hydrant hose equipped with capability to load sand for the flushing experiments. A total of 38 flushing experiments were conducted with different combinations of sand sizes, flushing velocities, flushing volumes, and other impact factors.

Figure 4.1 Pipe loop used for flushing experiments

Threshold Velocity and Sand size

Figure 4.2 depicts flushing velocity versus log-removal for three different sizes of sand. As indicated, the threshold velocity of 2.5 to 3.0 feet per second for successful flushing (2.5 to 3.0 log removal) of sand particles was observed. There was not a large difference in required velocities for the different sized particles.

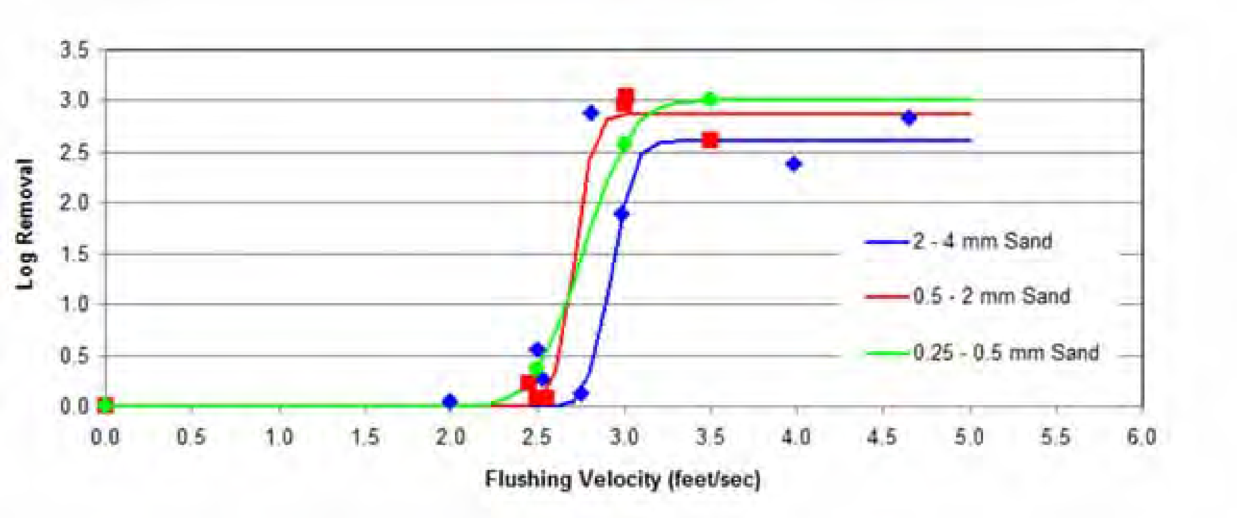

Figure 4.2 Removal of all fractions of sand by flushing

Effects of Biofilm on Effectiveness of Flushing

A biofilm was cultivated on the interior of the pilot test pipes and flushing tests were performed to determine if the presence of a biofilm would significantly affect the required velocity to remove the particles. Data from the tests indicate that removal velocities were similar for a pipe with and without the presence of a biofilm. Threshold velocities of 2.5 to 3.0 feet per second were required to attain 2.5 to 3.0 log removals whether biofilm was present or not. It should be noted that there was no intent to remove or scour the biofilm by flushing as part of this experiment.

Effects of Tubercles on Effectiveness of Flushing

A set of experiments was designed to simulate the effect of tubercles on threshold velocities and particle removal efficiency. Small gravel was glued to the inside of PVC pipe to simulate tuberculation and flow tests were conducted. Two different sections of simulated tuberculated pipe were used, one a heavily tuberculated pipe using a large amount of ¼” -1” gravel (Figure 4.3) and the other with a lesser amount of smaller gravel (Figure 4.4). Both sets of experiments were run using the 2-4 mm sand. The results with simulated heavily and moderately tuberculated pipe were similar in that fluidization occurred between a threshold of velocity of 2.5 to 3.0 feet per second.

Figure 4.3 Highly tuberculated pipe model

Figure 4.4 Low to moderately tuberculated pipe model

When the results for the pipes with tuberculation are shown together with the results from the smooth pipes (see Figure 4.5 below), it becomes apparent that tuberculation had a deleterious impact on removal of particles by flushing. While the tubercles may reduce the fluidization velocity (from approximately 2.7 ft/sec to 2.5 ft/sec), the presence of the tubercles greatly reduces the ultimate removal of sand, possibly by creating shielded areas that allow sand to escape fluidization. Without tuberculation (shown in blue), the ultimate removal of sand is approximately 2.7-log (99.8%). In pipes with moderate to heavy tubercles (shown in green), the ultimate removal drops to approximately 1.7-log (98%); therefore, the role of disinfection is especially critical in tuberculated pipes.

