FINAL
PRIORITIES OF THE DISTRIBUTION SYSTEM RESEARCH AND INFORMATION COLLECTION PARTNERSHIP

April 2010

Disclaimer

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Acronyms

AIP:	Agreement in Principle
AMWA:	Association of Metropolitan Water Agencies
ANSI:	American National Standards Institute
AWWA:	American Water Works Association
BP:	best practices
CC:	cross connection project area
Con:	contaminant accumulation project area
CWSS:	Community Water System Survey
DBP:	disinfection by-product
DS:	distribution system
DWINS:	Drinking Water Infrastructure Needs Survey
EPA:	US Environmental Protection Agency
Hea:	health effects project area
MAC:	*Mycobacterium avium* Complex
MCL:	Maximum Contaminant Level
Mon:	monitoring project area
MOU:	Memorandum of Understanding
NPDWR:	National Primary Drinking Water Regulation
NRWA:	National Rural Water Association
Pres:	pressure project area
PWS:	public water system
QMRA:	quantitative microbial risk assessment
RFP:	request for proposal
RIC:	Research and Information Collection
RICP:	Research and Information Collection Partnership
RisM:	risk management project area
SC:	Steering Committee
Stor:	storage project area
Sur:	survey project area
TCR:	Total Coliform Rule
TCRDSAC:	Total Coliform Rule / Distribution System Advisory Committee
WaterRF:	Water Research Foundation

Definitions

Partners –EPA and WaterRF (signatories to the RICP memorandum of understanding)
Experts (or subject matter experts) – Technical consultants to the partners in each of the seven topic areas, as well as in organizing and compiling the project area documents
Steering Committee – Advisory group to the RICP

EXECUTIVE SUMMARY

Spanning almost one million miles in the United States, drinking water distribution systems represent the vast majority of physical infrastructure for drinking water supplies, and thus constitute a primary management challenge from both an operational and public health standpoint. Potential public health risks can occur if the operation and functioning of the distribution system is compromised. Therefore, ensuring the integrity and effective operation of distribution systems is critical for public health protection. While infrequently reported, waterborne disease outbreaks and other events of public health significance do occur as a result of compromised distribution systems (NRC, 2006). The purpose of this document is to summarize what research and information collection would be valuable in order to more fully evaluate the public health risks associated with water quality degradation in the distribution system.

E.S. 1 Introduction

During 2007 and 2008, the US Environmental Protection Agency (EPA) convened the Total Coliform Rule / Distribution System Advisory Committee (TCRDSAC). EPA charged the TCRDSAC to provide recommendations on: (1) revisions to the Total Coliform Rule (US EPA, 1989a) and (2) what information about distribution systems is needed to better understand and address possible public health impacts from potential degradation of drinking water quality in distribution systems (US EPA, 2008). The TCRDSAC developed an Agreement in Principle (AIP) (US EPA, 2008) in September 2008. While most of the language in the AIP focuses on recommendations for changes to the Total Coliform Rule, the document also contains recommendations concerning distribution system water quality (Section 4 of the AIP). To address these needs, the AIP recommends the formation of a Research and Information Collection Partnership (RICP) to identify priorities for research and information collection. This document was developed as a result of these recommendations.

The AIP identifies seven technical topic areas, or issues, as the most relevant to protecting public health and maintaining the integrity of drinking water distribution systems and categorizes these topic areas into two tiers. The seven distribution system issues and their associated tiers are:

- Tier One: "The following issues have been associated with documented health outcomes. Some information is available to characterize the extent of these issues, although more national characterization of the occurrence and relationship between these issues is needed. Some best practices information is available." (US EPA, 2008)
  1. Cross connections and backflow of contaminated water
  2. Contamination due to storage facility design, operation or maintenance
  3. Contamination due to main installation, repair or rehabilitation practices
  4. Contaminant intrusion due to pressure conditions and physical gaps in distribution system infrastructure

- Tier Two: "For the following issues, some evidence exists that they do occur in public drinking water systems and adverse public health impacts are suspected to be associated with these topics, although available information is more anecdotal in nature and additional research and information collection is necessary to better define public health risks. Little occurrence information is available to document or characterize these issues." (US EPA, 2008)
  5. Significance and control of biofilm and microbial growth
  6. Nitrification issues that lead to public health effects
  7. Accumulation and release of contaminants from distribution system scales and sediments

E.S. 2 The Research and Information Collection Partnership (RICP) and the RICP Steering Committee

In the AIP, TCRDSAC recommended that a RICP be formed to inform and support the drinking water community in developing future national risk management decisions pertaining to drinking water distribution systems. The current members, hereafter called partners, of the RICP are EPA and the Water Research Foundation (WaterRF). EPA and WaterRF signed a memorandum of understanding (MOU) in January 2009, which officially formed the RICP.

The AIP specifies that the RICP is to "establish a science-driven, mutually-agreed-upon, strategically-focused, decision-relevant research and information collection agenda that encompasses short, medium, and long term research and information needs" (US EPA, 2008). The objective of the RICP is to stimulate distribution system research and information collection from all interested parties.

The AIP also specified that the RICP form a Steering Committee (SC). The role of the SC is to review and accept the products of the RICP. SC members were selected to provide a broad perspective on the relevant drinking water distribution system issues. The RICP SC contains nine members, including three members from EPA, three members from water utilities, one member representing a public health perspective, one representing an environmental advocate perspective, and one representing a state regulator perspective. In addition, at least one member also represents a small system perspective.

This document describes the results of the deliberations of the partners, with input from a Steering Committee. The partners followed a systematic process, described later in this document, to identify high priority research and information collection project areas for the relevant AIP issues. These priorities, when completed, are expected to support future risk management decisions by the drinking water community.

E.S. 3 Prioritization of Research and Information Collection Project Area Documents

The partners used a five step process to identify high priority research and information collection project areas. The steps included: (1) conducting research and information collection (RIC)

needs analysis for each of the seven issue areas in the AIP, (2) compiling RIC needs identified in the needs analysis, (3) sorting and organizing the RIC needs into related project areas, (4) developing project area documents based on results of RIC needs analysis, and (5) prioritizing project area documents. The partners solicited comments from the SC throughout the process.

The RIC needs analysis resulted in approximately 180 needs. After the partners compiled, sorted and organized the RIC needs, they developed 29 project area documents. The partners developed a scoring system to help evaluate which of the project areas should receive the highest priority and presented the initial score results to the SC. The criteria, or factors, that the scoring system takes into account are:

- relevance to each of the seven issues described in the AIP, with higher priority given to project areas that address multiple issues
- the extent to which the project area is expected to inform an understanding of the magnitude of public health risk
- the extent to which the project area is expected to inform an understanding of the mitigation of public health risk

The project area documents are meant to serve as guides for the areas of research or information collection related to distribution system issues. The project area documents are generally intended to identify groupings of similar needs rather than individual, stand alone projects. It is possible that some of these documents may be more appropriate to divide into multiple projects to fully address the information needs described.

The results of the project area documents are intended to inform decisions regarding the need for possible development of guidance, best management practices, regulations, or additional research and/or information collection on distribution system issues. Stakeholders may also use this information for education and training. Out of the 29 project area documents, the SC accepted ten as high priority project area documents (see Table E.S. 1)

Table E.S. 1 Final Ten High Priority Project Area Documents (in alphabetical order)

Project Area Document Code[1]	Project Area Document Title	Goals
CC1	Best Practices to Minimize Risks Associated with Cross Connections and Backflow	Identify and characterize the best practices (BPs) (including design, operations and costs) for cross connections and backflow that can be used to mitigate potential contamination concerns.
Con3	Contaminant Entry from Breaches in Storage Facilities	To compile data to better understand and predict health risks associated with contaminant entry through structural breaches in storage facilities.
Con4	Estimation of Contaminated Water Volumes and Contaminant Concentrations Introduced Into Distribution Systems Due to Backflow Events from Unprotected Cross-Connections Based on Model Predictions and Field and Pilot-Scale Experiments	To compile data to better predict health risks associated with entry of external contaminants into drinking water distribution systems through unprotected cross-connections.
Hea1	Quantitative Microbial Risk Assessment (QMRA) to Evaluate Exposure to Pathogens through Drinking Water Distribution Systems	To develop an adaptive tool that can be used to estimate relative risks of exposure to distribution system pathogens and the effectiveness of risk management strategies for preventing/controlling microbial risks.
Hea2	Epidemiological Studies of Health Effects Associated with Low or Negative Pressure Events in Distribution Systems	To obtain information on the incidence and severity of adverse health effects occurring among customers who are impacted by low or negative pressure events in water distribution systems. The information can inform estimates of both baseline risks and reduction in those risks from mitigation actions.

[1] CC, cross connection; Con, contaminant accumulation; Hea, health effects; Pres, pressure; Stor, storage; Sur, surveys

Pres1	Survey of Distribution System Pressure Management Practices	To assess pressure management practices in water distribution systems to determine the prevalence of specific high risk distribution system attributes leading to low or negative pressures.
Pres2	Characterize Propagation of Pressure Events through Water Distribution Systems to Improve Pressure Management Approaches	Evaluate the propagation of pressure events through the distribution system and compare field data with surge model results for the same events. Evaluate pressure propagation events at a number of systems and investigate the impact and cost of changes intended to mitigate the number and extent of such events.
Stor1	Best Practices for Minimizing Risks Associated with Storage Facilities.	Identify and characterize the best practices (BPs) for storage that can be used to mitigate potential contamination exposure concerns.
Sur1	Survey of Large Drinking Water Utility Distribution Systems	To identify characteristics of drinking water distribution and storage systems that serve > 50,000 people.
Sur4	Targeted Surveys to Obtain Information on State and Local Regulations, Policies, Manufacturing Practices and Guidelines for Distribution Systems	To evaluate extent to which distribution system risk management and mitigation practices are implemented by states or through manufacturing, installation, or inspection programs.

1. Introduction

1.1 The Total Coliform Rule / Distribution System Advisory Committee Agreement in Principle

During 2007 and 2008, the US Environmental Protection Agency (EPA) convened the Total Coliform Rule / Distribution System Advisory Committee (TCRDSAC) to provide recommendations on: (1) revisions to the Total Coliform Rule (US EPA, 1989a) and (2) what information about distribution systems is needed to better understand and address possible public health impacts from potential degradation of drinking water quality in distribution systems (US EPA, 2008). The TCRDSAC developed an Agreement in Principle (AIP) (US EPA, 2008) in September 2008. The AIP contains the recommendations of the TCRDSAC, which represent the consensus of the parties that are signatories to the document. While most of the language in the AIP focuses on recommendations for changes to the Total Coliform Rule, the document also contains recommendations concerning distribution system water quality (section 4 of the AIP). The TCRDSAC found that additional research and information collection is needed to inform potential additional national risk management decisions concerning distribution systems. To address these needs, the AIP recommends the formation of a Research and Information Collection Partnership (RICP) to identify priorities for research and information collection. Additionally, the AIP identifies seven technical topic areas, or issues, as the most relevant to protecting public health and maintaining the integrity of drinking water distribution systems.

The AIP categorizes the seven technical topic areas, or issues, into two tiers. The seven distribution system issues and their associated tiers are:

- Tier One: "The following issues have been associated with documented health outcomes. Some information is available to characterize the extent of these issues, although more national characterization of the occurrence and relationship between these issues is needed. Some best practices information is available." (US EPA, 2008)
  1. Cross connections and backflow of contaminated water
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- Tier Two: "For the following issues, some evidence exists that they do occur in public drinking water systems and adverse public health impacts are suspected to be associated with these topics, although available information is more anecdotal in nature and additional research and information collection is necessary to better define public health risks. Little occurrence information is available to document or characterize these issues." (US EPA, 2008)
  5. Significance and control of biofilm and microbial growth
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7. Accumulation and release of contaminants from distribution system scales and sediments

For more detailed information on the seven AIP issues and the TCRDSAC's recommended approach to identify research and information collection needs, see section 4.2 of the AIP (US EPA, 2008).

1.1.1 Research and Information Collection Partnership

In the AIP, the TCRDSAC recommended that a RICP be formed to inform and support the drinking water community in developing future national risk management decisions pertaining to drinking water distribution systems. The current members, hereafter called partners, of the RICP are EPA and the Water Research Foundation (WaterRF). EPA and WaterRF signed a memorandum of understanding (MOU) in January 2009, which officially formed the RICP.

The AIP specifies that the RICP is to "establish a science-driven, mutually-agreed-upon, strategically-focused, decision-relevant research and information collection agenda that encompasses short, medium, and long term research and information needs" (US EPA, 2008). The objective of the RICP is to stimulate distribution system research and information collection from all interested parties.

This document describes the results of the deliberations of the partners, with input from a Steering Committee. The partners followed a systematic process, described later in this document, to identify high priority research and information collection project areas for the relevant AIP issues. These priorities, when completed, are expected to support future risk management decisions by the drinking water community, such as possible development of guidance, best management practices, regulations, or additional research and/or information collection on distribution system issues. Stakeholders may also use this information for education and training.

1.1.2 Steering Committee

The TCRDSAC also recommended that the RICP form a Steering Committee (SC). The SC was selected to provide a broad perspective on the relevant drinking water distribution system issues. The RICP SC contains nine members, including three members from EPA, three members from water utilities, one member representing a public health perspective, one representing an environmental advocate perspective, and one representing a state regulator perspective. In addition, at least one member also represents a small system perspective. The members of the SC can be found in Appendix A.

As specified in the AIP, the SC developed and accepted operating principles which outline roles and responsibilities, decision making procedures, safeguards, and data and information management provisions. The operating principles establish that the SC is responsible for review and acceptance of the products of the RICP. The SC members agreed to avoid the actual or appearance of gain or preference in their role with the SC. Non-governmental SC members

agreed to an ethics policy developed for the committee, while the federal government SC members agreed to adhere to the federal ethics regulations.

The SC met a total of seven times during development of this priorities document. Three meetings were face-to-face (April 2009, September 2009 and April 2010) and four were conference calls (June 2009, November 2009, February 2010 and March 2010). The partners estimate that the SC will typically meet once per year over the duration of the research and information collection agenda (priorities) depending upon need and partner resources. For more detailed information on the SC, see section 4.1 of the AIP (US EPA, 2008).

1.1.3 Communications Process

The AIP also specifies that the partners develop a process for communicating research and information collection. In response, the partners developed a communications process to: (1) provide transparency to stakeholders and the public about the work of the Partnership; (2) inform and engage potential researchers about request for proposals (RFPs) and high priority on-going research; and (3) inform and engage potential participants and funders of information collection activities.

The partners expect to communicate the research and information collection activities by taking actions such as:

- Posting materials developed through the RICP to the partners' websites. This includes posting this document which includes research and information collection priorities, summaries of the SC meetings, and links to information about high priority research projects and RFPs sponsored by the partners, descriptions of high priority information collection sponsored by the partners, and results of completed high priority research and information collection projects sponsored by the partners.

- Disseminating fact sheets describing the activities of the RICP at conferences, symposia, and stakeholder meetings.

- Distributing e-mail messages to stakeholders, drinking water utilities, the water research community, and others who express interest, to announce the release of the research and information collection priorities. E-mail messages may also be sent to announce RFPs sponsored by the partners.

The specific form of the communication will vary depending upon the target audience. For instance, some fact sheets may target the general public, whereas much of the information related to RFPs will more specifically target the research community. The partners plan to collaborate with individuals and institutions engaged in research and information collection activities to leverage communication opportunities.

1.2 Overview of Public Health Risks Associated with Drinking Water Distribution Systems

1.2.1 General Overview of Public Health Risks

Water distribution systems consist of an interconnected series of pipes, storage facilities, and components that convey drinking water and are also designed to meet fire protection needs for cities, homes, schools, hospitals, businesses, industries and other facilities. Public water systems depend on distribution systems to provide an uninterrupted supply of pressurized safe drinking water to all consumers. Distribution systems convey water from treatment facilities (or from the source in the absence of treatment) to the consumer. Spanning almost one million miles in the United States, drinking water distribution systems represent the vast majority of physical infrastructure for drinking water supplies, and thus constitute a primary management challenge from both an operational and public health standpoint. Storage facilities provide in-line storage of water and also can modulate pressure fluctuations and provide additional capacity to equalize flow and pressure, particularly during high water usage times and emergency situations.

The sizes, materials, methods of construction, and age of drinking water distribution system components vary depending on regional and community development patterns. As distribution systems age deterioration can occur due to corrosion, materials erosion, and external pressures that can lead to breaches in pipes and storage facilities, intrusion, and main breaks. In recent years, deteriorating water infrastructure in many parts of the US has resulted in frequent water main breaks, openings in storage tanks, pressure aberrations, and other situations that can pose intermittent or persistent health risks (US EPA, 2009 and ASCE, nd.). For example, 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 distribution systems is critical for public health protection. While infrequently reported, waterborne disease outbreaks and other events of public health significance do occur as a result of compromised distribution systems (NRC, 2006).

EPA has promulgated regulations that pertain to drinking water distribution systems. These are the Surface Water Treatment Rules (disinfectant residual and sanitary survey requirements) (US EPA, 1989b; US EPA, 1998a; US EPA, 2002b; US EPA, 2006a), the Stage 1 and 2 Disinfectants and Disinfection Byproducts Rules (DBPR) (monitoring for DBPs in the distribution system) (US EPA, 1998b; US EPA, 2006b), the Ground Water Rule (sanitary surveys) (US EPA, 2006c) and the Total Coliform Rule (monitoring for bacterial contamination in distribution systems) (US EPA, 1989a).

Public health issues may also be a result of premise plumbing issues. Premise plumbing is a term that describes the pipes, faucets, showerheads, hot and cold water tanks, and other appurtenances that convey water within buildings. It includes the plumbing portion of the potable water system that delivers drinking water from the service line into and through schools, hospitals, commercial and industrial facilities, office buildings, public and private housing and

other buildings before reaching consumers at tap outlets. It is connected to the public drinking water distribution system via the service line. Virtually every change in water quality associated with the public water system can also occur in premise plumbing, although there are additional concerns such as those related to water temperature and stagnation that can be exacerbated in premise plumbing. The characteristics of the water provided from the treatment plant, and its interactions within the distribution system, and the unique characteristics of premise plumbing all affect the public health risk of the drinking water at the tap and complicate the formulation of coherent strategies to minimize risk.

1.2.2 Overview of the Seven Distribution System Issues Identified in the AIP

When the operation and functioning of the distribution system is compromised, potential public health risks can occur. As discussed in Section 1.1, the AIP identifies the following seven drinking water distribution system areas that can potentially contribute to public health risks:

Cross connections and backflow. A cross connection is any interconnection between a potable water supply and a non-potable source where it is possible for a contaminant to enter the drinking water supply. The presence of an unprotected cross connection represents a loss of physical integrity in a distribution system through which backflow of contaminants can occur (NRC, 2006). Contaminant introduction through an unprotected cross connection occurs when the non-potable contaminant source is at a greater pressure than the potable water distribution system. Backflow can occur from either backsiphonage or backpressure. Backsiphonage occurs when contaminants from the non-potable source enter the drinking water supply due to low or negative distribution system pressure. Backpressure occurs when the non-potable source of a contaminant exceeds a positive pressure in the potable water distribution system.

External contaminant introduction diminishes the water quality of drinking water distribution systems. While there are cross connection control programs in place in many locales, many others lack such programs. There is evidence that inconsistent implementation of such control programs can result in public health risk (NRC, 2006).