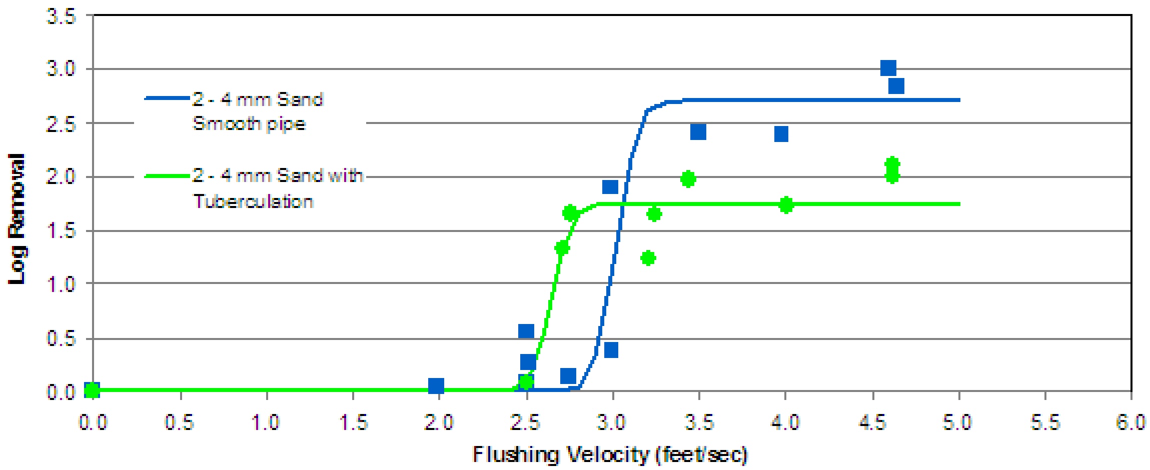

Figure 4.5 Removal of sand in smooth and tuberculated pipe by flushing

SUMMARY AND CONCLUSIONS FROM THE LABORATORY AND PILOT TESTS

These laboratory and pilot tests provide a technical basis for developing mitigation strategies and the following conclusions can be made based on these tests and previous literature:

- Pathogen entry into the distribution system during main breaks and depressurization events is possible and even with dilution in the system, the risk of infection would exceed the EPA criteria of 1 in 10,000.
- Mitigation procedures including disinfection and flushing of contaminants are appropriate and can significantly reduce the risk of exposure to pathogenic organisms that may have entered the system.
- Ambient free chlorine residuals could be rapidly consumed in the system by contaminants especially if they are organic in nature, whereas, chloramine residuals will likely have a much greater persistence. The type and level of contamination significantly influences the consumption rate and persistence of both free chlorine and chloramine residual disinfectants.
- Since virus is the risk-controlling micro-organism, free chlorine disinfection should be used for spot or slug disinfection even in chloraminated systems.
- For spot or slug disinfection, free chlorine disinfection can be used in the distribution system to address inactivation of bacteria and virus with reasonable CT values, but free chlorine cannot be used to address protozoan cysts such as *Cryptosporidium*.
- Particles can shield micro-organisms from disinfection and should be removed to the extent feasible through flushing of the water main. Since organic materials such as peat have a large affinity to react with disinfectants, it is especially important to remove them by flushing before the disinfectant is applied.
- Threshold particle fluidization velocities are normally between 2.5 and 3.0 feet per second. Most North American water distribution systems can reasonably attain the velocities during flushing in smaller diameter pipes, but may have difficulty when pipe sizes are 16 inches and larger. Further, disposing of large volumes of flushed water may be a problem.

- Biofilms that are present in many pipes appear to have little effect on the particle fluidization velocity.
- Tubercles present in pipes appear to have an influence on both particle fluidization velocity and on the removal efficiency of particles. Tubercles appear to inhibit the ability of flushing to remove particles from the system - smooth pipe interiors facilitate particle removal versus roughened surfaces.

ASSESSING THE EXTENT OF TUBERCULATION IN PIPES

If flushing is to be used as a mitigating strategy to remove particles, then it is appropriate for an assessment to be made with regards to the suitability of a pipe to be flushed adequately. In addition to flushing velocity, the internal condition with regards to tuberculation (roughness) becomes an issue. A report that Grades the extent of Tuberculation from the WRc (Dempsey and Manook1986) can be used to express the extent of Tuberculation as follows (Figure 4.6):