Storage. Finished water storage facilities play a vital role in providing a safe, adequate, and reliable supply of water. Many types of customers, including schools, hospitals, nursing homes, factories, fire departments, and home owners all depend on a consistent, dependable supply of safe water. Failure to maintain the structural and sanitary integrity of storage facilities can lead directly to the loss of property, (e.g. due to fires), illness, and death. Finished water storage facilities are designed to provide equalization of demands during high water usage times, additional supply for fires, and emergency water supply in case of outages. The type, configuration and quantity of finished water storage tanks and reservoirs vary from system-to-system depending on several factors, including local requirements and topography. The design and operation of storage facilities plays a key role in protecting public health. Contaminants can be present in storage facilities, either by introduction through openings or indirectly due to inadequate inactivation of pathogens brought on by increased disinfectant demand and microbial and chemical reactions that impact water quality (NRC, 2006). Variable water use patterns can trigger hydrodynamic fluctuations that may slough biofilms and solids that accumulate on tank

surfaces and suspend sediments present in the storage facilities, introducing contaminants into the bulk water. When storage facilities are located in areas prone to low water use rates, the water within the tank may stagnate. Long detention times (high water age) and variable temperatures in storage tanks also affect the rate and extent of disinfectant decay, microbial growth and die-off, and nitrification reactions (AWWA and EES, 2002). Because storage facilities contain large volumes of water and have the ability to affect a large number of consumers in a distribution system, undetected or unaddressed contamination events within storage facilities can result in public health risks.

Main breaks, repair, and installation. Construction, rehabilitation, and repair of water mains are common activities that occur in all water systems. Sanitary construction practices must be used during main repair and installation of new mains and other infrastructure to prevent the introduction of contaminants. Putting a new or repaired main into service requires vigilance. When distribution system pipes break, rapid response is needed to isolate the affected mains and restore service as quickly as possible. During the main repair and installation process, distribution systems may be vulnerable to potential entry of microbial or chemical contaminants from the surrounding environment (Pierson et al., 2001). Low pressure events during main repairs can trigger contamination from intrusion, backflow, and concurrent release of biofilms and sediments from storage facilities and pipes, all of which can result in decay of disinfectant residuals in systems that provide disinfection. These distribution system contamination events may result in degradation of water quality which may result in public health risks.

Intrusion/Pressure. Intrusion is defined as "the flow of non-potable water into drinking water mains through leaks, cracks, submerged air valves, faulty seals, and other openings resulting from low or negative pressures. Transient pressure regimes are inevitable; all systems will, at some time, be started up, switched off, or undergo rapid flow changes such as those caused by hydrant flushing, and they will likely experience the effects of human errors, equipment breakdowns, earthquakes, or other risky disturbances." (NRC, 2005, p. 22)

Positive pressure in water distribution systems mitigates infiltration of external contaminants that might be present in the soil or water outside the buried pipes (Kirmeyer et al., 2001). Maintenance of pressure is typically accomplished through a combination of pumping and elevated storage tanks. When pressure is not adequately maintained in a distribution system, several types of contamination events are possible. Depending on the system's operating conditions and other factors that could influence pressure fluctuations (e.g., main breaks, pump start up or shut down), pressure fluctuations can occur for various time intervals, on the order of seconds to minutes (Besner et al., 2007; Besner et al., 2010; Gullick et al., 2004; Gullick et al., 2005) or possibly hours for extreme events such as major pipe breaks (The Tech 2005). Sudden changes in water usage, main breaks, valves opening and closing, and other service changes can also cause pressure changes. When the pressure inside the pipes is lower than the external pressure exerted by soil and groundwater conditions, intrusion of contaminated water through leaks or holes in the pipe can occur (Kirmeyer et al., 2001). Low or negative pressure can occur for several hours or longer, during events such as main breaks, major fires, and power outages. Because of the risk of drawing contaminants into the distribution system, low to negative pressure events may pose a potential public health risk.

Biofilms. There is not one universally recognized definition for biofilms; however, common among the definitions is that a water distribution system biofilm is a complex mixture of microbes, organic and inorganic material accumulated amidst a microbially produced organic polymer matrix attached to the inner surface of the distribution system. Some organisms harbored within biofilms may be primary pathogens (i.e., those that cause disease in healthy individuals), while others may be opportunistic pathogens (i.e., those that cause disease in susceptible individuals with underlying conditions that may facilitate infection). Biofilms allow organisms, including some pathogens, to accumulate, grow and die-off (US EPA, 2002a). This cycle can release pathogens into the water delivered to consumers and is of potential public health concern. Drinking water systems are designed to produce safe water by controlling disease-causing organisms (pathogens), but water in distribution systems is not sterile. There are two general classes of pathogens, those that the water industry has focused on, which come from fecal contamination of waters, and pathogens that are native to aquatic environments, some of which may grow after drinking water treatment. Further, water contains harmless microbes that survive the treatment process or enter the distribution system through the pipe network. These naturally occurring microorganisms in water can colonize internal surfaces of pipes and storage facilities in growths known as biofilms.

The extent of biofilm growth within a given distribution system depends on many factors, including water chemistry, system design, materials, operation, and maintenance practices. Sudden changes in water velocity due to pressure events or changes in water chemistry can slough biofilms from internal surfaces (US EPA, 2002a). Biofilm growth in storage facilities (and release of pathogens from biofilms in such tanks) is also an important public health risk consideration. The role of pressure changes in distribution systems on biofilm—including sloughing, transport, reattachment, colonization, and interactions between biofilm in distribution systems and premise plumbing—is poorly understood and needs further study to help inform public health risk assessment of biofilm/pathogen dynamics in drinking water distribution systems.

Nitrification. For water systems that contain sources of ammonium (e.g., either source water ammonum, or ammonium added to provide chloramine residuals), reactions can occur in distribution and storage systems that convert ammonium to nitrate, most of which is further converted by different microorganisms to nitrite. Some water sources also contain dissolved nitrite and nitrate, particularly in water sources that are impacted by agricultural activities. Nitrification is undertaken by microbes that can survive and grow in biofilms (AWWA, 2006), some of which may be released back into drinking water and continue the process. The extent of nitrification varies from system-to-system depending on factors such as design, operation, and water quality. Secondary impacts from nitrification include decay of chloramine residual and release of ammonium, and reduction in pH, which can aggravate metal release and corrosion (AWWA and EES, 2002). National Primary Drinking Water Regulations (NPDWR) exist for nitrite and nitrate. The maximum contaminant levels (MCL) for nitrite and nitrate are (MCL=1 mg/L) and (MCL=10 mg/L), respectively. However, the point of compliance is at the entry point to the distribution system, not downstream where biofilm-related nitrification may occur. Therefore, limited information is available on the extent to which nitrification reactions impose

additional health risks and remove residual disinfectant in distribution systems at points further from the entry point to the distribution system.

Contaminant accumulation and release from scales and sediments. Inorganic contaminants, including minerals that vary in solubility (calcium, magnesium, iron, manganese), metals (lead, copper, vanadium, arsenic), and inorganic contaminants that are not completely removed in treatment, can precipitate onto internal surfaces within pipes and storage facilities and accumulate (US EPA, 2006d). When operational conditions, such as pressure events or high water demands, result in changes in water velocities or water quality conditions promote corrosion reactions, contaminants can be re-dissolved or re-suspended into the bulk water and may pose health risks (US EPA, 2006d). The surfaces of accumulated scales and sediments can also harbor biofilms and associated pathogens. Limited information is available on the extent to which these reactions occur, the potential public health risks they pose, and the effectiveness of risk management practices.

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2. Prioritization of Research and Information Collection Project Area Documents

The partners used a five step process to identify high priority research and information collection project areas. The steps included: (1) conducting research and information collection (RIC) needs analysis for each of the seven issue areas in the AIP, (2) compiling RIC needs identified in the needs analysis, (3) sorting and organizing the RIC needs into related project areas, (4) developing project area documents based on results of RIC needs analysis, and (5) prioritizing project area documents. The following subsections provide a description of these steps. The partners solicited comments from the SC throughout the process.

2.1 Research and Information Collection Needs Analysis

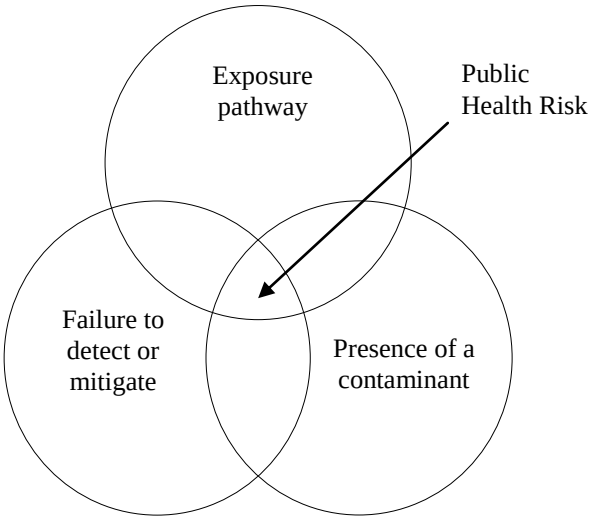
The first step in developing the Research and Information Collection Priorities was to identify a comprehensive list of research and information collection needs for each of the seven AIP issues. The RIC needs analysis defined distribution system-related research and information collection needs relevant to protect public health; or to inform possible future guidance, regulatory, or best management practices decisions related to the distribution system issues. To identify needs, the partners assembled teams of subject matter experts to assist in the development of an analysis for each of the seven AIP issues.

The partners directed the experts to perform literature reviews to define the state of the science for each issue by first defining a contamination event and then identifying potential public health risks in the context of distribution system vulnerabilities and risk management/interventions.

The clear definition of the contamination event, including the specific vulnerability factors and failures of mitigation barriers, provides a way to begin to understand commonalities among different public health outcomes and ways to predict, diagnose, prevent, and manage the potential health risk. A contamination event can occur either when contaminants gain entry into distribution and storage systems from external pathways, or as a result of internal microbial or physical/chemical reactions. In each case, contamination events occur only when specific barriers within the distribution system fail. Figure 1 illustrates the range of conditions necessary for a contamination event to pose a public health risk.

The experts used a systematic approach for each of the AIP issues to determine what relevant data, information, and models are currently available to aid in identifying potential public health risks. Data sources included monitoring and operations data, surveys, utility data, and research studies, publications and reports.

Figure 1 - Illustration of the Components of a Contamination Event



As part of the research needs analysis, conceptual models were developed to qualitatively assess gaps in information to better enable an estimation of public health risk and evaluate the effectiveness of risk mitigation strategies. Through this process the partners gained further insights into the uncertainties associated with different input variables and the value of completing research and information collection priorities.

Along with the consideration of individual contamination events, the experts also determined the types of research and information collection that would be most useful to estimate the potential national magnitude associated with the events. For several of the issues, the greatest gaps were not in the definition of the contamination event but rather in the estimation of the frequency and duration of such events in a given system, and by extension the national frequency of events that warrant public health concern. In addition, the experts explored available strategies for risk mitigation in order to be able to define which risk mitigation technologies, strategies and practices warranted more information in order to be more fully understood, especially with regard to the effectiveness of the risk mitigation.

The partners compiled the results of the experts' analyses and used this information to better assess the "needs" or current gaps in understanding the factors that may affect distribution system water quality. There were approximately 180 needs identified. Following the RIC compilation step, the partners categorized all the needs as either research or information collection needs. As an outcome of their discussions, the partners defined research as generating new data and information on a topic by conducting studies at the laboratory, bench, pilot, modeling, or full-system scales. Information collection was defined as obtaining existing data on a topic from water systems, equipment manufacturers, suppliers, or other related entities through surveys, data call-ins, or other similar means. The information should already be available and could be accumulated by surveying states, systems, or other entities. Information collection requires clearly defined information which the owner would be willing to share.

Subsequently, the partners sorted the needs from all seven topic areas and organized them into thematic project areas. The partners did not narrow down or eliminate the needs, but instead grouped them into project areas. Project areas include surveys to collect distribution system-related information, and specific projects focused on pressure and intrusion, public health assessment contaminant characterization, cross connections, storage, monitoring, and risk management. Table 1 defines the eight project areas.

Table 1. Project Areas (Code) and Definitions

Contaminant (Con): Identification or estimation of contaminants of concern as well as mechanism of entry and contaminant concentrations.
Cross Connection (CC): The SC felt that cross connections is a Tier One issue (as defined by the TCRDSAC) that is among the closest to final risk management decisions in terms of risk mitigation and management. Therefore, project areas focused on cross connections are appropriate.
Health Effects (Hea): Estimation of disease incidence and risk factor implications related to distribution systems.
Monitoring (Mon): Actual monitoring activity or development of monitoring techniques and strategy.
Pressure (Pres): Relates to ambient pressure and pressure events in the distribution system. Related to both pressure levels and consequences of ineffective pressure management.
Storage (Stor): The SC felt that storage is a Tier One issue (as defined by the TCRDSAC) that is among the closest to final decisions in terms of risk mitigation and management. Therefore, project areas focused on storage are appropriate.
Surveys (Sur): Efforts to collect information through a survey or questionnaire. The information should already be collected and could be accumulated by surveying states, systems, or other entities. It requires clearly defined information which the owner would be willing to share.
Risk Management (RisM): Improves understanding for directly evaluating risk mitigation options and effectiveness including: diagnostics and controls relevant to events in individual systems and nationally, and effectiveness of known risk mitigations and alternatives.

2.2 Project Area Documents

Once the categories of research and information collection needs were established, and the needs sorted into the project areas, the partners developed specific research or information collection project area documents. The partners determined that several of the needs were related or redundant. Therefore, it would not be efficient or practical to design a specific project around each individual need. Instead, the partners determined that it would be more feasible to develop a set of project area documents that would adequately address all the needs identified. The partners consulted the team of experts for each project area to assist with this task. Each team

developed a set of project area documents that would encompass needs in that project area. This process, with input from the SC, yielded 29 different project area documents[2] in the eight project areas. The project area documents are meant to serve as guides for the areas of research or information collection related to distribution systems. The project area documents are generally intended to identify groupings of similar needs rather than individual, stand alone projects.

2.2.1 Definition of a Successful Project

When a partner party decides to undertake a particular project stemming from the project area documents, it is expected that the partner or an outside party would create a more detailed project request for proposals based on such factors as technical feasibility, project methods, and funding levels. In the case of the partners, this may include a full request for proposal. However, other methods of accomplishing these project area documents may be more appropriate (such as for the survey projects). It is also possible that some of the project area documents may be more appropriate to divide into multiple projects to fully understand the information needs described. In addition, because all needs were grouped into project area documents, the goals and objectives of the documents may be met by only conducting a subset of the activities listed. It will be up to the partner or entity following up on the project to determine the most efficient way to meet the goals and objectives described in the project area document, considering what is learned from other projects or research and information collection conducted by the partners and other entities. The project area documents are not intended to provide complete detail on how the project areas are to be executed. This means that they are not intended to be used directly as requests for proposals.

Organizations that may conduct research or information collection have different funding levels, mechanisms, and prioritization approaches. These project area documents provide a starting point for developing specific project requests for proposals for research and information collection. Any organization with an interest in these topics will consider the priority project area documents in the context of their own processes for resource allocation.

While each of the project area documents is different and will require customized implementation steps based on the individual characteristics of the project areas, there are some aspects that all projects should contain in order to be considered successful. First and foremost, implemented projects should address the goals and objectives found in the project area documents. These goals and objectives were written specifically to address the research and information collection needs, which represent the information missing from the current understanding of each of the seven AIP issues to inform risk management decisions by the drinking water community.

As the projects are developed, it is suggested that the project sponsors invite an identification and evaluation of the potential impacts and existing risks on minority, low-income, tribal, and other vulnerable populations. This may involve an evaluation of the proximity of distribution system

[2] Twenty-seven out of the 29 project area documents were scored. See Section 2.3.3 for rationale.

issues (e.g., cross-connection and backflow, storage breaches, main breaks) to these populations, the number of distribution systems that may be impacting these populations, the type and amount of contaminants that may be affecting them, and whether there are any distinct exposure pathways that specifically affect them versus the general population.

In addition, it is important for researchers or those responsible for information collection to disseminate ongoing work related to their projects and not simply the completed published work. Since much of the ongoing work related to these project needs may be conducted by the RICP partners, it will be necessary for the partners to share, and encourage researchers to disseminate results as soon as practicable. This is to ensure efficiency, enhance the speed of knowledge transfer, promote coordination, and minimize duplication among researchers.

The results of the project area documents are intended to inform decisions regarding the need for possible development of guidance, best management practices, regulations, or additional research and/or information collection distribution system issues. Stakeholders may also use this information for education and training.

2.2.2 Prioritization Approach

The following subsections in this section describe the process that was used to set priorities among the project area documents. Out of the 29 project area documents, the SC accepted ten as high priority project area documents. Each project area document was assigned a project area document code. A table which lists each project area title and its identification code is found in Appendix B.

The partners worked with the SC to identify the high priority project area documents. Given limited overall resources and a lack of resources to complete work in all 29 project areas, it was vital to prioritize the project areas based on agreed-upon criteria. To aid in this prioritization, the partners developed a scoring system to help evaluate which of the project areas should receive the highest priority. The prioritization is helpful to assist funders and researchers to focus their efforts on the most important areas first. Focusing on the highest priority to fill the most important research and information needs is the strategy the partners believe will most likely yield a body of focused, decision relevant knowledge that may be applied to support risk management decisions.

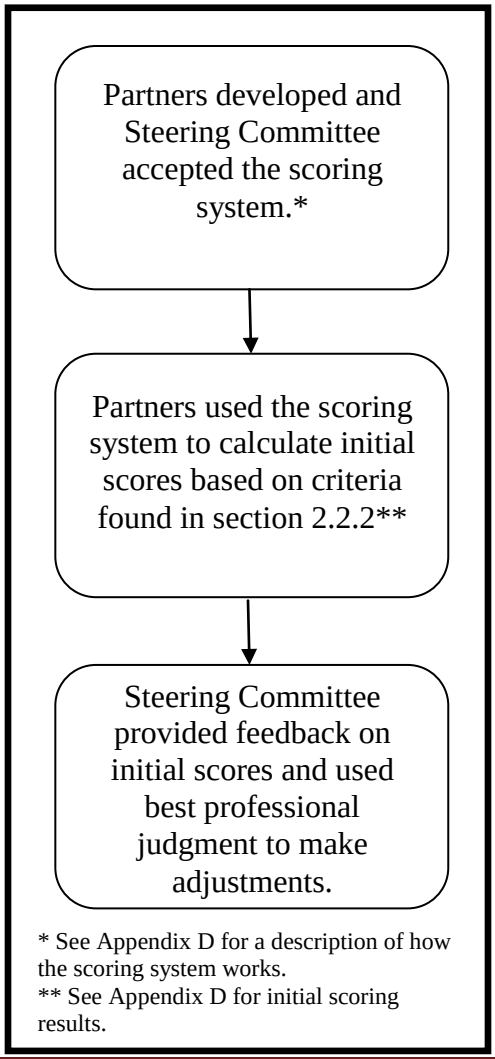
The criteria, or factors, that the scoring system takes into account are:

- relevance to each of the seven issues described in the AIP, with higher priority given to project areas that address multiple issues
- the extent to which the project area is expected to inform an understanding of the magnitude of public health risk
- the extent to which the project area is expected to inform an understanding of the mitigation of public health risk

In developing the scoring system, the partners sought input from the SC to ensure that the system would be a valuable tool for use by the SC and the RICP. The SC specifically recommended that the scoring system incorporate the AIP tiering structure for the seven issues in order to better reflect the recommendations in the AIP. The SC also noted that considerations for the timing of project area documents (when project would be complete) and dependencies (which projects areas could benefit from work in other project areas) are important. However, the SC felt that the three factors above should be the primary drivers of the scoring and ranking, while the dependencies and timing factors should be used primarily as a way to differentiate among project area documents that had very similar initial scores.

The partners completed the scoring for each of the project areas and compiled the scores using the scoring system. Figure 2 provides an overview of the process used to identify the ten high priority project area documents. A detailed description of the scoring process and criteria, as well as the final scores, can be found in Appendix D.

Figure 2 - Overview of Process to Identify the Ten High Priority Project Area Documents



2.2.3 Final Review by Steering Committee

The partners presented initial scores (found in Appendix D) to the SC for review. The SC elected not to rank each project area document in order. Instead, the SC separated the list of project area documents into two groups. The first group was identified as the group of highest priority project area documents. The remaining project area documents were not considered to be the most critical at this time because they were not as decision relevant. The list of high priority project area documents is found in Table 2. The full descriptions of these project area documents are found in section 3. The remaining project area documents can be found in Appendix C of this document.

2.2.4 Other Considerations Used in Steering Committee Decisions

In addition to the partner scores, the SC considered several other pieces of information when making their recommendations on the high priority project area descriptions. One main consideration for the SC was the sequence in which the project area documents would be addressed. In order to address these concerns, the SC used the results of a "generational approach" analysis that the partners provided.

In the generational approach, the partners evaluated all project area documents to determine which ones had a "strict dependence" relationship with other project area documents. A "strict dependence" relationship means that the results from a particular project area document are prerequisites for work to begin on another project area document. For example, if project area document B strictly depends on project area document A, then project area document A must be completed before work on project area document B begins. The generational approach also evaluated which projects had an "informational" relationship. An "informational" relationship means that while a project area document may not strictly require information from another project area document before proceeding, information learned in the first project area document is likely to be useful in carrying out research or information collection in the second project area document. For example, if project area document B is informed by project area document A, then it is possible to complete project area document B without waiting for the results of project area document A. However, the design and usefulness of the findings from project area document B will likely be maximized if work on project area document A is completed before work begins on project area document B.

The partners used best professional judgment to establish the generational and informational relationships among project area documents based on the definitions above. The relationships among the project area documents are listed in the table in the "Project Area Constraints and Timing" section of each project area document. Based on these tables, the partners produced a list of project area documents containing all possible projects that could begin first without the need for results from other project area documents. The project area documents on this list are project areas that do not strictly depend on other project areas and are not informed by other project areas. First generation project areas are those in which work could begin immediately and maximize the usefulness of the results by informing projects in later generations. The list of first generation of project area documents can be found in Appendix E.

2.2.5 List of SC adjustments with rationales

The SC used the top ten ranked project area documents from the initial scoring described in Appendix D as a starting point for their discussion. Based on that initial list, the SC made adjustments using principles outlined in section 2.2.4. The SC noted that several of the project area documents which received high scores were dependent on, or at least informed by, several other project area documents. They believed that it would not make sense to place these project area documents on the high priority list. Therefore, the SC removed project area documents Sur2, Sur3, RisM1 and Pres3 from the high priority list based on this rationale.

Sur2/Sur3 – Sur2 is dependent on partial completion of Sur1. Sur3 is in turn dependent on Sur2. The SC recognized that Sur2 is envisioned to rely heavily on lessons learned from Sur1 and that certain elements of Sur2 may be refined based on findings in Sur1. Similarly, Sur3 relies on Sur2 since baseline data and survey design elements could be incorporated from Sur2. Therefore, the SC did not consider a designation of high priority for Sur2 and Sur3 to be appropriate.

RisM1 – RisM1 is a project area that could be used to incorporate much of the information learned as part of the RICP process. It is either directly dependent on or could benefit from the completion of work in many different project area documents including Sur1, Sur2, Sur3, Sur4, Con2, Con3, Con4, RisM4.

Pres3 – Pres3, which develops strategies to monitor for pressure fluctuations, is dependent on several different project area documents which examine the causes and frequencies of pressure fluctuations, including Sur1, Sur2, Pres1 and Pres2.

The SC also added project areas to the list of high priority items that were not originally found on the list of top ranked project area documents from the initial scoring. These project area documents were given high priority based on circumstances that were not reflected in the scoring system. The SC added project area documents CC1, Stor1, Con3 and Con4 to the set of high priorities.

CC1 and Stor1 – The SC recognized both CC1 and Stor1 as high priority project area documents. The SC felt that Cross Connections and Storage are the two Tier One issues (as defined by the TCRDSAC) that are the closest to final risk management decisions. Both project area documents concern best practices for risk mitigation in those two specific areas. The SC recognized that while these two project areas did not receive a high score during the partner scoring process, this was due to the structure of the scoring mechanism. Project areas that address issues across several topic areas receive more points in the scoring system. Project area documents such as CC1 and Stor1, which only address one topic area in a specific way, therefore did not receive high scores from the scoring system. Therefore, despite their relatively low scores, the SC recognized that these two project areas were high priority based on the degree to which they will help address the Tier One topic areas in a specific way.

Con3 and Con4 – Con3 and Con4 were also added to the list based on similar rationale to CC1 and Stor1. The SC noted that these project areas also received low scores in the scoring process due to their focus on a specific topic area. In particular, the SC showed interest in Con3 and Con4 because they complement CC1 and Stor1 by informing the magnitude of risk from Cross Connections and Storage. Con3 concerns the incidence of risk factors associated with Storage contamination events and Con4 examines the incidence of risk factors associated with Cross Connections and backflow. The SC believed that the combination of CC1 and Con3, and Stor1 and Con4, is expected to provide decision relevant information. Therefore, they included Con3 and Con4 among the high priority project area documents. In particular, the SC recognized the results of Sur1, when combined with Con3 or Con4, should yield sufficient decision relevant information to support risk management decisions.

3. Research and Information Collection Priorities

As a result of their deliberations, the Steering Committee accepted a list of ten high priority project area documents. Table 2 provides a list of those documents as well as a summary of their goals.

Table 2. Final Ten High Priority Project Area Documents (in Alphabetical Order)

Project Area Document Code[3]	Project Area Document Title	Goals
CC1	Best Practices to Minimize Risks Associated with Cross Connections and Backflow	Identify and characterize the best practices (BPs) (including design, operations and costs) for cross connections and backflow that can be used to mitigate potential contamination concerns.
Con3	Contaminant Entry from Breaches in Storage Facilities	To compile data to better understand and predict health risks associated with contaminant entry through structural breaches in storage facilities.
Con4	Estimation of Contaminated Water Volumes and Contaminant Concentrations Introduced Into Distribution Systems Due to Backflow Events from Unprotected Cross-Connections Based on Model Predictions and Field and Pilot-Scale Experiments	To compile data to better predict health risks associated with entry of external contaminants into drinking water distribution systems through unprotected cross-connections.

[3] CC, cross connection; Con, contaminant accumulation; Hea, health effects; Pres, pressure; Stor, storage; Sur, surveys

Hea1	Quantitative Microbial Risk Assessment (QMRA) to Evaluate Exposure to Pathogens through Drinking Water Distribution Systems	To develop an adaptive tool that can be used to estimate relative risks of exposure to distribution system pathogens and the effectiveness of risk management strategies for preventing/controlling microbial risks.
Hea2	Epidemiological Studies of Health Effects Associated with Low or Negative Pressure Events in Distribution Systems	To obtain information on the incidence and severity of adverse health effects occurring among customers who are impacted by low or negative pressure events in water distribution systems. The information can inform estimates of both baseline risks and reduction in those risks from mitigation actions.
Pres1	Survey of Distribution System Pressure Management Practices	To assess pressure management practices in water distribution systems to determine the prevalence of specific high risk distribution system attributes leading to low or negative pressures.
Pres2	Characterize Propagation of Pressure Events through Water Distribution Systems to Improve Pressure Management Approaches	Evaluate the propagation of pressure events through the distribution system and compare field data with surge model results for the same events. Evaluate pressure propagation events at a number of systems and investigate the impact and cost of changes intended to mitigate the number and extent of such events.
Stor1	Best Practices for Minimizing Risks Associated with Storage Facilities.	Identify and characterize the best practices (BPs) for storage that can be used to mitigate potential contamination exposure concerns.
Sur1	Survey of Large Drinking Water Utility Distribution Systems	To identify characteristics of drinking water distribution and storage systems that serve > 50,000 people.
Sur4	Targeted Surveys to Obtain Information on State and Local Regulations, Policies, Manufacturing Practices and Guidelines for Distribution Systems	To evaluate extent to which distribution system risk management and mitigation practices are implemented by states or through manufacturing, installation, or inspection programs.

The remainder of this section contains the complete text of these ten high priority project area documents.

Project Area Document Code: CC1

Project Area Title: Best Practices to Minimize Risks Associated with Cross Connections and Backflow

Goal(s): Identify and characterize the best practices (BPs) (including design, operations and costs) for cross connections and backflow that can be used to mitigate potential contamination concerns. Help industry personnel to:

1 Better diagnose potential problems
2 Better understand risk factors (e.g., failure of a barrier) associated with cross connections and backflow events
3. Provide operators with best practices to reduce those risks
4. Provide information on the cost effectiveness of BPs

Rationale:
The presence of an unprotected cross-connection represents potential distribution system (DS) vulnerability, through which backflow can occur. This situation can provide a conduit for chemical, microbial and/or radiological contaminants to enter the DS, particularly when the pressure in the potable source is lower than the pressure in the contaminant source. These lower pressures result from common events in DS, including valve and pump operations, power outages, main breaks, high demand, flushing, and even a rise in pressures from the contaminant source (e.g., a boiler).

The extent and magnitude of health risks associated with backflows is site-specific and depends on the source of contamination (sewage, industrial discharges, etc.), the location of the backflow, the distribution system characteristics, and the effectiveness of prevention and inspection programs. The durations of consumers' exposures to the contaminants is highly variable and depends on water use practices, system hydraulics, the nature of the cross connection, an understanding by the system that a risk may exist and the ability of the system to find and remedy the problem. Given that limited monitoring occurs in DS, these events often escape detection. Frequently events are detected through customer complaints rather than routine monitoring. Even then, the event will often have passed by the time the utility investigates. As a result, undetected and uncorrected cross connections may result in recurring backflow occurrence, imposing unquantifiable health risks.

Currently, there are no federal regulations that explicitly require drinking water systems to protect against or document cross connections and backflow events. Based on 2001 data, while every state has a requirement related to cross-connection control and/or backflow prevention, only 32 states require that public water systems implement a cross-connection and/or backflow prevention *program* (EPA, 2001). There are variations among the states in the extent of

implementation, enforcement, inspection, and oversight due to local situations including competing priorities, funding and resource limitations, political factors, and the lack of federal drivers or incentives. Developing metrics to quantify program effectiveness, along with aggregating information about required elements of state programs and their relative effectiveness, and compiling components of programs from exemplary utilities, industry groups, universities, and other practitioners can be used by states and utilities to implement improved practices.

Objectives:

1. Compile existing materials that document BPs that are used by a range of different audiences (e.g., utility personnel, plumbers) to diagnose, prevent and mitigate backflow contamination risk factors, including cross connection hazard surveys, elements of effective cross-connection control programs and responses to contamination events. Information related to implementation costs and barriers to implementation will also be compiled.

2. Provide a single reference resource for industry personnel to evaluate cross connection and backflow related risk factors, and risk mitigation options (including costs and potential implementation obstacles). Risk factors are those factors which potentially contribute to the occurrence of backflow (e.g., unstable operating pressures).

3. Evaluate attributes of effective training programs provided to water utilities, plumbers, etc. and provide a resource from which training materials could be developed.

4. Determine key barriers to development, implementation and enforcement of cross-connection control and backflow prevention programs, and provide case study examples of how these barriers have been overcome.

5. Develop strategies to quantify and benchmark the effectiveness of BPs used by utility personnel, plumbers, etc. and document case studies of successful programs.

Suggested Approach:

Develop a "State-of-Knowledge" Synthesis of Existing Knowledge and Information Relative to Cross Connections and Backflow —Provide a comprehensive review and summary of key existing information and knowledge from literature, references, manuals, training materials, industry surveys, interviews and site visits, and existing cross connections and backflow materials.

- Collect and summarize available information on potential risk factors
- Collect and summarize evidence of links between backflow events, contaminant exposure, health effects, and waterborne disease outbreaks.
- Compile relative costs of components of cross-connection control and back-flow prevention programs, diagnostic approaches, and mitigation measures.

- Develop a glossary with illustrations, definitions, etc., that can be used by the water industry and others to promote dialog and to more fully characterize cross connections and backflow.
- Provide easy-to-use examples and case studies of cross connections and backflow risk-related regulations, standards, policies, certification programs, ordinances, key program elements, codes and best practices (assimilated from States/EPA, vendors, associations, inspectors, utility operators/managers, plumbing organizations) and provide comparative costs and constraints for adoption of risk evaluation, prevention and mitigation measures.
- Provide case study examples of how some systems have overcome key barriers to development, implementation and enforcement of cross-connection control and backflow prevention programs.
- Conduct follow-up as needed to gather, assemble and summarize key information and knowledge.

Assess the Effectiveness of Cross Connection Control and Backflow BPs –Incorporate key information useful for evaluating (1) potential backflow related risk factors and (2) backflow risk mitigation.

- Develop tools for industry personnel and others to better evaluate backflow risk factors and risk mitigation, including costs.
- Conduct expert review of BPs.

Strategies to Gauge Industry Application of BPs

- Develop strategies and approaches to assess application, usefulness and effectiveness of BPs and to assimilate data from applications of project area results.
- Develop metrics and benchmarks of program effectiveness

Results and Applications:

Information collected in this project area will help system operators better diagnose and correct problems related to cross connections and backflow. It will also help system operators to recognize and address potential risk factors (e.g., failure of a barrier) associated with cross connections and backflow and evaluate elements of effective cross-connection control and backflow prevention programs that help to mitigate risk factors. Information collected in this project area will identify opportunities for improving the effectiveness of BPs and will also evaluate barriers to implementation and mechanisms for improving adoption, implementation, and vigilance.

The results of information collection in this project area will provide BPs for use by a wide range of stakeholders (e.g., utilities, states, industry, and plumbing organizations). It will provide tools to assist utility personnel in diagnosing backflow related problems, highlight effective BPs, and provide strategies for overcoming obstacles for managing backflow risks. Information collected in this project area will inform a national perspective on the use, costs and effectiveness of the BPs. Information collected in this project area will also elucidate social science factors that might be relevant to improving the consistency of cross-connection control and backflow prevention programs.

Knowledge incorporated into the content and format of the BPs will facilitate more informative cross connection and backflow related surveys, sampling, and data analysis, and may also be useful in sanitary surveys required under the SWTRs and GWR. The results of information collection in this project area can also be used to assist with optimization of DS practices.

Decision Relevance:

How is information collection in this project area likely to inform evaluation of the magnitude of public health risk?

Information developed in this project area will include descriptions of cross connection and backflow contamination events where health impacts have occurred. These accounts will illustrate the severity and extent of outcomes that can result from cross connection and backflow events and will inform industry personnel and others of potential risks assisting in the selection of risk mitigation options. System level hazard assessments and cross connection and backflow risk evaluations will better inform utility personnel and others about the potential risks in their systems. The assimilation of data about the use of the BPs will yield more representative and useful cross connection and backflow related (performance and cost) information and knowledge than is currently available nationally.

How is information collection in this project area likely to inform opportunities for mitigation and risk reduction?

The results of information collection in this project area would go beyond informing opportunities for mitigation and risk reduction by providing BPs to implement known, effective, mitigation and risk reduction strategies. Increased industry personnel understanding will support efforts to plan more effective system level hazard assessments and cross-connection control and backflow prevention programs. For systems with advanced programs, the information will help them evaluate their current practices. Cost and performance effectiveness of existing cross-connection control and backflow prevention strategies can be evaluated as well. Utilities, contractors, and regulators can use these evaluation and mitigation BPs to address cross-connection and backflow risks in the interim period while national surveys and studies are ongoing, and national risk management decisions are pending.

What types of distribution system decisions could be supported by information collection in this project area?

If future decisions regarding the need for regulation, guidance, policy statements, or other actions are to be taken, the materials developed in this project area could be used to support those decisions. Follow up on the results of the availability of BPs and improved surveys and research will provide a better understanding of the national status of cross connection and backflow related risks and the obstacles to implementation of risk mitigation measures. Additionally, many of the BPs that are expected to be captured from information collection in this project area will be evaluated in more detail (in terms of degree of implementation and effectiveness) as part of the other RIC priority project areas under consideration by the DS RICP.

Project Area Constraints and Timing:

This project area is a stand-alone project that can begin immediately, and could be completed within two years. It is not dependent on the completion of information collection in other project areas, nor is any other project area dependent on completion of information collection in this project area. However, the completion of this information collection project area may influence several other project areas. See the table below for information on the project areas that build on CC1.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by the DS RICP)**	**Information needs (what will be used in follow-on project areas)**
This project area depends on. . .	No other project areas		NA
Project areas that this project area builds on	None.		NA
Project areas that build on this project area	Pres4	Toolkit for pressure management	Cross connection control best practices developed in CC1 may be considered for inclusion in pressure management toolkit.
	Sur4	Targeted surveys to obtain information on state and local regulations, policies, manufacturing practices and guidelines for distribution systems	Information on cross connection control practices from CC1 could be compared with information collected in Sur4.

Factors that might influence the timing of completion of information collection in this project area include:

- Familiarity with existing cross-connection control program publications.
- Access to state databases and/or other information needed from states
- Ability to obtain expert peer review and/or input regarding key elements for which additional understanding is needed.
- A quick project area timeline would enhance the understanding of backflow risks and mitigation, needed in the interim when DS RIC efforts are beginning and regulatory decisions are pending.

Relevance to the Agreement in Principle:
This project area is relevant to the cross-connection which is a Tier One priority area. Information collected in this project area will contribute towards fulfillment of the AIP objective of optimizing DS integrity by assembling BPs associated with cross-connection and backflow

prevention programs and providing the tools for utilities and states to evaluate existing programs. Information collection in this project area will also build upon the Cross Connection Control practices library outlined in section 3.17.a.

Key References:

ABPA (1999) American Backflow Prevention Association State Program Survey. *www.abpa.org/originalsite/ABPA_Survey_Report.pdf*

TCRDSAC Agreement in Principle (2008). *http://www.epa.gov/safewater/disinfection/tcr/pdfs/tcrdsac/agreementinprinciple_tcrdsac_2008-09-18.pdf*

EPA. (2001) Potential Contamination Due to Cross-Connections and Backflow and the Associated Health Risks. Distribution System White Paper. *www.epa.gov/safewater/disinfection/tcr/pdfs/issuepaper_tcr_crossconnection-backflow.pdf*.

Project Area Document Code: Con3

Project Area Title: Contaminant Entry from Breaches in Storage Facilities

Goal: To compile data to better understand and predict health risks associated with contaminant entry through structural breaches in storage facilities.

Rationale: Research in this project area will provide data on the extent to which contaminants can gain entry into distribution systems from storage breaches (e.g. poorly sealed hatches, unprotected vents, tears in covers, or structural cracks or holes). Research in this project area will involve monitoring and source tracking to determine the relative magnitude of contamination that may result from storage breaches. Since water that is released from above-ground and underground storage facilities into distribution systems has the potential to introduce contamination to significant populations, it is important to understand the magnitude of this risk. In addition, the variability of storage operations necessitates well-designed sampling efforts that are coupled with hydraulic modeling.

Storage facilities are uniquely vulnerable to contamination due to their often remote, elevated locations, unstaffed sites, the potential for long residence time (water age) and changes in temperature, disinfectant residuals, and other water quality parameters, and the challenges associated with regular programs for monitoring, inspecting and maintaining the structures. Animals, birds and insects can enter storage facilities through breaches and potentially introduce human/animal fecal pathogens (e.g. *Salmonella, Campylobacter, E. coli*). For example, in the 1993 storage-related outbreak in Gideon, Missouri, operator flushing of the system to resolve taste and odor problems dispersed *Salmonella*-contaminated water from storage causing more than 600 illnesses and 9 deaths (Clark et. al. 1996). Storage contamination was also cited as a cause of a waterborne disease outbreak in Alamosa, Colorado in 2008. Opportunistic pathogens (*Legionella,* MAC*)* have also been observed to thrive in biofilms and amoebae, apparently shielded from disinfectants (Lau and Ashbolt 2009), making storage sediments possible locations for these opportunistic pathogens to grow if introduced through storage breaches.