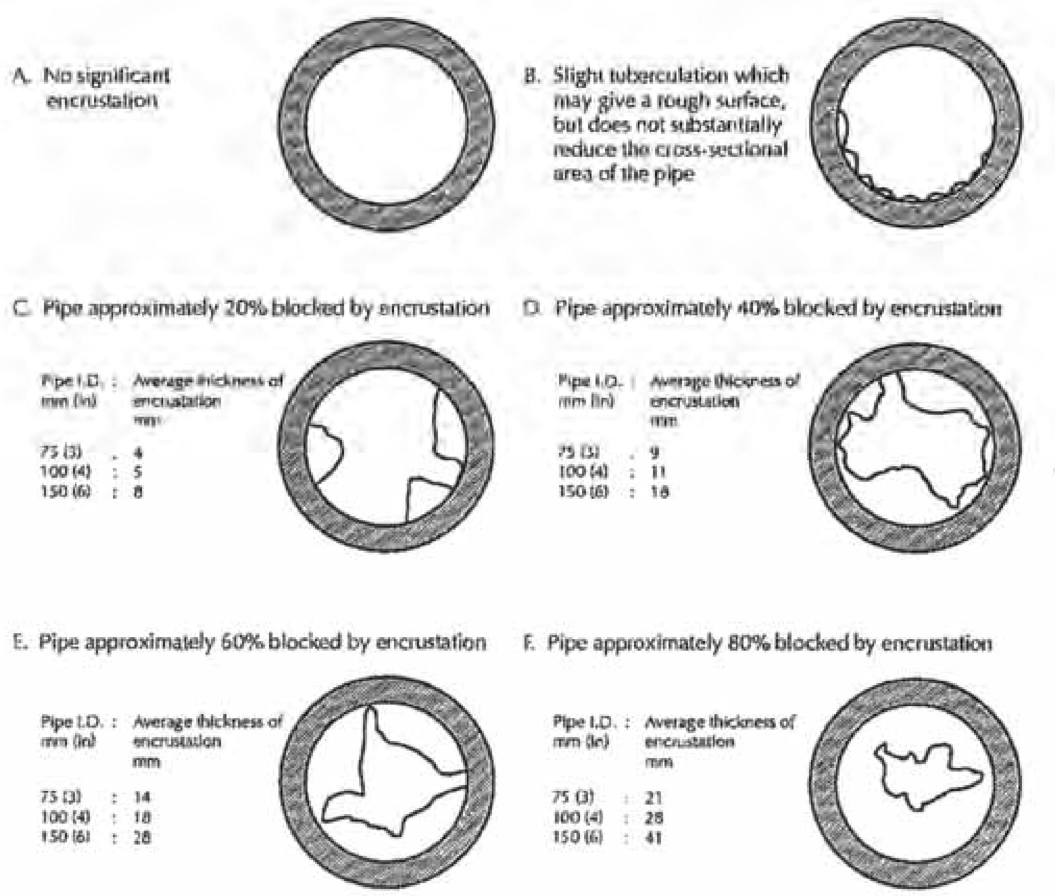

Figure 4.6 Grades for expressing the extent of tuberculation (Adapted from Dempsey and Manook 1986)

For purposes of practicality and ability to be used in the field, a utility could use this Grading system to determine if and how flushing can be used as an effective mitigating measure. Based on the pilot studies conducted as part of this Project, more tubercles (roughness) can make it more difficult to remove particles. As such, when applying flushing procedures to remove particles that may have entered the pipe, it would be most appropriate to flush pipes that are Grade A or Grade B. Beyond those Grade levels, the utility should consider higher flushing velocities (>5.0 feet per second) or other pipe cleaning methods (e.g. ice pigging, swabbing, pigging, etc.) than suggested in this Project Report.

CHAPTER 5:
RECOMMENDED SANITATION GUIDELINES IN RESPONSE TO MAIN BREAKS

OVERVIEW

The Guidelines described herein are based on the information from the literature, surveys of ongoing utility practices, applicable standards, laboratory and pilot testing performed as part of this Project, featured programs from participating utilities who described their best practices, field studies performed by participating utilities, and input from practitioners, field operations staff, utility engineers and managers, scientists, and public health professionals. Many of the ideas contained herein had their origin at the Project Workshop summarized in Appendix F. The important issues that drive the Guidelines are: (1) pressure both at the repair site and at other locations in the distribution system and whether it was maintained; (2) contamination type and potential for entering the system; (3) extent of the problem and type of customer affected; and (4) effectiveness of mitigation measures in response to breaches and low pressure events. Responses used by some water utilities and sometimes required by health authorities are boil water advisories and boil water notices, which put the responsibility for mitigation on the customer. The Guidelines contained in this Report attempt to apply such advisories and notices in cases where contamination is noted or likely and where pressures or circumstances warrant, rather than blanket issuing of such advisories or notices. Four categories of main breaks and low pressure events are suggested in a risk based triage approach, with increasing levels of risk and required mitigation responses.

INITIAL MAIN BREAK RESPONSE

Each utility has a series of procedures that they use to respond to main breaks and leaks, some formally documented and others considered as the normal course of business. Each state or regulatory entity has its approaches to addressing breaks, repairs and low pressure events and the Guidelines suggested here in are not meant to replace on going practices especially with regards to worker safety, risk to the public health or safety, or compliance with local, state or Federal regulations. The Project did develop a Field Checklist for Main Break Evaluation and it is contained in Appendix G. It contains lists and information that may be of use to the water supplier as it develops or modifies its own internal procedures to respond to Main Breaks.

CATEGORIES OF MAIN BREAKS AND REPAIR RESPONSES

Four Categories of Breaks are offered (Table 5.1 summarizes the Types of Breaks and General Response Procedures):

Type 1- Positive Pressure Maintained during Excavation and Repair
Type 2- Positive Pressure Maintained during Excavation, followed by Controlled Shut Down for Repair
Type 3- Loss of Pressure at Break site/ Possible Local Depressurization
Type 4- Catastrophic Failure, Loss of Pressure at Break site and Widespread Depressurization

Table 5.1
Main break types and responses

Type 1 Break	Type 2 Break	Type 3 Break	Type 4 Break
Positive pressure maintained during break	Positive pressure maintained during break	Loss of pressure at break site/ possible local depressurization adjacent to the break	Loss of pressure at break site/ widespread depressurization in the system
Pressure maintained during repair	Pressure maintained until controlled shutdown	Partial or un-controlled shutdown	Catastrophic event/failure
No signs of contamination intrusion	No signs of contamination intrusion	Possible contamination intrusion	Possible/ actual contamination intrusion
Procedures	Procedures	Procedures	Procedures
Excavate to below break	Excavate to below break	Uncontrolled shutdown	Catastrophic failure response
Maintain pit water level below break	Maintain pit water level below break	Document possible contamination	Document possible contamination
Repair under pressure	Controlled shutdown	Disinfect repair parts	Shut-off customer services in affected area
Disinfect repair parts	Disinfect repair parts	Conduct scour flush (3 ft/sec for 3 pipe volumes)	Disinfect repair parts
Check residual disinfectant level in distribution system	Conduct low velocity flush (flush 3 pipe volume)	Conduct slug chlorination (CT of 100 mg/L-min[3])	Conduct scour flush (3 ft/sec for 3 pipe volumes)
No Boil Water Advisory (BWA)	Check residual disinfectant level in distribution system	Check residual disinfectant level in distribution system and ensure it is adequate	Conduct slug chlorination (CT of 100 mg/L-min[3])
No bacteriological samples	No Boil Water Advisory (BWA)	Instruct customers to flush premise plumbing upon return to service	Instruct customers to flush premise plumbing upon return to service
	No bacteriological samples	[1,2]BWA – TBD; based on depressurization extent and presence of contamination	Check residual disinfectant level in distribution system and ensure it is adequate
		[1,2]Bacteriological samples - TBD; based on depressurization extent and presence of contamination	Issue BWA/ Boil Water Notice or "Do Not Drink" Order
			Bacteriological sampling required

Notes:

1. TBD – To be Determined
2. If depressurization is limited to the pipe section, or area flushed or disinfected, then a boil water advisory and/or bacteriological testing are not needed. However, if the area of depressurization is larger than the treated area, then a precautionary boil water advisory and/or bacteriological testing should be considered.
3. In highly tuberculated pipes, a higher CT should be considered to compensate for possible lower flushing efficiency.

There is an increasing risk of intrusion and contamination associated with the Types of Breaks proceeding from Type 1 (Minimal Risk) to Type 4 (Highest Risk). Likewise, the suggested mitigation responses are tailored to increase in intensity and effectiveness with each Type of Break from 1 to 4.

As indicated in Table 5.1, Type 1 Breaks are small, no contamination is observed and pressure is maintained throughout the repair. This type of break is often repaired with a repair clamp and there is very little potential for contamination to enter the piping system since positive pressure is maintained. Normal sanitation at the site is observed such as disinfection of repair parts and tools. No contamination is observed at the site. It is suggested that the chlorine residual level be measured at the break site to document that normal system residual levels are returned after the repair but that neither Boil Water Advisories nor bacteriological sampling are needed for a Type 1 break.

Type 2 Breaks are excavated under pressure, followed by a controlled shutdown to effect the repair. This means that the pipe is fully exposed while under pressure and that there is at least 1 foot of open space maintained between the bottom of the pipe being repaired and the soil or pit water beneath the pipe before the shutdown is completed. This type of break might include a severe circumferential break, a split pipe, a joint leak or a leak with surrounding pipe exhibiting severe corrosion or other weakness. There will be an area of depressurization in the immediate vicinity of the break/repair site, the extent of which is determined by nearby valving, but any depressurization occurs only after the break is fully exposed and there is a gap between pipe invert and soils or pit water. No sewage or other serious contamination is observed at the site. Normal sanitation procedures are observed. A low velocity flush is used to bring fresh water to the site after the repair is made. The chlorine residual level is measured to document return to normal levels but neither Boil Water Advisories/Notices nor bacteriological sampling are suggested for a Type 2 Category.

Type 3 Category Break is likely less common but has a higher potential for contamination to enter the system. There is loss of pressure at the break site and possible depressurization adjacent to the break. Entry of soil or contamination, if present, is possible due to the low or zero pressure perhaps aided by a pipe shutdown because of some hazard to the public or the workers. In addition to normal sanitation practices, flushing of the affected system at a minimum scour velocity of 3 feet per second (for a minimum of 3 pipe volumes) and a slug disinfection with free chlorine at a CT of 100 mg/L Cl_2-min are recommended. Note that highly tuberculated or occluded pipes are not as amenable to cleaning by flushing or to maintaining a disinfectant residual for disinfection and may require additional measures beyond those suggested in this Report. Consumers should be advised to flush their plumbing upon return to service. In addition to measuring chlorine residuals at the site, depending on the circumstances including but not limited to presence and extent of contaminants, type and extent of outage, and nature of customers affected; the water supplier or applicable health agency may want to consider a boil water advisory and bacteriological sampling as part of the procedures. If the depressurization is limited to the pipe section, or the area flushed or disinfected, then a boil water advisory and/or bacteriological logical testing is not needed. However, if the area of depressurization is larger than the treated area, then a precautionary boil water advisory and/or bacteriological testing should be considered.