The knowledge goals of research in this project area are: (1) Understanding of factors contributing to or controlling contaminant entry through storage breaches; (2) Characterization of types and patterns of contaminants that may enter storage directly via breaches, and; (3) Understanding the fate of, and risk from, breach-related contaminants in storage upon release to the system. The overarching questions this project area will answer are: (1) Under what conditions and scenarios do storage breaches lead to entry of contaminants into storage facilities, and/or inoculation of distribution systems resulting from storage breaches? (2) What factors affect the types and quantities of contaminants that can enter/occur via storage breaches? (3) What is the expected fate or the behavior of storage-associated contaminants during storage and transport through the distribution system?

Objectives:

- Enhance the understanding of effectiveness of various storage breach-related risk mitigation measures, costs, and implementation obstacles.
- To characterize storage breach entry pathways, causes, sizes, convection mechanisms, durations, and frequencies of occurrence.
- Measure contaminants in bulk and stored water, and sediments within storage facilities.
- Estimate the extent to which pathogen accumulation, growth, or die-off occurs due to storage conditions or operations (e.g., fill/draw, mixing, stratification, disinfection effectiveness, entrapment in sediments or biofilms) to develop predictive models to estimate release from storage into the distribution system.

Suggested Approach:

- Summarize scientific literature on environmental pathogen occurrence, survival rates, and disinfection susceptibility in storage tanks and underground finished water reservoirs. Identify potential pathogen sources of contaminants that might gain entry to storage facilities (mostly animals, birds, and insects).
- Delineate possible storage contamination scenarios and relative risks including animal access.
- Conduct observational studies of storage facilities to evaluate the potential for animal access.
- Develop and implement plans to characterize and sample storage systems with a range of potential vulnerabilities to external contamination, including a range of influencing factors such as geographical and seasonal variability, storage facility design, etc. Plans should include systematic approaches for selecting representative sampling sites, the number of samples to be collected per site, and the total number of scenarios to be sampled to inform a national estimate of the magnitude of risk.
- Conduct targeted sampling and laboratory testing of storage conditions that impact pathogen viability (e.g. disinfectant type and concentration, stratification, temperature, biofilms, or solids accumulation)
- Estimate pathogen concentrations in different types of storage facilities and underground finished water reservoirs, and the extent to which accumulation, amplification or die-off occurs due to storage conditions or operations (e.g., fill/draw, mixing, stratification, disinfection effectiveness, entrapment in sediments or biofilms).
- To the extent feasible research this project area should include a qualitative estimation of the effects of mixing on the dispersion of pathogens in the stored water.
- Develop preliminary predictive models to estimate release from storage into distribution systems which encompass a range of storage configurations (e.g. range of cycling, mixing, and stratification, disinfectants).

Results and Applications: Concentrations, types, and patterns of storage breach-related contaminants measured through research in this project area can be used as inputs into fate and transport models and risk models to estimate exposures/health risks from storage breach-related contamination events. Research in this project area will provide new insights on the types, quantities, patterns, and pathways of pathogens entering systems via various storage breach pathways. Understanding storage-related events gained through research in this project area will

provide insights about the magnitude of risks and opportunities for risk mitigation across a wide array of systems. Although not the direct intent of this project area, the results from research in this project area may also provide a measure of the effectiveness of best practices comparing vulnerable systems that implement versus those that do not implement best practices.

Decision relevance:

How is research in this project area likely to inform the evaluation of the magnitude of public health risk?

Research in this project area is designed to characterize contaminants that gain entry to water distribution systems directly from storage breaches. It will provide key new insights about sources and occurrence patterns from animal and insect-borne pathogens introduced to storage, and which may be harbored or grown in storage and transported into and through systems.

How is research in this project area likely to inform opportunities for mitigation and risk reduction?

The nature and occurrence of the pathogens will help develop a greater understanding of the potential risk mitigation options that systems may want to use to target these risks through the identification of specific types of breaches that may be present and the types of pathogens that can enter storage through these breaches. This understanding is critical to the selection and ongoing evaluation of appropriate risk mitigation measures relative to storage breaches.

What types of distribution system decisions could be supported by research in this project area?

Research in this project area will provide information important in decisions regarding storage inspection or monitoring. Research results will be important for consideration in decisions utilities may make related to storage inspections and monitoring, utility associations may make regarding the substance of storage guidance, and regulatory agencies may make about storage-related requirements or guidance.

Project Area Constraints and Timing:

Research in this project area should be able to proceed based on information already available in existing industry surveys and other sources.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas or what will be used in follow-on project areas**
This project area depends on. . .	No other project areas.		N/A
Project areas that this project area builds on	None.		N/A

Project areas that build on this project	RisM1	Decision support for managing potential distribution systems public health risks from potential contamination events and daily operations	Identification of the mechanisms of storage contamination will inform the most appropriate best practices for controlling contamination.
	RisM5	Develop next generation models for informing distribution system and storage water quality including episodic release/mobilization of chemical contaminants from accumulated solids and biofilm	Identification of potential storage contamination will inform the contaminants of concern and release mechanisms.

* While this project area could benefit from data and information generated under Sur1 and Sur2, this project area does not directly depend on or build on those project areas. Instead, this project area along with Sur1 and Sur2 will provide information on the occurrence of risk factors that must be present for storage related contamination of distribution systems to result.

What are the potential constraints to the implementation of this project area?

- Cross-disciplinary knowledge and expertise is needed for study design, implementation and results interpretation—[e.g. natural environment (weather, wildlife), storage design & operations; microbiology of pathogens; disinfection alternatives and efficacy; mechanisms of sediment and biofilm formation, accumulation and release; storage sampling and monitoring techniques, etc.];
- Technical expertise is required to properly select, apply, and evaluate ongoing effectiveness of various mitigation strategies;
- Access to storage facilities is needed and participation of utilities;
- Historical data on storage inspection and monitoring is needed for study design.

Relevance to the Agreement in Principle:

Research in this project area helps address multiple issues identified as high priorities in Section 4.2a of the AIP under headings of "contamination due to storage facility design operations and maintenance," "significance and control of biofilm and microbial growth;" and "accumulation and release of contaminants from DS scales and sediments." For example, enhanced understanding of storage-breach-related pathogen occurrence, potential, and management options will aid understanding of storage impacts on pathogen occurrence in the system overall. This will, in turn, enhance the understanding of important storage design, operation, and maintenance practices. Research in this project area will also provide important knowledge/content to help address the TCRDSAC recommendation (in Section 3.17c of the AIP) that EPA, in cooperation with primacy agencies, develop minimum qualifications and a standardized training program for sanitary surveyors, and evaluate the need for certification.

Key References:

Clark, RM, EE Geldreich, KR Fox, EW Rice, CH Johnson, JA Goodrich, JA Barnick, F Abdesaken, JE Hill, and FJ Angulo. (1996). A waterborne *Salmonella typhimurium* outbreak in Gideon, Missouri: results of a field investigation. *Intl. J. Environ. Health Res.* 6:187-193.

Lau, H.Y. and Ashbolt, N.J. (2009) . The Use of *Acanthamoeba* as a tool for understanding *Legionella* pathogenesis: Implications for drinking water. *Journal of Applied Microbiology* **106**, 368-378.

National Research Council. (2006). Drinking Water Distribution Systems: Assessing and Reducing Risks, The National Academies Press, Washington D.C.

USEPA. (2002). *Finished Water Storage Facilities*. Washington D.C.: USEPA. Distribution System Issue Paper.

Project Area Document Code: Con4

Project Area Title: Estimation of Contaminated Water Volumes and Contaminant Concentrations Introduced Into Distribution Systems Due to Backflow Events from Unprotected Cross-Connections Based on Model Predictions and Field and Pilot-Scale Experiments

Goal: To compile data to better predict health risks associated with entry of external contaminants into drinking water distribution systems through unprotected cross-connections.

Rationale:
Contamination of the distribution system through unprotected cross-connections has resulted in documented public health impacts. US EPA has compiled information describing 469 backflow incidents which occurred between 1971 and 2006. In 164 of these events (35 percent), contaminants reached the distribution system serving the public. Contaminated water was contained within the premise plumbing at the source for 185 events (39 percent). The contaminant entry point to the distribution system was undocumented or undetermined for the remaining 120 events.

While the mechanisms that can result in backflow (including backsiphonage and backpressure) are well understood, and the effectiveness of backflow prevention devices is well documented, limited data are available on the extent of the distribution system that can potentially become contaminated through unprotected cross-connections. A better understanding of the magnitude and duration of pressure events that cause contaminants to reach the distribution system under various flow, pressure, and piping configuration boundary conditions (e.g., causes of pressure events that may lead to reductions of possible public health significance) is needed. Additionally, statistically sound information is needed on the magnitude of contamination that can occur under various scenarios. This project area would inform the definition of the conditions under which contaminants are likely to enter the distribution system and potential exposure consequences, thereby providing quantitative information on potential public health risk.

Objectives:
1. To determine the magnitude and duration of pressure reductions under which contaminated water could be introduced to the DS through unprotected cross-connections.
2. To estimate the potential frequency and volume of contamination that may be occurring nationwide through unprotected cross-connections.
3. To estimate the contaminant concentration in the contaminant sources (if feasible).

Suggested Approach:
- Review utility records and existing literature to identify contaminants of concern, number of unprotected cross-connections per service connection, and available information (e.g., duration of pressure reductions) on contamination events reaching the distribution system versus those events for which contaminants were isolated within the premise. Research conducted in this project area should use the same definition of pressure reduction as that developed for Sur1.

- Review design standards and plumbing codes to estimate most typical lengths and sizes of service lines for various types of service connections. Compile information related to configuration, and causative factors (e.g., system operating pressure) for different types of services (i.e., residential, commercial, industrial).
- Identify a minimum of three "representative" physical configurations (e.g., representing the distance, pipe size, meter size, etc. for residential, commercial, industrial services) to be used in subsequent analyses.
- Estimate contaminant concentrations in sources from which backflow contaminants originate.
- Using existing models or by building a computer model calculate the magnitude and duration of pressure events needed to draw a contaminant through service plumbing and past the service connection into the distribution system for the three representative service types. Conduct sensitivity analyses regarding pipe diameter, flow rate, pipe length and configuration, pressure, number and location of contaminant sources at the service connection, etc. Both backsiphonage and backpressure events should be evaluated. It is assumed that both spreadsheet and hydraulic/surge models will be needed for this task.
- Construct a pilot-scale system or field demonstration projects to test different configurations of service connections, multiple types of cross-connections, plumbing configurations, pressure conditions, etc. Pilot-scale units were constructed and evaluated for intrusion investigations during transient pressure events as reported in Lee et al., (2009) and Friedman et al., (2004).
    - Phase 1 - demonstrate the range of magnitude and duration of pressure events needed to allow contaminants to reach the DS through an unprotected cross-connection for the given configuration.
    - Phase 2 - determine the range of contaminant volumes that could reach the DS as a function of pressure, flow rate, and other boundary conditions identified during modeling. Determine contaminant concentrations in sources.
- Use modeling and pilot-scale or field results to extrapolate range of contaminant volumes and frequency of contamination at unprotected cross-connections within and across full-scale systems.

Results and Applications: The project area results can be used as inputs to a fate and transport/risk model to estimate the potential exposure/health risk from backflow of contaminated water through unprotected cross-connections. The results can also be used to estimate the national potential for public health risk due to contamination through unprotected cross-connections by assessing the frequency with which the minimum pressure and durations allowing for contamination occur. For example, the results may indicate the ranges of pressure event magnitude and duration that are needed to draw contamination through varying lengths of residential and service line piping. If pressures are maintained above those boundary conditions, then it is very unlikely that contaminants from an unprotected cross-connection at residential,

commercial or industrial service connections could reach the distribution system. Ultimately completed research and analyses will look at information to clarify and update distribution system areas of concern. This evaluation may result in follow-up studies that can provide more detail on significant factors that may impact public health.

Decision relevance:

How is research in this project area likely to inform evaluation of the magnitude of public health risk?

Research in this project area will provide the data needed to assess the likely frequency and magnitude of distribution system contamination events through unprotected cross-connections, under a variety of operating conditions. This can help determine the potential public health risks posed by these events, which will inform local and national risk management decisions.

How is research in this project area likely to inform opportunities for mitigation and risk reduction?

Research in this project area could be used to assess the need for risk management strategies in all or only vulnerable areas of distribution systems. It will help to identify conditions under which contamination is unlikely, thereby allowing for the best use and focus of risk management strategies. It will help the drinking water community (PWSs, States, EPA) determine whether and what type of policies should be implemented to reduce potential risks.

What types of distribution system decisions could be supported by this research in this project area?

Research in this project area will provide information on the possible need to emphasize the application of cross-connection control and backflow prevention programs, through voluntary standards, local policies, municipal ordinances, plumbing standards, and State or Federal guidance or regulation. It will provide a technical basis for determining what the minimum pressures or optimal operating ranges needed to prevent contamination due to backflow through unprotected cross-connections.

Project Area Constraints and Timing:

Con 4 could be conducted on its own schedule, as funding is made available. The literature search and data compilation pieces are not necessarily dependent on other project areas; but, if Con 4 is conducted afterwards some project areas (e.g., Sur 2), duplication in efforts could theoretically be avoided. Similarly, the output of Con 4 will be useful as inputs to other project areas; however, it is not necessary to delay research and information collection in the other project areas until Con 4 is completed.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas or what will be used in follow-on project areas**

This project area depends on. . .	No other project areas.		N/A
Project areas that this project area builds on	Sur1	Survey of Large Drinking Water Utility Distribution Systems	Baseline data, identification of additional information gaps, pool of potential participants.
Project areas that build on this project area	RisM1	Decision support for managing potential distribution systems public health risks from potential contamination events and daily operations	Identification of the potential for and mechanisms of contamination from cross connections and backflow will inform the most appropriate best practices for controlling contamination.
	Pres4	Toolkit for pressure management	Evaluation of different system configurations and sources of contamination will inform the most appropriate best practices for controlling contamination.

* While this project area could benefit from data and information generated under Sur1, Sur2 and Pres2, this project area does not directly depend on or build on those project areas. Instead, this project area along with Sur1, Sur2 and Pres2 will provide information on the occurrence of risk factors that must be present for cross connection and backflow related contamination of distribution systems to result.

Factors that might influence the timing of completion of research in this project area include:

- Willingness of utilities to provide information during the modeling and pilot phases and participate in monitoring for potential contamination events as pilot systems.
- Ability of utility personnel to provide timely response to pressure events during the pilot phase in order to determine the potential volumes of contaminated water entering the system.
- Ability of pilot utility personnel to accurately pinpoint the source of the contamination and obtain data on the contaminant concentrations from these sources.
- Ability to construct a computer model that adequately simulates the ranges of physical and hydraulic conditions of interest

- Ability to construct a pilot facility that adequately simulates the ranges of physical and hydraulic conditions of interest

Relevance to Agreement in Principle:
As stated in the Introduction section of the AIP, one of the major objectives of the TCRDSAC was to provide advice and recommendations on what data should be collected, research conducted, and/or risk management strategies evaluated to better inform distribution system contaminant occurrence and associated public health risks in distribution systems. This was intended to "initiate a process for addressing cross connection control and backflow prevention requirements and consider additional distribution system requirements related to significant health risks".

As described in section 4.2c, cross-connection control and backflow are listed as Tier 1 topics. Con 4 specifically provides the inputs needed to assess potential public health impacts as well as fate and transport studies by providing the data needed for risk assessment modeling. Con 4 also provides the needed information for estimating the national potential for contamination of distribution systems through unprotected cross-connections.

Key References:

Friedman, M., Radder, L., Harrison, S., Howie, D., Britton, M., Boyd, G., Wang, H., Gullick, R., LeChevallier, M., Wood, D. & Funk, J. 2004. *Verification and Control of Pressure Transients and Intrusion in Distribution Systems*. AWWARF, Denver, Colorado, USA.

Lee, Juneseok, V. K. Lohani, A. M. Dietrich, and G.V. Loganathan. 2009. *Low Pressure Propagation at Service Lines*. World Environmental and Water Resources Congress. Great Rivers ASCE.

Research and Information Collection Needs Analysis – Cross-Connection and Backflow. CC Deliverable 1. September, 2009.

TCRDSAC Agreement in Principle (2008). *http://www.epa.gov/safewater/disinfection/tcr/pdfs/tcrdsac/agreementinprinciple_tcrdsac_2008-09-18.pdf*

Project Area Document Code: Hea1

Project Area Title: Quantitative Microbial Risk Assessment (QMRA) to Evaluate Exposure to Pathogens through Drinking Water Distribution Systems

Goal: To develop an adaptive tool that can be used to estimate relative risks of exposure to distribution system pathogens and the effectiveness of risk management strategies for preventing/controlling microbial risks.

Rationale: Quantitative microbial risk assessment (QMRA) is a systematic approach for evaluating potential health consequences associated with distribution system vulnerabilities and the effectiveness of risk mitigation alternatives. The effectiveness of QMRA depends on the availability of data on microbial risks and system vulnerabilities. Research in this project area will involve designing QMRA models to integrate information from literature reviews, surveys, modeling, and other research activities. Research in this project area will be coordinated with other RICP activities to inform the need for guidance or policies to address different distribution system vulnerabilities. In addition, QMRA will be used to conduct sensitivity analyses to identify additional research and information collection needs.

Objectives:

- Develop models that will enable quantification, as sufficient information becomes available.
- Depending on available and sufficient information, quantify magnitude of exposure to pathogens associated with distribution systems and identify sources of microbial contamination (bulk water, biofilms, cross-connection, infrastructure breaches or failures), fate and transport factors (growth, die-off, interactions with internal surfaces and biofilms), and potential public health concerns.
- Apply QMRA to identify approaches to optimize monitoring and improve the ability to diagnose, prevent, and manage microbial risks.
- Integrate QMRA into the design and implementation of pathogen-related studies to provide a common framework for interpreting data and evaluating the extent to which management options are effective at reducing health risks associated with exposure to water from distribution systems.

Suggested Approach:

This project area will proceed in two phases. Phase 1 - model development, and Phase 2 - application of the model to inform risk management implications.

Phase 1 – Develop/refine existing models (e.g., models for intrusion, cross connection and backflow, storage facility breaches, etc.) to characterize potential pathogen exposure associated with individual distribution system contamination events. Use model to identify data needs that are most influential in reducing model uncertainties.

Phase 2 – Using additional research and information collection to fill gaps, run QMRA models to inform robust risk mitigation decision making. Phase 2 may require iterative model runs to identify and fill data gaps.

Phases 1 and 2 will include the following steps with a goal towards iteratively reducing data and model uncertainty:

- Conduct statistical analyses of frequency and magnitude of contamination events for different types of distribution system vulnerabilities.
- Evaluate scenarios under which contamination events results in pathogen exposure through public water systems considering different scales and intensity of contamination events (general population and vulnerable sub-populations such as young children, pregnant women, home-bound elders).
- Apply dose-response models to translate estimates of pathogen densities in drinking water to estimates of disease, including consideration of variations in pathogen concentrations over time and secondary spread.
- Use QMRA to define drinking water system conditions necessary to avoid exceeding health based targets (such as a daily infection benchmark) at locations within distribution systems and storage, including the role of biofilms in modulating pathogen fate, transport, and virulence.
- Use research in this project area to evaluate microbial risks associated with alternative designs and management outcomes from a wide range of distribution system-related studies.
- To the extent feasible research in this project area will provide a tool to examine the degree of risk reduction provided by the use of various distribution system risk management strategies.
- Research in this project area includes: 1) development of computer-based tools for QMRA using a synthesis of any available data on distribution system pathogens; 2) collection of data from epidemiologic and research studies that inform exposures; and 3) implementation of QMRA modeling in conjunction with hydraulic models to evaluate fate and transport, monitoring alternatives, and the type of data needed to determine the degree to which management practices may be effective at reducing microbial and related chemical risks.
- Provide documentation of the basis for parameter assumptions used in the sensitivity analyses.