Type 4 Category Break is the most serious type of break requiring the most prescriptive measures to protect the system and consumers prior to return to service. It involves loss of pressure at the break site and widespread depressurization in the water system. Contamination is assumed because of the nature of the break and its consequences. All of the measures listed above in a Type

3 Break apply and in addition, a Boil Water Notice and bacteriological sampling are recommended as part of return to service procedures. There is a potential risk of contamination beyond the work area because loss of pressure would allow reverse flow from customer supply lines and possible backsiphonage from unidentified losses of pipe integrity in the area affected.

TRIAGE OF BREAKS AND RESPONSES

There are many types of breaks that occur in systems and they have different risks associated with them. They may occur in urban, suburban and rural areas and some are emergencies where as others may be planned repairs. It is recognized that all breaks do not fall neatly into one of the four categories described previously and informed judgment calls will need to be made. Knowledge of the system, its condition, resilience to outages and operating parameters are essential. This requires an understanding of water quality, public health significance, critical customers, system operations, maintenance procedures, valve location and condition, and more. If the risks and circumstances are not well understood for a specific break incident, it is recommended to err on the side of caution and apply a more conservative response.

The ability to place a break into Type 1 or 2 categories depends greatly upon the ability to locate and operate valves to regulate flow and maintain pressure. Without this ability, higher levels of risk of contamination are likely to occur. There are many other constraints and regulations that affect the ability of repair crews to throttle flows and pressures including safety, environmental, property damage, other utilities, traffic, fire protection, legal issues, etc., and these may not allow the utility to focus solely on the most effective pipe repair methods. Further, as noted in the laboratory and pilot tests detailed in Appendix D, the effectiveness of mitigation measures including scour flushing and slug disinfection depend on the condition of the pipe with respect to tuberculation or roughness. Small pipe may not be connected to hydrants or blowoffs and flushing the pipes may be a challenge. Large diameter pipe may present a challenge in achieving the desired flush flow rate. Highly tuberculated or occluded pipes are not as amenable to cleaning by flushing or to maintaining a disinfectant residual for disinfection and may require extraordinary measures beyond those suggested in this Report. To better define the condition of pipes, the reader is referred to Figure 4.6, which contains Grades for expressing the extent of tuberculation (Dempsey and Manook 1986). The Grades of pipes that enable the mitigation measures contained in this Report to be used effectively are Grades A and B. As the condition of pipes moves beyond Grades A and B, the mitigation measures likely become less effective and may require higher flushing velocities (e.g. > 5 feet per second) and higher CT values. Pipes with Grades E or F were not meant to be addressed through the processes recommended here and in fact the pipe should likely be rehabilitated or replaced.

To assist in the decision process, a flowchart was developed and is depicted in Figure 5.1. Use of the flowchart requires upfront knowledge of the condition and operation of the water system or area of the water system in question. The responder needs to have information on the pressures, the levels and type of residual chlorine, the condition of the piping system, location and operability of valves and whether there are critical customers involved. It is assumed that an initial responder will have access to this information in order to make best use of the Main Break Risk Triage Flowchart (Figure 5.1). It is envisioned that most breaks and subsequent repairs within a system will fall into Type 1 or Type 2 Categories, with fewer in Type 3 and very few in Type 4. With all repairs, it is assumed that certain basic sanitation techniques will occur including disinfection of materials and tools used in the repairs, segregation of tools such that crews who do both potable water and sewage collection system repairs have separate tools that are not interchanged, swabbing of accessible system components with chlorine solution, diversion of storm runoff around the repair site, proper storage of pipe and repair parts to preclude contamination, and proper human sanitation by maintenance personnel.