Results and Applications:

Research in this project area will provide a basis for evaluating the relative importance of factors that impact microbial risks in distribution systems. The results of research in this project area will provide information on target parameter levels for the management of safe drinking water. Also, identification of potential premise plumbing issues may also be included to the extent to which they are influenced by distribution system factors and conditions.

Decision relevance:

How is research in this project area likely to inform evaluation of the magnitude of health risk?
Research in this project area will inform an evaluation of the magnitude of pathogen risks on an individual and across system basis for vulnerability factors associated with cross connection and backflow; storage; main construction and repair; pressure and intrusion; biofilm; nitrification; and contaminant accumulation.

How is research in this project area likely to inform opportunities for mitigation and risk reduction? T
he use of QMRA in conjunction with results from other research projects and surveys can inform the extent and effectiveness of risk reduction that may be available for different mitigation strategies in different DS topic areas and for specific vulnerability factors.

What types of distribution system decisions could be supported by research in this project area?
Research in this project area would inform the potential benefits that might be realized for various distribution system risk management strategies on the local, regional, state and national level.

Project Area Constraints and Timing:
The quality and robustness of the final risk assessment in any topic area will be constrained by the quality and uncertainty of the input data and model constructed to use that data. The strength and limitations of the QMRA should be explicitly delineated to appropriately inform both research and information collection priorities and risk management decisions.

Research in this project area can begin without dependence on any other effort under consideration by the DS RICP.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by the DS RICP)**	**Information needs (what will be used in follow-on project areas)**
This project area depends on. . .	No other project areas.		NA
Project areas that this project area builds on	None.		NA
Project areas that build on this project area	None.		NA

Relevance to Agreement in Principle:

Research in this project area will provide information relevant to needs identified in Section 4.2.b of the AIP "Conceptual Framework for Knowledge Gaps", and specifically the following items:

- Health Effects and Risk to the Public
    - Measure health consequences from exposure to contaminants
    - Monitor for situations that pose a public health concern
    - Measure and track the national significance of the described situations
- Effectiveness of mitigation measures
    - Characterize preventative measures or steps to minimize or prevent exposure
    - Identify and implement remediation steps when contamination occurs
    - Quantify the national significance of additional mitigation measures

Research in this project area that characterizes the health risks and distribution system risk factors is highly relevant to the Tier One priority topic areas, namely intrusion and cross connection/backflow. It is also highly relevant to the Tier One priority topic areas, storage and main construction/repair.

Key References:

Medema G, Loret J-C, Stenström TA, Ashbolt N. 2006. Quantitative Microbial Risk Assessment in the Water Safety Plan. Final Report on the EU MicroRisk Project. Brussels: European Commission.

Mons MN, Van der Wielen JML, Blokker EJM, Sinclair ML, Hulshof KFAM, Dangendorf F, Hunter PR, Medema GJ. 2007. Estimation of the consumption of cold tap water for microbiological risk assessment: an overview of studies and statistical analysis of data. Journal of Water and Health 5: 151-170.

Storey MV, Ashbolt NJ. 2003. A risk model for enteric virus accumulation and release from recycled water distribution pipe biofilms. Water Science and Technology: Water Supply 3: 93-100.

Van Lieverloo JHM, Blokker EJM, Medema G. 2007. Quantitative microbial risk assessment of distributed drinking water using faecal indicator incidence and concentrations. Journal of Water and Health 5: 131-149.

Project Area Document Code: Hea2

Project Area Title: Epidemiological Studies of Health Effects Associated with Low or Negative Pressure Events in Distribution Systems

Goal: To obtain information on the incidence and severity of adverse health effects occurring among customers who are impacted by low or negative pressure events in water distribution systems. The information can inform estimates of both baseline risks and reduction in those risks from mitigation actions.

Rationale: Several studies suggest linkage between low or negative pressure events and adverse human health effects, e.g. Nygard K et al. 2007, Hunter PR et al, 2005; Geldreich EE, 1992. However, these studies did not fully characterize risks, or the potential for risk reductions among the population served by public water systems where these events occur. The primary purpose of this study is to assess whether low pressure events result in increased incidence of AGI and ARI among populations served by PWS in the U.S. and to provide the data to allow for a more thorough risk characterization associated with pressure events (e.g., such as those caused by main breaks).

Objectives:

- Identify rates of adverse health effects, including gastrointestinal illness, and other diseases occurring in customers consuming drinking water in periods following known low or negative pressure events.
- Develop estimates of risk measures (e.g., relative risks, odds ratios) to differentiate the potential for these adverse health effects between customers consuming water affected by low pressure events and those not affected.
- Develop estimates of potential reduction in the risk associated with the most common pressure management strategies to reduce the system's vulnerability to intrusion events (e.g., the extent to which reductions in pressure events would reduce AGI and possible strategies for achieving this)

Suggested Approach:

Research in this project area is expected to proceed in two sequential phases: Phase 1 – Develop the method and approach for the study, and Phase 2 – Implementation of full scale epidemiology studies.

Phase 1 - The first phase will be a scoping effort and the second will be one or more full scale epidemiology studies.

- The scoping phase of the research will be aimed primarily at:
    - Developing the method and approach for the full epidemiology study. This will include such aspects as developing system vulnerability and community eligibility criteria, identifying the specific health end-points to consider (e.g., whether to include respiratory illness in addition to gastroenteritis) and how to obtain

necessary information on those health outcomes from both affected and non-affected water system customers

- Developing power calculations that indicate the extent to which different survey designs can inform risk attributed to pressure events
- Identifying approaches to determine where and when major pressure events occur in the participating systems and how to best identify customers in both the exposed and unexposed areas
- Determining the appropriate risk measures to use to characterize potential differences in the incidence of adverse health effects among the affected and non-affected customers

- The scoping phase may also include some limited pilot study efforts in communities and their water systems to test and if necessary revise the initial method, and approach including data collection protocols, and system and community selection criteria.
- During the scoping phase, efforts will also be made to identify and recruit public water systems to participate in the full epidemiology study.

Phase 2 – The second phase is implementation of the full scale study. It is anticipated that the full epidemiology study will be structured as a prospective, cohort study involving multiple (3 to 5) public water systems. Systems will be selected on the basis of known histories of low/negative pressure events, and other eligibility criteria, including the willingness of the utility management to collaborate and participate in the study. Each participating system will enroll for a period of one year and agree to follow the study protocol.

- For the participating systems, it is expected that it will be necessary to conduct a baseline assessment of the system's vulnerability to intrusion events and to develop a system-specific data collection plan in line with the epidemiology study's methodology. It may also be necessary to install some pressure monitoring devices and conduct hydraulic modeling to characterize conditions in various sections of the participating systems that will be studied. It will be necessary to resolve the details of the baseline assessment and system monitoring with the individual utilities recruited to participate in the study.
- Data on system risk factors will be collected to provide information to assess distribution system associated mitigation practices.
- An approach to support data management will be needed.
- Inclusion of a consumer risk communication plan needs to be seriously considered.

Results and Applications:

- The results from the epidemiology studies are characterizations of whether low pressure events are associated with increased incidence of adverse health events, including gastroenteritis (and potentially respiratory illness) in U.S. populations served by PWS. If

the study results find no significant risk attributable to pressure events, this finding will only indicate the absence of risk below a particular level which still might be a concern (only not detectable due to the power limitations of the study).

- The application of these results is expected to contribute to an understanding of the potential health benefits from implementing the risk mitigation strategies either through technical guidance and/or regulations.

- The results may provide a basis to assess benefits due to distribution system infrastructure upgrades that reduce leaks, pipe failures and pressure fluctuations, and to increased risk-targeted distribution system monitoring and component inspection and maintenance.

Decision Relevance:

How is research in this project area likely to inform evaluation of the magnitude of health risk?

Ideally, Research in this project area will provide quantitative estimates on the degree of risk attributed to low or negative pressure events occurring in the distribution system.

How is research in this project area likely to inform opportunities for risk reduction?

Depending upon whether positive point estimates are found with low or negative pressure events, research in this project area could also inform the extent to which risks due to low or negative pressure events might be reduced by implementation of various mitigation strategies.

What types of distribution system decisions could be supported by research in this project area?

The results of this study will help inform the basis to determine whether the current risks and risk reduction potential regarding low or negative pressure events merit regulatory action, technical guidance, or both.

Project Area Constraints and Timing:

Research in this project area can begin without dependence on any other effort. The full study phase depends upon the successful completion of the scoping phase, including a pilot and development of a data collection protocol that meets the study's data requirements. The scoping phase should be able to be completed in 1-2 years and the full scale study within another 1-2 years. Potential constraints include gaining full cooperation of water system managers, to participate in the study for its full planned duration.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by the DS RICP)**	**Information needs (what will be used in follow-on project areas)**
This project area depends on. . .	No other projects.		NA
Project areas that this	None.		NA

project area builds on		
Project areas that build on this project area	None.	NA

* Although this project area is not dependent on the Pres2 project area, there would be advantages to the same utilities participating in Pres2 as this project area since the field monitoring data generated under Pres2 would be useful for this project area.

Relevance to the Agreement in Principle:
Research in this project area will provide information relevant to needs identified in Section 4.2.b of the AIP "Conceptual Framework for Knowledge Gaps", and specifically the following items:

- Health Effects and Risk to the Public
    - Measure health consequences from exposure to contaminants
    - Monitor for situations that pose a public health concern
    - Measure and track the national significance of the described situations
- Effectiveness of mitigation measures
    - Characterize preventative measures or steps to minimize or prevent exposure
    - Identify and implement remediation steps when contamination occurs
    - Quantify the national significance of additional mitigation measures

Research in this project area is highly relevant to the following Tier One priority topic areas of AIP: intrusion, cross connection/backflow, storage and main construction/repair.

Key References:

Geldreich, E.E., Fox, K.R., Goodrich, J.A., Rice, E.W., Clark, R.M. & Swerdlow, D.L. 1992. Searching for a Water Supply Connection in the Cabool, Missouri Disease Outbreak of Escherichia coli OI57:H7. *Water Research.* 26 : 8. 1127-1137.

Hunter, P.R., Chalmers, R.M., Hughes, S. & Syed, Q. 2005. Self-Reported Diarrhea in a Control Group: a Strong Association with Reporting of Low-Pressure Events in Tap Water. *Clinical Infectious Diseases.* 40 : 4. e32-e34.

Nygard, K., Wahl, E., Krogh, T., Tveit, O.A., Bohleng, E., Tverdal, A. & Aavitsland, P. 2007. Breaks and Maintenance Work in the Water Distribution Systems and Gastrointestinal Illness: a Cohort Study. *International of Journal Epidemiology.* 36 : 4. 873-880.

Project Area Document Code: Pres1

Project Area Title: Survey of Distribution System Pressure Management Practices

Goal: To assess pressure management practices in water distribution systems to determine the prevalence of specific high risk distribution system attributes leading to low or negative pressures.

Rationale: Low or negative pressures in water distribution systems can result in drinking water contamination through unprotected cross connections or intrusion of external contaminants. Low or negative pressure events are typically transient in nature, with durations of only seconds to minutes (Friedman, 2004; Gullick, 2004), although main breaks can result in prolonged negative pressures. A number of design and operational factors have been shown to lead to transient low and negative pressure events in distribution systems (Fleming, 2006). Design or operational conditions that may lead to low or negative pressure transients include:

- Few floating storage facilities, especially for systems in locations with flat or moderately hilly terrain
- Areas of the distribution system near no floating storage facilities
- Operation at steady-state pressures less than 60 psi
- Dead-end areas of the distribution system, especially those far away from floating storage facilities
- Operation of equipment such as valves or fire hydrants that causes sudden flow changes
- Pump operated with on/off cycles
- Loss of power at pump stations
- Lack of surge control equipment

Although there is evidence indicating the causes of pressure transients, the nationwide prevalence of these risk factors is largely unknown. Currently available distribution system inventories such as WaterSTATS from the American Water Works Association (AWWA) contain a variety of distribution system design attributes but do not capture the operational parameters and design details to fully assess the national risk of contamination due to low or negative pressure events. Furthermore, the development of a national understanding of distribution system pressure management provides an opportunity to evaluate the cost impacts associated with elimination of these risk factors through various available mitigation strategies.

Objectives:

1. Identify 400-600 utilities to participate in survey. Sur1may be used to identify the sampling frame of utilities for such a survey
2. Generate a comprehensive information base characterizing the diversity of distribution system infrastructure and operation related to pressure and pressure management in the U.S.
3. Assess the prevalence of pressure-related distribution system attributes that may increase the risk of low or negative pressures.

Suggested Approach:
This research and information collection project area is intended to collect detailed design and operational information associated with distribution systems. It is intended to build on information collected in Sur 1 and Sur 2, so surveys in this project area should be designed to supplement the information in those survey areas, and not collect any of the same information. Approximately 400-600 utilities would be asked to compile pressure-related information from existing records and enter the information into electronic surveys. Follow-up will include specific written communications, telephone interviews, and site visits as necessary to confirm or expand on survey responses. Key information of interest includes:

- System size, service population, wholesale accounts, water sources, topography and demand patterns; number of pressure zones, overall system design and operational parameters
- Type and nature of surge protection infrastructure
- Number and type of storage facilities with design and operational parameters
- Number of pump stations with design and operational criteria including pumped entry points
- Number of pressure control valves with design and operational criteria
- Number of pumps and pressure control valves with backup power
- Frequency of power failures and percent of service connections affected
- Frequency of hydrant, valve and pump operation (automated and manual)
- Frequency of low pressure events tabulated from customer complaints and existing pressure recorders
- Numbers and types of main leaks and breaks
- Description of any efforts to optimize pressure management and a summary of the results

Results and Applications:
Research conducted and information collected in this project area is expected to generate a dataset of pressure management infrastructure attributes and operational practices across all regions, system sizes, source waters, and topographies. Research collected and information collected in this project area will indicate the prevalence of known risk factors leading to low or negative pressures and generate an understanding of the level of effort associated with driving the drinking water industry toward optimized pressure management.

Decision relevance:
How will research conducted and information collected in this project area inform the evaluation of the magnitude of public health risk?
Information collected will identify how low and negative pressure events impact distribution contamination events (e.g., cross-connection, intrusion). The results from this project area may be used to identify the frequency and degree of potential distribution system contamination resulting from low and negative pressure events. The results combined with other project results (e.g., Con3, Hea1) will support the estimation of the risk level of detrimental health outcomes due to cross-connection and intrusion.

How are research conducted and information collected in this project area likely to inform opportunities for mitigation and risk reduction?

The results from this project area will inform future efforts to determine whether and what type of policies might be implemented to reduce potential risks. Research conducted and information collected in this project area will also inform the activities for the distribution system optimization program specified in the AIP, and possibly identify candidate utilities for participation.

What types of distribution system decisions could be supported by research and information collection in this project area?
Research conducted and information collected in this project area will contribute to the determination of whether guidance or regulation is more appropriate to limit low or negative pressure events nationally.

Project area constraints and timing:

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas or what will be used in follow-on project areas**
This project area depends on. . .	No other project areas.		NA
Project areas that this project area builds on	Sur1	Survey of Large Drinking Water Utility Distribution Systems	Survey results may aid in refining the project area design of Pres1.
Project areas that build on this project area	Pres3	Develop strategies to diagnose and monitor pressure fluctuations in water distribution systems	Survey results may provide a range of pressure management practices that are being implemented throughout the US.

Relevance to the Agreement in Principle:
This research and information collection project area will provide information relevant to needs identified in Section 4.2.b of the AIP "Conceptual Framework for Knowledge Gaps", and specifically the following items:

- Exposure and Vulnerability to the Public
    - Identify situations that may result in contamination of public health significance
    - Assess the exposure to contaminants
- Health Effects and Risk to the Public

    - Monitor for situations that pose a public health concern
    - Measure and track the national significance of the described situations
- Effectiveness of mitigation measures
    - Quantify the national significance of additional mitigation measures

This research and information collection project is specifically relevant to the Tier 1 priority topic areas of intrusion and cross connection/backflow. It also has relevance to the Tier 1 priority topic areas of storage and main construction/repair. In addition, it will inform the distribution system optimization partnership identified in the AIP.

Key References:

Fleming, K.K., R.W. Gullick, J. P. Dugandzic, and M. W. LeChevallier. 2006. *Susceptibility of Distribution Systems to Negative Pressure Transients.* AWWARF, Denver, Colorado, USA.

Friedman, M., Radder, L., Harrison, S., Howie, D., Britton, M., Boyd, G., Wang, H., Gullick, R., LeChevallier, M., Wood, D. & Funk, J. 2004. *Verification and Control of Pressure Transients and Intrusion in Distribution Systems*. AWWARF, Denver, Colorado, USA.

Gullick, R.W., LeChevallier, M.W., Svindland, R.C. & Friedman, M.J. 2004. Occurrence of Transient Low and Negative Pressures in Distribution Systems. *Journal of the American Water Works Association.* 96 : 11. 52-66.

Project Area Document Code: Pres2

Project Area Title: Characterize Propagation of Pressure Events through Water Distribution Systems to Improve Pressure Management Approaches

Goal(s): Evaluate the propagation of pressure events through the distribution system and compare field data with surge model results for the same events. Evaluate pressure propagation events at a number of systems and investigate the impact and cost of changes intended to mitigate the number and extent of such events.

Rationale: While pressure management has been a long-term focus in distribution system management, there is a growing awareness that pressure and pressure fluctuations may be more important in distribution system management than previously thought. The practical use of surge models as management tools to aid identification and mitigation of pressure events will also be advanced in this work. The results of this work could lead to improved pressure management in distribution systems.

Objectives:

- Promote further understanding of risk and mitigation factors associated with pressure events by generating field and modeled data on the occurrence and propagation of pressure events through water distribution systems.
- Implement changes expected to eliminate or minimize pressure events (or the area of the distribution system impacted by pressure events) and generate field and modeled data on the occurrence and propagation of pressure events under the new conditions (e.g. hydrant, valve, pump or storage structural or operational changes, or main repair procedural or operational changes).
- Evaluate the effectiveness of the changes in eliminating or minimizing pressure events.
- Describe the use, application and limitations of surge models as tools in pressure management.

Suggested Approach:

This project area involves full-scale field monitoring and modeling studies. Research will be conducted at 4 - 5 utilities that represent a variety of distribution system attributes that are significant for pressure propagation such as systems with and without elevated storage, and with a variety of geography/geology, climate, size, and infrastructure age and types. These attributes will be determined in conjunction with the pressure information collection project area and by the project area examining the frequency of pressure events.

- Each utility will be evaluated with field monitors and through the use of surge models. Participating systems will be extensively instrumented with high-speed electronic pressure data loggers in areas susceptible to low or negative pressures or to wide pressure variations, as well as areas expected to be unaffected by pressure events. A number of monitors will be needed at each utility studied.

- Monitoring at a utility will be conducted for at least one year in order to capture data from a variety of predictable and unpredictable causes of pressure events (such as fire flows).
- Field data will be compared with modeled data to verify and evaluate the usefulness of surge models in terms of predict and aid management of pressure events.
- Pressure data from district metered areas or mini-pressure districts should be considered if available.
- Analysis of field and model data will be used to determine the likely number of service connections and associated populations impacted by system events which lead to low or variable pressure (e.g. main breaks, power outages, fire flows, pump or control valve failures, tank or fire hydrant operations).
- Once baseline conditions are understood, the design or operations of the system will be changed at some of the utilities in ways expected to reduce low pressure events. Field monitoring will be conducted following the change, and field data will be compared with model results following the change. This comparison will be used to evaluate the impact of the change, and the predictive value of the model in that situation.
- The cost of potential strategies to reduce the impacts of pressure events will be estimated in order to inform the value of enhanced pressure management. Data associated with distribution system operations will be compiled in parallel with pressure monitoring data to help illustrate and explain causes of each pressure event recorded, including main breaks, and the value of surge models to evaluate these pressure events.

Results and Applications:

- Research in this project area will improve the understanding of risk factors that lead to pressure events, as well as propagation of events throughout distribution systems.
- Provide a better understanding for how to mitigate risk factors that lead to the occurrence or greater propagation of pressure events.
- Help to establish the value of surge models and pressure monitors in predicting areas susceptible to low or variable pressure events, and the use of these models in predicting the quantitative impact of mitigation measures.
- Further characterize the relationship of pressure and pipe break incidence and the potential for contamination related to intrusion, cross connection or storage events.
- Investigate the relative balance of field data to modeled data so that models with adequately predictable results can be run with a minimum of field data, and situations where field data are absolutely needed will be better understood.
- Help to estimate the potential health risks associated with pressure events through improved understanding of the occurrence and propagation of the event through the distribution system.
- Inform improved pressure management approaches that could lead to improved distribution system water quality (due to reduced intrusion, backflow, and mobilization of contaminants from sediments or simply mobilization of the sediments), reduced quantities of non-revenue water (lost due to leakage), and reduced pipe breaks.
- The beneficiaries of work in this project area will be utilities, environmental consultants, and environmental regulators with a focus on public health. Utilities are expected to gain practical insights and methods of evaluation regarding pressure management in their

distribution systems. Environmental consultants will benefit from this work because the general risk factors, evaluation, and management approaches developed in this work will be described to allow adaptation to the specific situation at other utilities. Environmental regulators are expected to be provided with an additional understanding of the number and propagation of pressure events in the distribution system, which can be used to better estimate public health risks and means to reduce those risks.

- Critical research and information collection needs addressed by this project area include:
  - Percent of service area (or number of service connections) exposed to low pressures.
  - Number of service connections provided with stable and reliable operating pressures.
  - Effect of increasing or variable water pressure on current infrastructure conditions in low pressure areas.
  - Further understanding of the relationship of pipe breaks and pressure conditions.
  - More application of transient analysis (modeling) to full-scale distribution systems and comparison of predicted pressures to field pressure data.

Decision Relevance:

How is research in this project area likely to inform evaluation of the magnitude of public health risk?

Research in this project area will improve the understanding of the number of distribution systems likely to be impacted by pressure events of different severity. This information will be useful to help estimate how many people may have been "exposed" to low pressure events, and can be used together with information obtained from other projects to evaluate the magnitude of potential health risks associated with propagation of pressure events in distribution systems. The analysis is particularly relevant to intrusion, cross-connections and backflow, main repair, and storage topics.

How is research in this project area likely to inform opportunities for mitigation and risk reduction?

Research in this project area will assess potential design and operational changes that could be used to eliminate or minimize pressure events. If implemented and effective, these changes could reduce potentially exposed populations. Also, the use and limitations of surge models as tools to aid pressure management objectives will be further established so that these models can be appropriately and effectively applied.

What types of distribution system decisions could be supported by research in this project area?

Design, engineering, and operational changes to distribution systems to improve pressure management could be informed by this project area. Limited research to date indicates that in many cases, relatively low-cost system changes may provide more stable distribution system pressures.

Project Area Constraints and Timing:

This project area could go forward almost immediately, but more benefit may be gained if it is implemented after the Large Systems Survey project area (Sur1) is substantially underway, or complete. The Large Systems Survey project area could provide relevant information on the

incidence of pressure events, which could focus efforts in this project area on cases that would be helpful in better management of pressure in distribution systems.

Targeted utilities are those that will allow a considerable amount of monitoring of their systems. Monitoring may prove somewhat disruptive and time consuming for utility employees and operations. Also, changes to operations or design and engineering of at least some of the utilities are also anticipated from research in this project area. Participating utilities will need to be willing to conduct this work with limited data and limited indications of the possible value of the outcomes.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be used in follow-on project areas)**
This project area depends on. . .	No other project areas.		NA
Project areas that this project area builds on	None.		NA
Project areas that build on this project	None.		NA

* Although the Hea2 project area is not dependent on this project area, there would be advantages to the same utilities participating in Hea2 as this project area since the field monitoring data generated under this project area would be useful for Hea2.

Relevance to the Agreement in Principle:
Research conducted in this project area will provide information relevant to needs identified in Section 4.2.b of the AIP "Conceptual Framework for Knowledge Gaps", and specifically the following items:

- Exposure and vulnerability of the public
  - Identify situations that may result in contamination of public health significance.
  - Characterize the contamination or conditions of public health significance that are introduced during those situations.
  - Assess the exposure to contaminants (considers occurrence, pathway and host susceptibility).
- Effectiveness of mitigation measures:
  - Characterize preventative measures or steps to minimize or prevent exposure.
  - Identify and implement remediation steps when contamination occurs.
  - Quantify the national significance of additional mitigation measures.

This project area is highly relevant to the all of the Tier One priority topic areas: intrusion, cross connection/backflow, storage and main construction/repair.

Key References:

Fleming, et al. 2006. *Susceptibility of Distribution Systems to Negative Pressure Transients.* Water Research Foundation and American Water. Denver, Colorado.

Friedman, et al. 2004. *Verification and Control of Pressure Transients and Intrusion in Distribution Systems.* Water Research Foundation. Denver, Colorado.

Pearson, et al. 2005. *Searching for N2: How does Pressure Reduction Reduce Burst Frequency?* Presented at the 2005 Leakage Conference, Halifax, Nova Scotia, Canada.

Project Area Document Code: Stor1

Project Area Title: Best Practices for Minimizing Risks Associated with Storage Facilities.

Goal(s): Identify and characterize the best practices (BPs) for storage that can be used to mitigate potential contamination exposure concerns.
Help industry personnel to:

1. Better diagnose potential problems
2. Better understand the conditions that influence storage-related contamination events,
3. Provide operators with best practices to reduce those risks
4. Provide information on the cost effectiveness of BPs

Rationale:
While storage-related industry standards exist, there are no national requirements to design or operate storage for effective mixing or regular cycling, or to monitor quality of stored water, or to regularly inspect or maintain storage. Storage facility configuration and operations vary widely, with decisions often driven by cost and fire flow needs. Due to large volumes of water in storage, and often limited monitoring of storage, undetected storage breaches and/or contaminant accumulations could potentially impose health risks that impact large areas of the system and associated consumer populations. Finished water storage facilities have been associated with a range of health risks that can include acute or fatal illness from exposure to waterborne pathogens, exposure to intermittent, chronic or persistent contamination that can result from breaches in tank integrity or internal reactions including nitrification, solids accumulation and mobilization, and release of pathogens from biofilms. In addition, aesthetics concerns (taste and odor) may be linked to perturbations in storage operations and associated water quality variations.

Information collected in this project area will characterize BPs (design, operations, maintenance, inspection, and costs) for use by water utilities and support entities (states, inspectors, contractors, and researchers). Such BPs will help users understand, prevent, diagnose, and mitigate storage-related risks in distribution systems.

Objectives:

- Document the elements of effective storage best practices currently in use. Information related to implementation costs and other barriers to implementation will also be compiled.
- Provide a single reference resource for evaluation of storage facility design, operations or maintenance-related risk factors, and risk mitigation options (including costs, and other potential implementation obstacles).
- Determine key barriers to development, implementation and enforcement of storage related best practices, and provide case study examples of how these barriers have been overcome.
- Develop strategies to quantify and benchmark the effectiveness of BPs and document case studies of successful programs.

Suggested Approach:

Develop a "State-of-Knowledge" Synthesis of Existing Knowledge and Information Relative to Storage — Provide a review and summary of key existing information and knowledge from literature, references, industry surveys, and existing storage guidance.

- Collect and summarize available information on potential risk factors.
- Collect and summarize evidence of links between storage-related contamination events, contaminant exposure, and waterborne disease outbreak and potential "lessons learned".
- Compile relative costs of components of existing storage facility maintenance and operation programs (including diagnostic approaches, and mitigation measures).
- Develop a glossary with illustrations, definitions, units of measure, etc., that can be used by the water industry to promote dialog and to more fully characterize storage physically and operationally, including relative costs of various structural and/or operational alternatives for storage.
- Provide easy-to-use examples and case studies of storage risk-related regulations, standards, policies, and BPs (assimilated from States/EPA, storage manufacturers, fabricators, and modifiers, inspectors, utility operators/managers) and provide comparative costs and constraints for adoption of risk minimization or mitigation measures where needed.
- Provide case study examples of how some systems have overcome key barriers to development, implementation and enforcement of storage related best practices.
- Conduct follow-up as needed to gather, assemble and summarize key information and knowledge.

Assess the Effectiveness of Storage BPs –Incorporate key information useful to evaluate: (1) potential storage related risk and (2) storage risk mitigation.

- Describe BPs for industry personnel to better evaluate storage risks and risk mitigation, including costs and implementation obstacle comparisons.
- Collect information about online monitoring of water quality parameters that have been obtained and how the information was used to improve storage operations and maintenance.
- Conduct expert review of BPs.

Strategies Gauge Industry Application of BPs

- Develop strategies and approaches to assess industry application, usefulness and effectiveness of BPs and to assimilate data from applications of project results.
- Develop metrics and benchmarks of effectiveness of BPs.

Results and Applications:

BPs identified through this project area will help utilities (and other industry professionals, such as storage operators, designers, regulators, inspectors, tank fabricators, modifiers, and trainers) to more effectively inspect, operate, and maintain storage to diagnose and mitigate storage-related contamination risks. BPs will also aid identification, selection, implementation and ongoing evaluation of performance and cost-effectiveness of risk mitigation alternatives. Information collected in this project area will document the status, costs and limitations of existing storage

design, operations and maintenance as well as ongoing cost and effectiveness of storage risk mitigation options. Information collected will facilitate more informative/effective storage-related surveys, sampling, and data analysis, and may also be useful in sanitary surveys required under the SWTR and GWR. Under this project area utilities and others will verify and document storage-related contamination risks. The results will inform choices regarding the benefits, costs and constraints relative to various risk mitigation options. Use of BPs by utilities, contractors, and states could lessen DS health risks during the interim while other DS research and information collection project areas are ongoing and regulatory decisions are still pending.

Decision Relevance:

How is information collected in this project area likely to inform evaluation of the magnitude of health risk?

Information developed through this project area will include descriptions of storage contamination incidents where exposure to contamination has occurred. These accounts illustrate severity and extent of outcomes that can occur where there are failures in storage design, operation and/or maintenance. Case studies from actual storage events can help inform industry personnel of potential risks relative to storage and may be helpful in selection of risk mitigation options. Storage risk evaluations and data regarding mitigation resulting from BPs have the potential to yield more representative and useful storage risk-related (performance and cost) information and knowledge than is currently available.

How is information collected in this project area likely to inform opportunities for risk reduction?

The results will assist the industry in planning and evaluating storage structure design and performance relative to contamination risk, and in reducing potential risks. Cost and performance effectiveness of existing storage structures and operations (e.g. sampling, continuous monitors, inspections, cleaning, repairs) can be evaluated as well. Information collected in this project area will highlight the effects of a variety of typically-used facility configurations and will increase the understanding of various storage evaluation, monitoring and control techniques and approaches. Examples from existing studies of storage and storage modifications (including costs) can be used to evaluate potential effectiveness and obstacles to utilization of various risk mitigations.

What types of distribution system decisions could be supported by information collected in this project area?

Enhanced knowledge and understanding gained through information collected in this project area will enable collection of more useful information in DS surveys, and can improve other DS research projects. Data from future utility use of BPs and subsequently improved surveys and research will provide better understanding of national status of storage and related risks and the obstacles to implementation of risk mitigation measures. Need, focus, and feasibility of new DS and storage-related guidance or regulations will be informed by information collected in this project area.

Project Area Constraints and Timing:

This project area is not dependent on other project areas and can begin immediately and be completed within two years. The results of this project area may influence Sur4, under consideration by the DS RICP. See the table below for more details.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by the DS RICP)**	**Information needs (what will be used in follow-on project areas)**
This project area depends on. . .	No other project areas.		NA
Project areas that this project area builds on	None.		NA
Project areas that build on this project area	Sur4	Targeted surveys to obtain information on state and local regulations, policies, manufacturing practices and guidelines for distribution systems	Stor1 results may aid in refining the project design of Sur4. Also, information on storage facilities practices from Stor1 could be compared with information collected in Sur4.

Factors that might influence the timing of completion of this project area include:

- Knowledge of industry personnel regarding storage-related design and operational concepts and BPs, existing research publications (literature), guidance, industry standards, and other resources;
- Access to existing storage infrastructure-related state and federal database databases, existing industry surveys, and other unpublished resources and information;

Relevance to the Agreement in Principle:
This project area is directly relevant to the storage which is a Tier One priority area. This project area will contribute towards fulfillment of the AIP objective of optimizing distribution system integrity by assembling BPs associated with storage design, operation and maintenance and providing the tools needed for utilities and other responsible parties to evaluate existing storage risk and risk mitigation options.

Key References:

Clark, R.M., E.E. Geldreich, K.R. Fox, E.W. Rice, C.H. Johnson, J.A. Goodrich, J.A. Barnick, F. Abdesaken, J.E. Hill, and F.J. Angulo. 1996. A Waterborne *Salmonella typhimurium* Outbreak in Gideon, Missouri: Results from a Field Investigation. *International Journal of Environmental Health Research* 6:187-193.

USEPA. 2002. *Finished Water Storage Facilities*. Washington D.C.: USEPA. Distribution System Issue Paper.

Walski, Thomas M., Donald V. Chase, Dragan A. Savic, Walter Grayman, Stephen Beckwith, Edmundo Koelle. 2003. *Advanced Water Distribution Modeling and Management*. Waterbury, CT: Haestad Press.

Project Area Document Code: Sur1

Project Area Title: Survey of Large Drinking Water Utility Distribution Systems

Goal(s): To identify characteristics of drinking water distribution and storage systems that serve > 50,000 people.

Rationale:
This information collection project area will evaluate the current status of distribution system conditions and practices. It will provide data on the type, condition and vulnerabilities of drinking water and storage systems that serve >50,000 people; inform potential risk implications; and characterize the use of risk management strategies. This project area could also identify opportunities and impediments to mitigate and manage risks pertinent to systems that serve >50,000 people.

Objectives:

- Identify drinking water distribution and storage systems at public water supplies to target for surveys conducted in this project area.
- Identify key variables related to the type, quantity, and condition of distribution system infrastructure elements that may contribute to increased public health risks in distribution systems.
- Assess the prevalence and use of various risk management strategies on distribution systems.
- Provide baseline information on distribution system conditions, operations, and management practices.
- Identify additional research and information collection needs.
- Identify a subset of utilities with varied infrastructures, distribution system conditions, and/or water quality conditions to assist in construction of a representative sample for subsequent distribution system related research and information collection projects.

Suggested Approach:
This project area will proceed in two sequential phases: Phase 1 - Review and analyze available data and information, and Phase 2 - Survey targeted utilities based on findings in Phase 1.

Phase 1 – The first phase of this project area is a comprehensive review of literature and available data relevant to water distribution systems. Examples of data sources include the Community Water System Survey (CWSS), the Water Utility Distribution Surveys (WaterStats), the 2007 Drinking Water Infrastructure Needs Survey (DWINS), the 2006 Water Research Foundation Study – Susceptibility of Distribution Systems to Negative Pressure Transients. Implementation data from sanitary surveys for drinking water regulations (e.g., Surface Water Treatment Rule, Total Coliform Rule, etc.) may also provide information. Key variables will be identified and the data sources will be mined to compile, synthesize, and evaluate the available data.

Information collected will be analyzed to determine characteristics of drinking water distribution and storage systems, and identify information gaps.

Phase 2 - Based on the results from Phase 1, survey instruments will be developed targeted at utilities that serve populations > 50,000. The survey should be developed with a statistical design to yield meaningful results. All key terms used in the surveys will be carefully and explicitly defined in order to ensure there is no confusion between the survey respondents and those using the results. To facilitate responses, it is recommended the surveys be organized into sub-surveys that correspond to the expertise of individual utility departments such as:

- Operations/Maintenance,
- Design/Engineering/Infrastructure, and
- Water Quality/Monitoring.

The below list includes examples of types of information that may be available, compiled, and analyzed in Phase 1. The survey designs should include measures to anonymize security-related survey data to avoid security concerns. Survey designers will organize questions into groups based on the expertise of individual departments of utilities. This will improve efficiency and accuracy of responses by ensuring that the most qualified people answer each question and do not waste effort on questions which are not related to their area of expertise.

Phase 1	
Operations / Maintenance	• Type and frequency of rehabilitation activities performed per year, • Number of service connections with stable/reliable operating pressure, • Percent of water loss through pipe leaks, • Number of emergency main breaks per mile per year, • Storage disinfection practices (type, usage, frequency, dosage, and application point), • Determination of representative system's operation / configuration (storage tanks, detention times, dead-end mains).

Phase 1	
Design / Engineering / Infrastructure	• Frequency of power failures that affect pump operations, • Miles of new mains constructed and old mains with planned replacement per year, • Frequency of main breaks by pipe diameter and pipe material • Frequency of construction on distribution/transmission mains, • Number of pressure zones and storage facilities per zone, • Number and types of storage facilities (e.g. cylinder, spheroid, standpipe, pedestal, in-ground; above-ground elevation; populations served), • Location of storage relative to supply source, and volume of storage relative to piping.

Each sub-survey will be designed in an easy-to-use electronic format to minimize the amount of effort that systems must exert in order to complete the surveys (e.g. yes/no, multiple choice, and simple short-answer questions). The list below includes examples of the types of information that may be collected in the surveys in Phase 2. The actual information to be collected will be based on information gaps identified in Phase 1.

Phase 2	
Operations / Maintenance	• Status of implementation of cross-connection control programs, • Number of direct cross-connections and cross connections with health risks, • Frequency of temporary or illegal connections, • Number and size of systems without floating storage tanks, • Fraction of flooded underground vaults, height of water above submerged meters and air vacuum valves, • Percentage of emergency main repairs that required depressurization, • Practices for removal of solids accumulated in storage (amount removed, percent removed of total solids, and frequency of removal).

Phase 2	
Design / Engineering / Infrastructure	• Presence and type of surge suppression, • Number of pumps on universal power supply, • Number of service connections with backflow prevention devices, • Percentage of piping submerged beneath water table (and depth), • Number air-vacuum valves and meters installed in underground vaults, meter orifice sizes, • Existence and use of calibrated hydraulic or water quality models for the distribution system, • Number and types of storage facilities with specific types of internal coating.
Parameter Monitoring	Stored water volume monitoring (e.g. levels, sensors, SCADA) frequency, type, content, cost, reporting, rationales, data use. Current and planned installation of online water quality monitoring instruments

Results and Applications:
The survey results will be used to identify distribution system characteristics including the prevalence of specific infrastructure components, perceptions of infrastructure condition in large systems, and the extent to which specific risk management practices are employed. The survey results are expected to enable a comparison of engineering, operations, and maintenance practices and effectiveness. The survey results are expected to help explain and estimate the prevalence of risk factors and the degree of use of specific risk management strategies, as well as barriers to implementation.