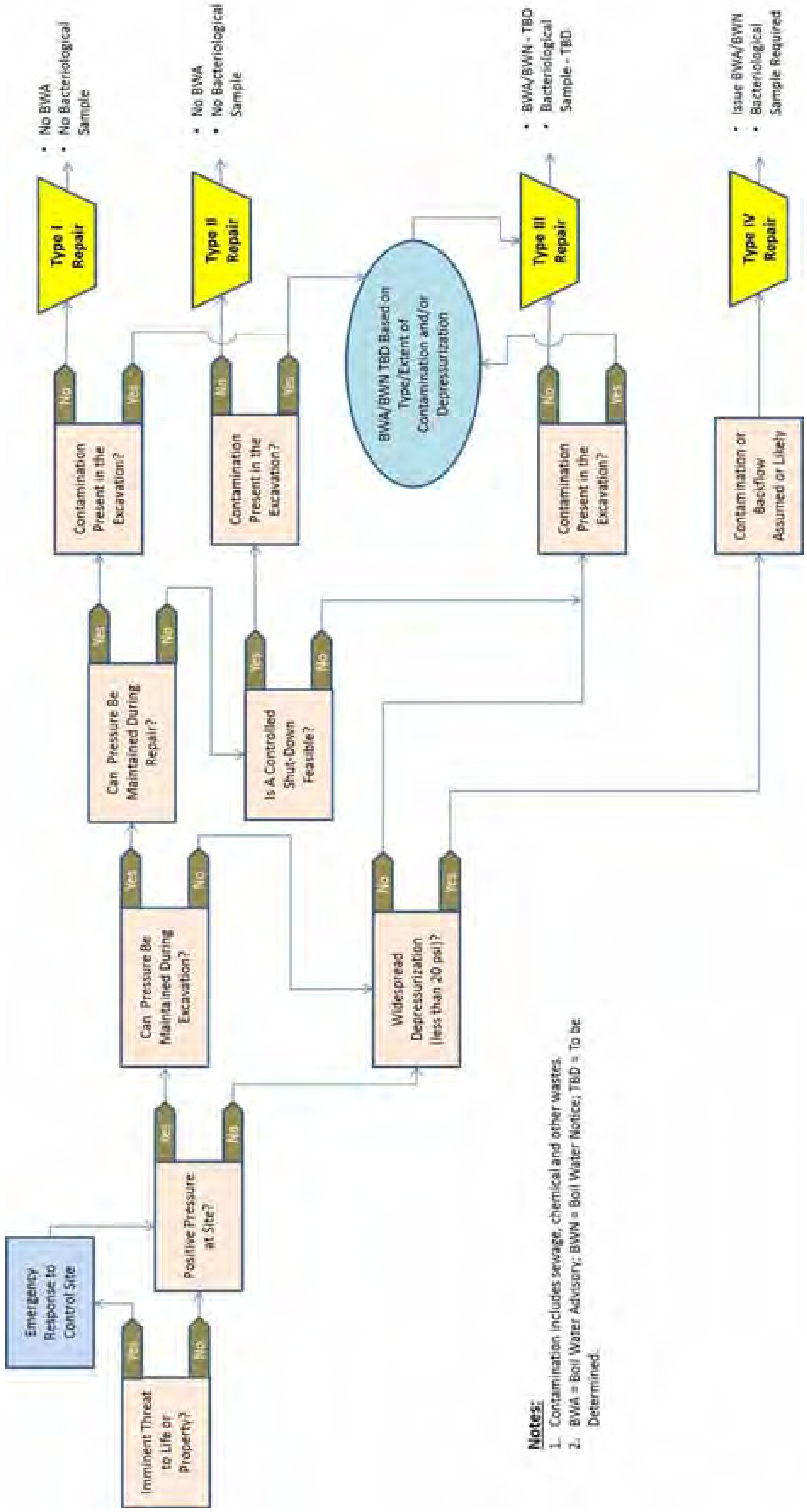

Figure 5.1 Main break risk triage flowchart

The basic questions that need to be answered to move thru the decision tree are as follows:

- Are there overriding conditions (such as a threat to public health or damage) that mandate an immediate shutdown?
- Can positive pressure be maintained at the site of the break?
- Can positive pressure be maintained during excavation of the pipe or joint?
- Can positive pressure be maintained during the repair?
- Is there contamination such as sewage, chemical or other wastes noted at the excavation site?
- Is depressurization limited to the immediate vicinity of the break/ repair site?
- Is there widespread depressurization around or remote from the repair site?
- Are there critical customers that need special attention such as hospitals, medical clinics, dialysis centers, or others of a critical nature in the depressurized or affected areas?

Certain pathways in the Flowchart (Figure 5.1) require that the responder decide whether or not to issue a Boil Water Advisory/Notice and/or collect bacteriological samples before release to service.

Some key facts associated with the various Types of Breaks and Repairs are as follows:

- The main difference between a Type 1 and Type 2 Category is that with a Type 1 repair, positive pressure is maintained through out both the excavation and repair; and with Type 2, pressure is maintained during excavation but goes to zero in the immediate vicinity of the break during the repair.
- The main differences between a Type 2 and Type 3 Category are that with a Type 2, the shut down is more controlled, with no signs of contamination; and with a Type 3, the shut down is uncontrolled resulting in loss of pressure at the break site/local vicinity of site and there is possible contaminant intrusion.
- The main differences between Type 3 and Type 4 Categories are that with a Type 3 break, the depressurization is limited to the local vicinity with contamination possible; where as with a Type 4 break, the depressurization is widespread and contamination is assumed to be present or have occurred.
- Depressurization is defined as less than 20 psi outside of the immediate repair site.
- Positive pressure at the break site can be confirmed by visually observing a steady flow or spray of water coming from the pipe, or observation of a hose bib or hydrant located near and at a higher elevation than the break site.
- Target minimum velocity of 3 feet per second for scour flushing velocity needs to be measured/confirmed at the site by an acceptable method as described in Appendix F.
- When measuring chlorine residual after making a repair, the intent would be that the residual level would be returned to at least 90% of ambient or pre break levels and not more than 4.0 mg/L as required by State or Federal regulations.
- Slug chlorination is with free chlorine and needs to attain a CT of 100 mg/L Cl_2- mins to address the risk levels used in this Project Report (see Appendix D).

FIELD APPLICATION OF THE TRIAGE AND MITIGATION APPROACHES

Field Testing

This Project included several utilities who were willing to either carry out or attempt to carry out key procedures developed in the Project to help understand the implications and field worthiness of suggested mitigation and repair techniques. These field tests were used to refine and adjust the techniques to streamline and make them better while maintaining the intent of minimizing risk due to microbial intrusion. The utilities who helped in these field studies included Bellevue Utility Department, WA; Boulder, CO; Charlotte-Mecklenburg Utilities Department; and Fort Worth Water Department. The Project is deeply indebted to these utilities and their field crews, who went beyond the call of duty to help test field protocols and provide documentation. Their efforts were appreciated and helped to make this a better Project on multiple accounts and are summarized in Appendix F.

Risk Based Triage of Main Breaks

Overall the Risk based Triage approach as depicted in the Main Break Risk Based Triage Flowchart (Figure 5.1) was favorably received by utilities involved in this Project. Use of the Triage Flowchart requires substantial preparation by the responding teams before the break occurs in understanding their distribution system and the four Types of breaks and repair procedures suggested herein. Additional training of field crews and modification of existing field procedures – both written and on the job training– will be required to implement the Triage approach. In distribution systems with multiple pressure zones, different types of breaks and pipe conditions, it may require that different approaches be applied within the same water system. As an example, if a utility has highly tuberculated, cast iron pipe (Grade E or F, Figure 4.6) in one area of its distribution system, it is not amenable to scour flushing or slug disinfection; where as, newer pipe or pipe without tuberculation in another area would be effectively scoured and disinfected by the methods suggested in this Report. The bottom line is that using the Triage approach to categorize breaks may require a different mind set for staff and will definitely require additional training and likely modified procedures within the utility. With the assistance of utility participants, a listing of important information to be considered in responding to main breaks was developed as part of this Project report and is contained in Appendix G. It contains information beyond triage and sanitation such as Notifications and Site issues, and can be used as guidance and a list of important issues to be considered as the utility develops its tailored program.

FIELD MITIGATION ACTIVITIES

There are four types of field activities suggested in this Report that merit further discussion:

- Measuring and documenting disinfectant residual;
- Developing, measuring and documenting a scour water main flushing velocity;
- Maintaining and documenting positive pressures at the break site and at other affected locations; and
- Applying chlorine and attaining a CT of 100 mg/L-min associated with Slug Disinfection

Measuring Disinfectant Residual

In terms of measuring and documenting disinfectant residual in the field, some utilities perform this test in the field related to main break repair, others do not. It is important that ambient levels of residual disinfectant are returned to the repair site as part of release to service procedures. Some utilities have water quality staff measure residuals, others have trained field crews to use the chlorine kits. Chlorine residual was one of three important parameters identified by Water RF project 4109, Criteria for Optimized Distribution Systems, (Friedman et al. 2010), and is a significant part AWWA's Distribution System Partnership for Safe Water Program. To document that safe water with an ambient disinfectant level is returned to the repair site, the Guidelines in this Report suggest monitoring the residual as part of returning to service for all four Types of Breaks. It is suggested that a minimum goal of 90% of ambient level and a maximum level of 4.0 mg/L be used or other range to be established by the water supplier or regulatory agency. Note that measuring disinfectant residual was successfully tested in the field by multiple repair crews participating in this study, on actual main break repairs, and is unanimously considered to be a practical response procedure. Suggestions for monitoring and documenting chlorine residuals are contained in Appendix G.

Scour Flushing

With regards to scour flushing velocity, this Report suggests a minimum velocity of 3 feet per second be attained in the largest pipe affected by the break. Three feet per second assumes minimal tuberculation is present (Grades A or B in Figure 4.6), and that higher velocities may need to be established for Grades C and D in Figure 4.6. This Project did not address pipes that would fall into the Grades E or F in Figure 4.6 as they should likely be rehabilitated or replaced rather than repaired. Scour flushing is applicable to Categories Type 3 and 4 breaks. There are many issues to be considered in implementing the flushing procedure to attain desired minimum velocities and the reader is referred to various AWWA manuals and books for those procedures. One key issue is disposal of large quantities of water containing disinfectant residual, with issues related to both volume and presence of chlorine residual. It is important that the utility select a form of technically sound measurement technique to be employed to confirm scour velocities were attained and that technique is documented. Note that achieving a scouring flush was successfully tested in the field by multiple repair crews participating in this study, on actual main break repairs, and is considered to be a practical response procedure for smaller pipe diameters. The practical pipeline diameter size limit for achieving a scouring flush must be determined on a case-by-case basis for each individual utility and even without a pipe network. Appendix G in this Report provides three feasible measurement methods for consideration along with a documentation list.

Positive Pressure

Maintaining a positive pressure at the break site throughout the repair or at least during excavation until the pipe or joint is exposed should reduce risk where pressure is used to place the break and repair in a category from 1 to 4. Utilities may deal with pressure during a repair in different ways, e.g., a situation may allow maintaining positive pressure during repair, but another situation may call for responders to reduce flow as soon as possible to prevent property damage, reduce the amount of water they have to deal with, and/or to help prevent cave ins. Pressure maintenance and regulation is part of all breaks and repairs and each utility needs to determine how they will address these issues to meet the multiple and sometimes competing requirements. This Project and Report did find that it is feasible in many systems to throttle valves and control flow such that pressure at the break site can be maintained during the excavation and repair on smaller breaks and leaks. There are also other breaks and circumstances that require complete shut down as soon as possible to reduce property damage and enable crews to safely access the pipe or joint for repair. When a utility deems it feasible and advisable to maintain pressure at the site, this Project suggested two methods of observation as well as documentation that pressure was maintained, 1) Flow is observed at a nearby hydrant or tap at a higher elevation than the break, and 2) flow/spray is observed at the break site. It was suggested in this Report that visual observation of flow/spray be verified and documented from start to finish during the repair process. This means that pressure will be positive but may be less than 20 psi in the immediate vicinity of the break site. Note that maintaining positive pressure during applicable repairs was successfully tested in the field by multiple repair crews participating in this study, on actual main break repairs, and is considered by all to be a practical response procedure. Appendix G contains information on maintaining pressure and documenting it during repairs.