Specifically, the data from these surveys are intended to help in better understanding:

- Number of high-hazard cross-connections and degree of implementation of various cross-connection control program elements,
- Potential for occurrence of low pressures or highly variable pressures,
- Potential for intrusion through leaks and other orifices,
- Degree of implementation of surge control strategies,
- Types of storage facilities and the degree to which storage facilities are configured/operated for sufficient turnover, breach avoidance, etc.
- Frequency and characteristics of planned and emergency main installations and repairs.

The results of these surveys may provide a baseline for follow-up research or information collection projects that inform the magnitude of public health risks and/or the use and effectiveness of risk management strategies. The survey results are expected to provide baseline information on distribution system conditions, operations, and management practices. These surveys are expected to provide information on practices already in use to help utilities make

informed decisions about distribution system operations, maintenance, rehabilitation, or replacement. The information can provide a reference point of current conditions from which the effectiveness of potential actions such as guidance, regulations, or policies that arise from the RICP process may be assessed.

The results of these surveys may also identify a pool of utilities with varied infrastructures, distribution system conditions, and/or water quality conditions. Such recognition will assist in the identification of a representative sample for subsequent distribution system related research and information collection projects. Screening of survey participants will identify potential candidate utilities for follow-up field research or additional information collection projects.

Decision Relevance:

How is information collected in this project area likely to inform evaluation of the magnitude of public health risk?

Information collected in his project area will provide a perspective of the quantity, type and condition of existing distribution system infrastructure. This information combined with information from RisM1 and Hea2 is expected to better estimate the frequency of events which carry with them increases in public health risk.

How is information collected in this project area likely to inform opportunities for mitigation and risk reduction?

Information collected in this project area will provide an initial understanding of the degree to which various risk management practices are used. This information can help the drinking water community (PWSs, States, EPA) determine whether and what type of policies might be implemented to reduce potential risks.

What types of distribution system decisions could be supported by information collected in this project area?

Information from this project area could be used to inform national policy on distribution system issues. Possible policy outcomes that could be supported may include guidance, regulation, or other options.

Project Area Constraints and Timing:

The completion of this information collection project area may influence several other project areas under consideration by the DS RICP. In most cases, the baseline data from Phase 1 will improve design of follow-on projects or be used to identify appropriate subpopulations for in-depth sampling, field work, or modeling. See the table below for information on the project areas that build on Sur1.

Relationship to other RICP project areas	Project area document code	RICP project area document title (Projects under consideration by DS RICP)	Information needs (what will be used in follow-on project areas)

This project area depends on. . .	No other project areas.		NA
Project areas that this project area builds on	None.		NA
Project areas that build on this project area	Con1	Characterization of pathogens and chemicals in soil and water adjacent to distribution system infrastructure	Survey results may aid in refining the project designs of Con1.
	Con2	Distribution system contamination associated with repair of water main leaks and breaks	Survey results may aid in refining the project designs of Con2.
	Con4	Estimation of contaminated water volumes and contaminant concentrations introduced into DSs from cross-connection contamination events based on model predictions and field and pilot-scale experiments	Survey results may aid in refining the project designs of Con4.
	Con6	Understanding the growth potential within distribution systems of indigenous bacterial pathogens (*Legionella* and *Mycobacterium*)	Survey results may aid in refining the project designs of Con6.
	Con7	Understanding the survival of enteric pathogens and ammonia-oxidizing organisms under different DS conditions and disinfection practices	Survey results may aid in refining the project designs of Con7.
	Con8	Baseline data on episodic release/mobilization of chemical contaminants from biofilms and accumulated solids in distribution and storage systems	Survey results may help target sample locations.
	Pres1	Survey of Distribution System Pressure Management Practices	Survey results may provide information on attributes leading to low or negative

			pressures.
	Pres3	Develop strategies to diagnose and monitor pressure fluctuations in water distribution systems	Survey results may provide information regarding pressure management strategies.
	Pres4	Toolkit for pressure management	Survey results may provide insightful information that may aid in refining the design of Pres4.
	RisM1	Decision support for managing potential distribution systems public health risks from potential contamination events and daily operations	Survey results could be used to refine the menu of risk management strategies.
	Sur4	Targeted surveys to obtain information on state and local regulations, policies, manufacturing practices and guidelines for distribution systems	Survey results will identify data gaps. Sur4 design may help to fill data gaps.

Factors that might influence the timing of completion of this project area include:

- Familiarity of investigators with distribution system concepts and survey design and data analysis
- Complexity and scope of survey design and survey data analysis
- Survey response/data quality review
- Ability of surveyors to solicit or require sufficient responses
- Willingness of recipients to participate
    - Issues associated with providing potentially sensitive information (data confidentiality)
    - Lack of information in utility files
    - Lack of utility resources (personnel-time, computer expertise) to complete survey responses
- Participation by enough (and sufficiently diverse) recipients to provide meaningful results
- Communication/approvals for survey data use in follow-on project areas

Relevance to the Agreement in Principle:
The AIP specifically recommends in section 4.1.e that the RICP explore several mechanisms for collecting and analyzing data, including surveys implemented through research project areas or

by interested organizations such as EPA, AWWA, AMWA, NRWA, WaterRF, and others. The completion of this project area is relevant to all seven priority topic areas.

Key References:

TCRDSAC Agreement in Principle (2008).
http://www.epa.gov/safewater/disinfection/tcr/pdfs/tcrdsac/agreementinprinciple_tcrdsac_2008-09-18.pdf

Project Area Document Code: Sur4

Project Area Title: Targeted Surveys to Obtain Information on State and Local Regulations, Policies, Manufacturing Practices and Guidelines for Distribution Systems

Goal: To evaluate extent to which distribution system risk management and mitigation practices are implemented by states or through manufacturing, installation, or inspection programs.

Rationale:
This information collection project area will provide data on state and local regulations, industry standards/guidelines, and manufacturing and inspections practices that may affect potential health risks associated with distributions systems.

Objectives:

- Evaluate inspection practices and results (e.g., plumbing/backflow prevention devices, main installations, storage).
- Evaluate certification requirements for inspecting distribution system components (storage tanks, backflow prevention devices, new construction, main repair, etc).
- Evaluate fire department practices for operating and maintaining hydrants and level of coordination with water utilities.
- Evaluate the extent to which backflow prevention device are used and failure frequency (manufacturers).
- Evaluate trends in storage tank types, configurations, construction materials, and ages (tank fabricators and designers).
- Estimate the frequency of state and/or local sewer leak and breaks and repair strategies that might impact water distribution systems (wastewater utilities and municipalities).
- Compare requirements in state laws, regulations, policies, and industry standards/guidelines concerning distribution systems.

Suggested Approach:
This project area will proceed in two sequential phases: Phase 1 - Review and analyze available, and Phase 2 - Survey targeted utilities based on findings in Phase 1.

Phase 1- The first phase of this project area is a comprehensive review of literature and available data relevant to water distribution systems including: state laws, regulations, and policies. Possible sources of data include the primacy application packages which EPA requires from States. Key variables will be identified and these data sources will be mined to compile, synthesize, and evaluate the available data quality. The information collected will be analyzed to identify information gaps.

Phase 2 – Based on the results from Phase 1, survey instruments will be developed to obtain specific information from inspectors, manufacturers, fire departments, and wastewater treatment utilities, and consultants. Suitable entities to target for the surveys will be determined by

consulting with States and industry consultants. To the extent practicable, electronic surveys will be used. The surveys will be designed and administered to facilitate the compilation and assessment of needed data by survey participants. All terms used in the surveys will be carefully and explicitly defined in order to ensure there is no confusion between the survey respondents and those using the results. Examples of information that could be obtained include:

Source of Information	Examples of Data that May be Obtained	Examples of Data Sources
Inspectors, Certifiers of Inspector	• Inspector certification criteria • Extent of cross connections and backflow prevention devices found at service connections and inspection frequency • Frequency and scope of inspections of distribution systems • Internal and external status of distribution system infrastructure	• Guidance manuals
Fire Departments	• Hydrant operation practices, policies, and flow requirements.	• State and local codes and insurance requirements
Backflow Prevention Device Manufacturers	• Number of devices produced by type • Historic sales records • Failure rate and pressure ratings of backflow prevention devices	• Device certification standards
Storage Tank Manufacturers, Inspectors and Cleaners	• Number and configuration of storage facilities produced per year • Materials used in storage tanks and their frequency	• Device/materials certification • Industry standards
States	• Laws, regulations, and policies concerning o Distribution system design/engineering (function, capacity, etc.) o Cross connection control programs o Distribution system inspections o Sanitary practices o Storage facilities o Operations o Operator training • Training on regulations, policies, guidances and best practices	• US EPA records • State websites and guidance documents

Results and Applications:
The project area results will be used to help assess the prevalence of specific infrastructure components and the extent to which specific risk management and mitigation practices are

employed including design/engineering, inspection, operations, and maintenance. The survey results are expected to help explain and estimate the prevalence of risk factors, and the degree of use of specific risk management strategies, as well as help identify barriers to implementation.

Specifically, the data from these surveys may help in better understanding:

- Number of high-hazard cross-connections and degree of implementation of various cross-connection control program elements,
- Practices associated with cross-connection control program,
- Protocols for preventing and detecting health hazards associated with sewage intrusion into distribution systems including inspection programs, responsible parties, and communication strategies,
- Frequency of activities which can result in low pressure events that can cause intrusions,
- Types of storage facilities and the chemical and use of storage risk mitigation options.
- The degree to which training is used to improve utility personnel understanding of State and Federal regulations, policies, guidance, and best practices.

The results of these surveys may provide a baseline for follow-up research or information collection projects that inform the magnitude of public health risks or the effectiveness or risk management and mitigation strategies. These surveys are expected to provide information on practices already in use to help utilities make informed decisions about distribution system operations, maintenance, rehabilitation, or replacement. This information can provide a reference point of current conditions from which the effectiveness of potential actions such as guidance, regulations, or policies that arise from the RICP process may be assessed.

Decision Relevance: The survey results will help characterize the prevalence of risk factors. They will also help to understand the extent that best practices are currently implemented.

How is information collected in this project area likely to inform evaluation of the magnitude of public health risk?

Information collected in this project area will provide a description of the quantity, types, and conditions of existing distribution infrastructure. This information is expected to better estimate the frequency of events which carry with them increases in public health risk.

How is information collected in this project area likely to inform opportunities for mitigation and risk reduction?

Information collected in this project area will provide an initial understanding of the degree to which various risk management practices are used. These surveys will also inform the extent of risk-related activities and the level of surveillance. This information can help the water supply community (PWSs, States, EPA) determine whether and what type of policies would be prudent to reduce risks.

What types of distribution system decisions could be supported by information collected in this project area?

Information from these projects could be used to inform national policies on distribution system issues. Possible policy outcomes that could be supported may include guidance, regulation, or other options.

Project Area Constraints and Timing:
This project area does not strictly depend on the completion of other project areas, but completion of CC1 and Stor1 might provide useful information. These surveys may yield results which need to be verified or expanded upon by the inspector surveys.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas or what will be used in follow-on project areas**
This project area depends on. . .	No other project areas.		N/A
Project areas that this project area builds on	CC1	Best Practices to Minimize Risks Associated with Cross Connections and Backflow	Information on cross connection and backflow best practices that systems use from CC1 will inform survey questions.
	Stor1	Best Practices for Minimizing Risks Associated with Storage Facilities.	Information on storage best practices that systems use from Stor1 will inform survey questions.
Project areas that build on this project area	None.		N/A

Factors that might influence the timing of this project area include:

- Agreement on key terms to be used in the survey instruments
- Completion of pre-survey alternative exploration and analysis
- Development of multiple, different, concise survey requests for a variety of non-utility entity groups
- Assembly/selection of appropriate samples of, and contacts for, non-utility entities
- Cooperation from certifying agencies and other non-utility entities
- Willingness for entities to share information
- Completion of alternative resource studies, such as the 2011 Drinking Water Infrastructure Needs Survey

Relevance to the Agreement in Principle:
The AIP specifically recommends in section 4.1.e that the RICP explore several mechanisms for collecting and analyzing data, including surveys implemented through research projects or by interested organizations such as EPA, AWWA, AMWA, NRWA, WaterRF, and others. The completion of this project area is relevant to all seven priority topic areas.

Key References:

ANSI/AWWA (2004). Standard G200-04, Distribution Systems Operation and Management, Denver, CO.

TCRDSAC Agreement in Principle (2008). *http://www.epa.gov/safewater/disinfection/tcr/pdfs/tcrdsac/agreementinprinciple_tcrdsac_2008-09-18.pdf*

Appendix A – Steering Committee Members

Language concerning the Steering Committee from the AIP:
"The RICP will be directed by a Steering Committee (SC)comprised of three members from EPA, three members from water utilities, plus three members, one each representing public health (e.g. CDC), environmental advocate, and state regulator perspectives. The Committee recommends that one or more members of the SC bring a small system perspective."

RICP Steering Committee members as of April 2010:
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**also represents the small systems perspective*

The Steering Committee of the Distribution System Research and Information Collection Partnership met on April 15th, 2010 and accepted the Priorities of the Distribution System Research and Information Collection Partnership.

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Appendix B – Project Area Titles and Codes

Code	Project Area Title
CC1	Best Practices to Minimize Risks Associated with Cross Connections and Backflow
CC2	Assess Distribution Systems Characteristics that May Lead to Cross Connection and Backflow Problems and Potential Health Risks
Con1	Characterization of Pathogens and Chemicals in Soil and Water Adjacent to Distribution System Infrastructure
Con2	Sampling to Determine Potential Distribution System Contamination Associated with Repair of Water Main Leaks and Breaks
Con3	Contaminant Entry from Breaches in Storage Facilities
Con4	Estimation of Contaminated Water Volumes and Contaminant Concentrations Introduced into Distribution Systems Due to Backflow Events from Unprotected Cross-Connections Based on Model Predictions and Field and Pilot-Scale Experiments
Con5	Computation of Intrusion Volumes through Orifices
Con6	Understanding the Growth Potential within Distribution Systems of Indigenous Bacterial Pathogens (*Legionella* and *Mycobacterium*)
Con7	Understanding the Survival of Enteric Pathogens and Ammonia-Oxidizing Organisms under Different Distribution System Conditions and Disinfection Practices
Con8	Baseline Data on Episodic Release/Mobilization of Chemical Contaminants from Biofilms and Accumulated Solids in Distribution and Storage Systems

Hea1	Quantitative Microbial Risk Assessment (QMRA) to Evaluate Exposure to Pathogens through Drinking Water Distribution Systems
Hea2	Epidemiological Studies of Health Effects Associated with Low or Negative Pressure Events in Distribution Systems
Hea3	Response Teams to Prepare Case Studies on Adverse Public Health Effects from Distribution System Events
Hea4	Molecular Epidemiology of Distribution System Associated Pathogens
Mon1	Collection of Distribution System and Storage Monitoring Data for Nitrite, Nitrate, and Related Physical and Chemical Constituents
Pres1	Survey of Distribution System Pressure Management Practices
Pres2	Characterize Propagation of Pressure Events through Water Distribution Systems to Improve Pressure Management Approaches
Pres3	Develop Strategies to Diagnose and Monitor Pressure Fluctuations in Water Distribution Systems
Pres4	Toolkit for Pressure Management
RisM1	Decision Support for Managing Potential Distribution Systems Public Health Risks from Potential Contamination Events and Daily Operations
RisM2	Improving Hydraulic Models for Distribution Systems
RisM4	Tracking How Water Quality Modifications and Distribution System O&M Impact Stability and Release of Chemical Contaminants from Accumulated Solids and Biofilms in Distribution and Storage Systems

RisM5	Develop Next Generation Models for Informing Distribution System and Storage Water Quality Including Episodic Release/Mobilization of Chemical Contaminants from Accumulated Solids and Biofilm
Stor1	Best Practices for Minimizing Risks Associated with Storage Facilities
Stor2	Assess Distribution Systems Characteristics that May Lead to Storage Related Problems and Potential Health Risks
Sur1	Survey of Large Drinking Water Utility Distribution Systems
Sur2	Survey of Small and Medium Drinking Water Utility Distribution Systems
Sur3	Field Survey to Collect Information on Risk Management Practices Employed in Water Distribution Systems
Sur4	Targeted Surveys to Obtain Information on State and Local Regulations, Policies, Manufacturing Practices and Guidelines for Distribution Systems

Appendix C – Lower Priority Project Area Documents

Note that the Steering Committee focused their review and comments mainly on the high priority project area documents. Therefore, the project area documents in this appendix did not get the same level of review as the ten high priority project area documents. They are listed here in alphabetical order.

Project Area Document Code: CC2

Project Area Title: Assess Distribution Systems Characteristics that May Lead to Cross Connection and Backflow Problems and Potential Health Risks

Goal(s): To better understand the potential public health risks and the magnitude of the health risks related to cross connection and backflow contamination events.

Rationale:
The presence of an unprotected cross-connection represents a potential distribution system (DS) vulnerability, through which backflow can occur. This situation can provide a conduit for chemical, microbial and/or radiological contaminants to enter a DS, particularly when the pressure in the potable source is lower than the pressure in the contaminant source. These lower pressures result from common events in DS, including valve and pump operations, power outages, main breaks, high demand, flushing, and even a rise in pressures from the contaminant source (e.g., a boiler).

Contamination of the distribution system through unprotected cross-connections has resulted in documented public health impacts. US EPA has compiled information describing 469 backflow incidents which occurred between 1971 and 2006. In 164 of these events (35 percent), contaminants reached the distribution system serving the public. Contaminated water was contained within the premise plumbing for 185 events (39 percent). The contaminant entry point to the distribution system was undocumented or undetermined for the remaining 120 events.

The extent and magnitude of health risks associated with backflows is site-specific and depends on the source of contamination (sewage, industrial discharges, etc.), the location of the backflow, the distribution system characteristics, and the effectiveness of prevention and inspection programs. The durations of consumers' exposures to the contaminants is highly variable and depends on water use practices, system hydraulics, the nature of the cross connection, an understanding by the system that a risk may exist and the ability of the system to find and remedy the problem. Given that limited monitoring occurs in DS, these events often escape detection. Frequently events are detected through customer complaints rather than routine monitoring. Even then, the event will often have passed by the time the utility investigates. As a result, undetected and uncorrected cross connections may result in recurring backflow occurrence, imposing unquantifiable health risks.

Research in this project area will examine distribution system characteristics that may contribute to backflow through cross connections. In particular, the research will examine the potential frequency at which the convergence of three distribution system characteristics exist that must simultaneously occur for backflow contamination from cross connections to result. The three factors that must occur are the presence of a contaminant in a contaminant source, the presence of an unprotected cross connection, and the failure of a barrier to prevent contamination (in this case a pressure differential between the contamination source and the potable water supply). To estimate the potential public health impacts from cross connections and backflow research in this project area will examine data on these characteristics from other RICP project areas, as well as existing data.

Objectives:

1. Collect and synthesize information that may inform the frequency and magnitude of potential health risks related to cross connection and backflow contamination events
2. Conduct additional targeted literature searches, if needed, that may provide information on the frequency and magnitude of potential health risks related to cross connection and backflow contamination events

Suggested Approach:
This project area has two suggested approaches to obtain information needed to assess distribution system characteristics that may lead to cross connection and backflow problems and potential health risks

1. Collect and synthesize information from completed RICP project areas related to cross connection and backflow and that may inform the magnitude of potential health risks related to cross connection and backflow contamination events. This step includes determination of the extent to which barriers to contamination (e.g., sufficient pressure levels) exist and the causes and frequencies of barrier failure.