With regards to maintaining pressure or documenting low pressures outside of the immediate break site, this requires knowledge of the system, location of pressure gauges, SCADA monitoring points, and other operating conditions. If there is low pressure at or adjacent to the immediate break site, then there could be other areas in the pressure zone, such as at higher elevations that might have pressures below a threshold level. This Report suggests a minimum threshold of 20 psi to be maintained elsewhere in the system outside of the immediate repair area. The reader can refer to the Water RF report Criteria for Optimized Distribution Systems (Friedman 2010) for more information on pressure maintenance.

Slug Disinfection

Regarding slug disinfection with chlorine to attain a CT of 100 mg/L Cl_2-min to address potential virus contamination, the CT approach has been widely used for disinfecting new mains but to this point has not been a common practice during repair of existing mains. Certainly swabbing of accessible components is common, but the more rigorous application of CT principles has not been common for pipe repairs. Slug disinfection is applicable to Type 3 and 4 main breaks and repairs as defined in this report. To remove any materials that may have entered the distribution system during the repair or local depressurization, the main will need to be flushed at a minimum scour velocity of 3 feet per second, expelling three pipe volumes prior to implementing slug disinfection procedures. The slug of chlorinated water will need to be monitored during the process to make sure that the residual and contact time are sufficient to meet the minimum CT of 100 mg/L-mins. Depending upon local/state regulations or as the situation requires, attention must be given to dechlorinating the highly chlorinated slug before it reaches surface waters as the slug is flushed from the distribution system. As ambient water is brought back into the repaired pipe section, a chlorine residual sample should be collected to ensure that residual levels are a minimum of 90% of pre break levels and no more than 4.0 mg/L. Customers should be advised to flush their premise piping systems and depending on the local or state requirements, boil water advisories/notices and/or bacteriological samples may be required. Note that achieving slug disinfection with a minimal CT of 100 mg/L Cl_2-min was not tested by repair crews participating in this study. Although more than one agency reviewed the draft protocols prepared by the study team and agreed to attempt the procedure, there were no breaks that occurred during the testing period that required slug disinfection. Review comments received from the repair crews that would have tested the method varied with regard to how practical this procedure might be. This is an area where further study would be warranted. Further information regarding slug disinfection is contained in Appendix G.

POCKET FIELD GUIDE

To help field crews who are doing repairs to remember and implement good practices during repair of water main breaks, a Pocket Guide listing good practices was developed as part of this Water RF Project. The pocket guide may also be useful in utility training programs for crews involved in these activities.

CHAPTER 6:
RELATED STUDIES AND MATERIALS

There are several references that have direct bearing on the sanitation practices related to repair of water mains and these are briefly described as follows:

AWWA STANDARD 651

This publication has been the basis of most sanitation related repair practices in North America for several decades. This standard applies to both installation of new mains and to activities during repair of water main breaks as well. It is copyrighted and may be obtained from the American Water Works Association in Denver, CO or thru the following website www.awwa.org.

UNITED KINGDOM TECHNICAL BULLETIN

The United Kingdom was a co- sponsor of this Project along with the Water RF and they were represented at the Project Workshop offering their experiences and advice on the Project. The Water UK has guidance that parallels many of the good practices that are used in North America and their guidance is contained in Technical Guidance Note No. 3 in Appendix E for handy reference by the reader.

PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION GUIDANCE ON DEPRESSURIZATION EVENTS

The Pennsylvania Department of Environmental Protection participated in the Project Workshop and described their approach to addressing main breaks and loss of positive pressure events in the distribution system. Their Guidance is thorough and well documented and contains information that may be of use to regulatory agencies and water utilities. It contains information on many of the practices and issues that are addressed in this Project including loss of pressure, high risk contamination, bacteriological sampling, boil water advisories and notices, and good sanitation practices. The PA Guidance materials are attached and may be found in Appendix E.

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ABBREVIATIONS

ANSI American National Standards Institute
APHA American Public Health Association
AWWA American Water Works Association
AwwaRF Awwa Research Foundation

CDF cumulative distribution function
CT product of disinfectant concentration and exposure time

Erf Gauss error function

ILSI International Life Sciences Institute

k_1 fitting parameter
k_2 fitting parameter
k_3 fitting parameter

MPN most probable numbers

NRC National Research Council

PCR polymerase chain reaction
Project This Water Research Project – No. 4307
psi pounds per square inch

QMRA Quantitative Microbial Risk Assessment

R log removal by flushing

T a period of time
t time
TOC total organic carbon

EPA United States Environment Protection Agency

V fluid velocity

WRF Water Research Foundation

μ_ι mean
μ_μ mean of means
μ_σ mean of standard deviations
σ_ι standard deviation
σ_μ standard deviation of means
σ_σ standard deviation of standard deviations