- Presence of a pathway for contamination
- Number of direct cross-connections and cross connections with health risks (Sur1)
- Frequency of temporary or illegal connections (Sur1)
- Number of service connections with backflow prevention devices (Sur1)

- Failure of a barrier
- Number of service connections with stable/reliable operating pressure (Sur1)
- Number of pressure zones (Sur1)
- Frequency of power failures that affect pump operations (Sur1)
- Frequency of main breaks by pipe diameter and pipe material (Sur1)
- Percentage of emergency main repairs that required depressurization (Sur1)
- Model magnitude and duration of pressure events (Con4)
- Determination of the extent of a distribution system affected by a pressure event (Pres2)

- Presence of a contaminant
- Identification of contaminants of concern (Con4)
- Estimated contaminated water volumes introduced to the distribution system from cross

connections and backflow events (Con4)
- Estimated contaminant concentrations from cross connection and backflow contamination sources (Con4)

2. If needed, conduct additional targeted literature searches for existing information that may provide information on the frequency and magnitude of potential health risks related to cross connection and backflow contamination events. These searches would fill in gaps in the areas of knowledge that are listed in section 1, but were not able to be obtained from RICP completed project areas. Evaluate resulting information to estimate the frequency and magnitude of potential public health risks resulting from cross connections.

Results and Applications:
The results of research in this project area will inform the magnitude of potential public health risks associated with distribution system contamination from backflow through cross connections. Specifically, the research will assess information from other RICP project areas and information from research and information collection efforts outside of the RICP, if needed, to determine the frequency at which various distribution system characteristics occur which contribute to cross connections and backflow. These pieces of information are essential inputs to a calculation of risk from cross connections and backflow.

Decision Relevance:
How is research in this project area likely to inform evaluation of the magnitude of public health risk?
Research in this project area will evaluate information on the occurrence of distribution system characteristics that lead to contamination from cross connections and backflow. The information evaluated under this project area includes information from other RICP project areas and may also include research and information generated outside of the RICP. The characteristics evaluated are those that lead to contamination of distribution systems from cross connections and backflow, and the resultant public health risks from the contamination.

How is research in this project area likely to inform opportunities for mitigation and risk reduction?
Research in this project area will help identify the prevalence, frequency and magnitude of problems related to cross connection and backflow.

What types of distribution system decisions could be supported by research in this project area?
Research in this project area will support future decisions regarding the need for regulation, guidance, policy statements, or other actions be taken to control potential public health risks from cross connections and backflow.

Project Area Constraints and Timing:
The focus of research in this project area is to analyze information generated through other research and information collection efforts, including some conducted as part of the RICP.

Therefore, research in this project area cannot be completed until the information generated from those other RICP project areas is available. These project areas are listed in the table below.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by the DS RICP)**	**Information needs (what will be learned from the predecessor project areas or what will be used in follow-on project areas)**
This project area depends on. . .	Sur1	Survey of Large Drinking Water Utility Distribution Systems	The presence of distribution system characteristics that contribute to contamination from cross connections and backflow.
	Con4	Estimated contaminated water volumes and contaminant concentrations introduced into DSs due to backflow events from unprotected cross-connections based on model predictions and field and pilot-scale experiments	The estimated concentrations of contaminants entering the distribution system during a backflow event, and the volumes of contaminated water.
	Pres2	Characterize Propagation of Pressure Events through Water Distribution Systems to Improve Pressure Management Approaches	The estimated occurrence of pressure events that enable contamination from cross connections and backflow to occur.
Project areas that this project area builds on	None.		NA
Project areas that build on this project area	CC1	Best practices to minimize risks associated with cross connections and backflow	The problem identification assessment from CC2 may be used to evaluate the

			effectiveness of existing best practices.
	Pres1	Survey of Distribution System Pressure Management Practices	Information on barriers to cross connection and backflow contamination.
	RisM1	Decision support for managing potential distribution systems public health risks from potential contamination events and daily operations	Information on barriers to cross connection and backflow contamination.

Factors that might influence the timing of completion of research in this project area include:

- Completion of research in preceding RICP project areas listed in the table above
- Quality and completeness of information from the preceding project areas
- Availability of supplemental information from sources other than RICP project areas

Relevance to the Agreement in Principle:
Research in this project area is relevant to the cross-connection which is a Tier One priority area. Research in this project area focuses on the analysis of information on cross connection and backflow contamination to inform local and national risk management decisions by the drinking water community. Support for these risk management decisions through the RICP was a recommendation in the Agreement in Principle.

Key References:

TCRDSAC Agreement in Principle (2008).
http://www.epa.gov/safewater/disinfection/tcr/pdfs/tcrdsac/agreementinprinciple_tcrdsac_2008-09-18.pdf

EPA. (2001) Potential Contamination Due to Cross-Connections and Backflow and the Associated Health Risks. Distribution System White Paper. *www.epa.gov/safewater/disinfection/tcr/pdfs/issuepaper_tcr_crossconnection-backflow.pdf*.

Project Area Document Code: Con1

Project Area Title: Characterization of Pathogens and Chemicals in Soil and Water Adjacent to Distribution System Infrastructure

Goal: To identify types of contaminants and their concentrations in soil and water adjacent to distribution system infrastructure relevant to intrusion events and main installation/repair/rehabilitation procedures

Rationale: External contaminants that are found in the vicinity of the distribution system can find their way into the system if there is a breach in physical integrity. The characterization of microbial indicators of contamination and of some viruses in the soil and water adjacent to drinking water mains was the topic of two studies (Karim et al., 2003; Besner et al., 2008). This is a limited set of data, characterized by conflicting results between the two studies regarding the frequency of detection for both the indicators of fecal contamination and viruses. In addition, only one study has looked at the microbial characterization of the water found in flooded air-valve vaults, another potentially major intrusion pathway into a distribution system (Besner et al., 2009). The primary purpose of this study is to provide more data regarding the presence of pathogenic microorganisms (not only indicators) and chemical contaminants in the vicinity of drinking water mains, to allow for a more thorough exposure evaluation associated with intrusion events due to low/negative pressure events and contamination from main installation/repair/rehabilitation procedures.

Objectives:

- Develop plans for representative sampling of contamination sources (soil/water) adjacent to possible entry pathways (such as pipe leaks, flooded air-vacuum valves) from a number of case study systems targeting a variety of system characteristics.

- Characterize and quantify contaminants of public health concern in soil and groundwater around drinking water mains, and in flooded vaults in several U.S. distribution systems with a variety of system characteristics
    - Determine types and concentrations of microbial indicators and pathogenic microorganisms representing a range of distribution system characteristics (such as *Cryptosporidium*, *Giardia*, Norovirus, *E. coli* O157:H7); determine viability of pathogens.
    - Identify and analyze organic and inorganic contaminants (regulated and emerging) representing a range of distribution system characteristics.
    - Considering the different types of entry pathways (pipe leaks, flooded air-vacuum valves, etc.) and circumstances studied, identify relationships between contaminant presence, concentrations and system characteristics (e.g., proximity to leaking sewer lines) to provide a framework upon which different circumstances could be evaluated as to the probable risk of contributing to distribution system contamination.
    - Identify model baseline conditions to evaluate.

Suggested Approach:
This project area involves field investigations to identify the some of the contaminants that can enter distribution systems from the external environment.

- Design sampling plans to capture the range of system vulnerability to external contamination (based on influencing factors such as height of water table, proximity between sewer and drinking water mains, type of soil, etc.). Plans should include a systematic approach for determining statistically-significant number of sample sites, types of samples (soil, water, etc), appropriate analytes and detection limits, the number of samples to be collected per site, and the total number of scenarios to be sampled to inform a national estimate of the magnitude of risk. The designs should include plans for how non-detects will be reported and interpreted.
- Collect soil and groundwater samples from pipe trenches at pipe repair sites and water samples from flooded valve and meter vaults.
- Analyze samples for a suite of pathogens and indicators using molecular tools. Conduct supplemental analyses on a subset of the samples to evaluate potential viability and likely source.
- Analyze samples for organic and inorganic constituents that may present a hazard.
- Collect system data and associated metadata (distance between sewer and drinking water main if reliable data can be generated, age/type of sewer, height of water in vault, etc.).

Results and Application:
- Research in this project area will provide information regarding the presence (or absence) and concentrations of contaminants of public health concerns that could be introduced into the distribution system under various pressure scenarios
- Research in this project area will provide information useful for the evaluation of the relative risks associated with different system characteristics (e.g. submerged pipes, sewer overflows, and flooded vaults) by providing for a linkage between the presence of a condition and the occurrence of the contaminants.
- The range of concentrations obtained for microorganisms and chemicals will provide inputs for fate and transport/risk models to estimate exposure/health risks from intrusion and main repair contamination events.

Decision Relevance:
How is research in this project area likely to inform the evaluation of the magnitude of public health risk?
Research in this project area will provide information regarding the presence and concentrations of contaminants of public health concern that could be introduced into distribution systems under various pressure scenarios. This is fundamental information needed to conduct a risk assessment of the public health impacts associated with intrusion events and contamination from main installation/repair/rehabilitation procedures. It will reduce the current uncertainty in possible pathogen concentration levels external to distribution system pipes and provide new information on the presence of organic/inorganic constituents that is not available at this time.

How is research in this project area likely to inform opportunities for mitigation and risk reduction?

Research in this project area is oriented towards the assessment of the potential levels of contamination external to water mains. The results are not likely to directly inform on the effect of mitigation strategies but will rather provide incentives to apply such strategies (such as leak detection/reduction, underground vaults inspection, sewer replacement/rehab, flushing/disinfection after repairs, etc.) to reduce the risk of contaminant introduction into the system. They will help identify the breach, which will help in determining appropriate corrective strategies.

What types of distribution system decisions could be supported by research in this project area?

Research in this project area will provide information on the possible need to: (i) emphasize the application of leak detection/reduction strategies, (ii) establish inspection programs for underground vaults in distribution systems, (iii) establish requirements for installation/retrofitting of air-vacuum valves in distribution systems, (iv) establish requirements for cleaning/disinfection after pipe repairs, (v) emphasize the need for sewer replacement/rehabilitation, (vi) provide supporting evidence for the need to upgrade certain distribution system components that may be experiencing significant decay.

Project Area Constraints and Timing:

This project area could benefit from being implemented after the Large Systems Surveys (Sur1) and Small and Medium Systems Surveys (Sur2) are substantially underway or complete. These surveys could provide candidate water utilities for research in this project area. For example, the surveys will help determine if these utilities have high leakage rates, high pipe break rates, high frequency of rehab activities or flooded underground vaults. The studies would then inform external contaminant conditions at sites highly vulnerable to contamination in order to establish estimates of contamination in reasonable worst case scenarios. Other systems could be selected and compared to these high risk systems.

Depending on how the research is structured, there is a need for coordination between participating utilities, samplers (if not conducted by utility crews), and laboratories performing the sample analyses. The time between sample collection and analysis is sometimes critical, especially for microbiological analyses. To collect soil and water samples at sites of pipe repairs, there is a need for repairs to take place. The predictability of these is also difficult. The same situation arises with flooded underground air-valve vaults, where there is a need for flooded vaults, hence the selection of more vulnerable water utilities as discussed above.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas or what will be used in follow-on**

			project areas)
This project area depends on. . .	No other project areas.		N/A
Project areas that this project area builds on	Sur1	Survey of large drinking water utility distribution systems	Baseline data, identification of additional information gaps, pools of potential participants.
	Sur2	Survey of small and medium drinking water utility distribution systems	Baseline data, identification of additional information gaps, pools of potential participants.
Project areas that build on this project area	None.		N/A

Relevance to the Agreement in Principle:
Research in this project area will provide information relevant to needs identified in Section 4.2.b of the AIP "Conceptual Framework for Knowledge Gaps", and specifically the following items:

- Exposure and vulnerability of the public
  - Identify situations that may result in contamination of public health significance.
  - Characterize the contamination or conditions of public health significance that are introduced during those situations.
  - Assess the exposure to contaminants (considers occurrence, pathway and host susceptibility).

This project area is highly relevant to the Tier One priority topic areas, namely of intrusion, and main construction/repair.

Key References:

Karim, M.R., Abbaszadegan, M. and LeChevallier, M. 2003. Potential for pathogen intrusion during pressure transients. *J. Am. Water Works Assoc*. 95 (5), 134-146.

Besner, M.C., Lavoie, J., Morissette, C., Payment, P. and Prévost, M. 2008. Effect of water main repairs on water quality. *J. Am. Water Works Assoc*. 100 (7), 95-109.

Besner, M.C. and Prévost, M. 2009. Microbial characterization of intrusion pathways and pitfalls of modeling negative pressure events. In Proceedings of AWWA-WQTC, Seattle, WA.

Project Area Code: Con2

Project Area Title: Sampling to Determine Potential Distribution System Contamination Associated with Repair of Water Main Leaks and Breaks

Goal(s): To develop a greater understanding of the public health risk associated with microbial and chemical drinking water contamination occurring during the repair of water main leaks and breaks and to characterize the effectiveness of available mitigation strategies employed following these repairs.

Rationale: Though voluntary standards exist to prevent drinking water contamination following water main repair activities (AWWA Standard C651; Pierson et al., 2001), there is a need to validate the effectiveness of existing industry standards. Previous research has detected microbial contaminants in flushed water from planned repairs of pipe leaks which can result in contamination of the distribution system (Besner et al, 2008). This previous research indicates that flushing alone (without pipe disinfection) following planned pipe leak repairs successfully avoided contaminated water from reaching consumers (Besner et al, 2008). However, the result is dependent upon a variety of factors including the level of contamination present in the soil and groundwater surrounding the repaired main and the degree to which industry guidance is used during repairs. Additionally, very limited data exists to characterize the level of microbial contamination that may occur following catastrophic pipe failures that require emergency repair. The purpose of research in this project area is to characterize the extent of contaminant introduction associated with planned and emergency water main repairs. This research also seeks to validate existing industry guidance on shock disinfection following main repair, rehabilitation and replacement activities that systems use for the prevention of microbial drinking water contamination.

Objectives:
To characterize the extent of possible contamination associated with planned and emergency water main repairs.

- To characterize the effectiveness of shock disinfection as a mitigation strategy for systems using shock disinfection following water main repair, rehabilitation and replacement.
- To provide data to better predict health risks associated with drinking water contamination during repair of water main leaks and breaks.

Suggested Approach:
Research in this project area consists of both field surveys to estimate the extent of contamination that occurs before and during water main repairs as well as controlled laboratory or pilot scale studies to characterize the effectiveness of existing industry guidance.

- To conduct these studies sampling protocols with a statistically significant representative number of sites are needed to determine the extent of contamination introduced before and during planned and emergency water main repairs. The methods used by Besner et al. (2008) provide an ideal starting point for the development of these sampling protocols. The data will be generated in a manner that will enable the estimation of the national public health risk.

- Laboratory or pilot scale pipe systems will be constructed to simulate field repair conditions under controlled conditions and to validate industry guidance for preventing microbial contamination following main repair activities.

Results and Application:
The results generated in these studies are expected to:
1. Provide data to contribute to the estimation of the magnitude of public health risk associated with construction activities.
2. Generate a greater understanding of the effectiveness of existing industry standards intended to prevent drinking water contamination during construction.

Decision Relevance:
How is research in this project area likely to inform evaluation of the magnitude of health risk?
Research in this project area will provide data to enable a quantitative estimate of contaminant introduction, to estimate the public health risk associated with main installation, repair and rehabilitation activities.

How is research in this project area likely to inform opportunities for risk reduction?
Existing industry guidance to prevent drinking water contamination during construction activities will be validated. In doing so, the research may also provide data that indicates a need to revise existing industry guidance.

What types of distribution system decisions could be supported by research in this project area?
The results of these studies are needed to identify risks and the associated risk reduction opportunities associated with main installation, repair and rehabilitation activities. The results of research in this project area are also likely to confirm or identify areas of improvement for existing technical guidance.

Project Area Constraints and Timing:

The results of Con1: "Characterization of pathogens and chemicals in soil and groundwater adjacent to distribution system infrastructure*"* are required for the development of the sampling protocol used here.

A number of systems with a variety of distribution system characteristics willing to participate must be identified. Furthermore, the logistics of collecting samples to document contamination associated with emergency water main repairs may present some challenges.

Relationship to other RICP project areas	**Project area document**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the**

	code		predecessor project areas or what will be used in follow-on project areas)
This project area depends on. . .	Con1	Distribution system contamination associated with repair of water main leaks and breaks	Identification of microbial and chemical constituents for sampling. Sampling protocol from Con1.
Project areas that this project area builds on	Sur1	Survey of large drinking water utility distribution systems	Baseline data, identification of additional information gaps, pools of potential participants.
	Sur2	Survey of small and medium drinking water utility distribution systems	Baseline data, identification of additional information gaps, pools of potential participants.
Project areas that build on this project area	RisM1	Decision support for managing potential distribution systems public health risks from potential contamination events and daily operations	Identification of the effectiveness of risk mitigation strategies will inform the most appropriate best practices for controlling contamination.

Relevance to the Agreement in Principle:
Research in this project area will provide information relevant to needs identified in Section 4.2.b of the AIP "Conceptual Framework for Knowledge Gaps", and specifically the following items:

- Exposure and vulnerability of the public
  - Identify situations that may result in contamination of public health significance.
  - Characterize the contamination or conditions of public health significance that are introduced during those situations.
  - Assess the exposure to contaminants (considers occurrence, pathway and host susceptibility).
- Effectiveness of mitigation measures:
  - Characterize preventative measures or steps to minimize or prevent exposure.
  - Identify and implement remediation steps when contamination occurs.

- Quantify the national significance of additional mitigation measures.

Research in this project area is highly relevant to the AIP Tier One priority topic area of main construction/repair.

Key References:

American Water Works Association. 1992. ANSI/AWWA 651-92 - AWWA Standard for Disinfecting Water Mains. Denver, CO: AWWA.

Besner, M. C.; Lavoie, J.; Morissette, C.; Payment, P.; and Prevost, M. (2008) Effect of water main repairs on water quality. *Journal of the American Water Works Association.* 100(7) 95-109.

Pierson, G., K. Martel, A. Hill, G. Burlingame, A. Godfree. (2001) *Practices to Prevent Microbiological Contamination of Water Mains*. Denver, CO: Water Research Foundation.

Project Area Document Code: Con5

Project Area Title: Computation of Intrusion Volumes through Orifices

Goal(s): Conduct experiments to determine if the orifice equation used to calculate intrusion flow rates is adequate to correctly quantify intrusion volumes through various types of pipe leaks (circular holes, longitudinal cracks, and circumferential cracks) and to allow for a better prediction of the public health risks.

Rationale: The orifice equation ($Q_i = C_d A\sqrt{2g\Delta H}$) is generally used to compute the intrusion flow rate through holes in pipes when a difference in pressure exists between the exterior and interior of the pipe. Although it may provide a first estimation of the volumes of water (flow rate x duration of event) that could be coming in during an intrusion event, there is some uncertainty associated with the use of an exponent value of 0.5. Investigation of the pressure-leakage relationship (under positive pressure conditions in pipes) by several researchers has shown that the exponent value may differ from 0.5 when the effective leak area may, in some cases, be pressure-dependent (Lambert, 2001; Greyvenstein and van Zyl, 2007). Exponent values higher than 2 have been reported, increasing the importance of the pressure differential and significantly increasing estimated flow rates compared to those mediated by the standard equation. However, much uncertainty exists whether these results are also applicable to leaking pipes under negative pressure conditions. No studies have been conducted to validate the use of this equation for the several types of pipe leaks that may be found in distribution systems (round holes, longitudinal and circumferential cracks) under negative pressure conditions. Computation of realistic intrusion volumes is essential to adequately assess the resulting public health risk from such events.

Objectives:

1. Synthesize findings from "surveyable" variables (for potential sizes of intrusion orifices) and pressure-related variables (for potential difference in pressure between the outside and the inside of a pipe) and use these findings as input into the equation used to estimate intrusion flow rate (variables A and ΔH).
2. Under the reported conditions, assess the potential intrusion volumes from various pathways (pipe leaks, flooded air-vacuum valves, and meters).
3. Assess accuracy of the equation used to calculate intrusion flow rates ($Q_i = C_d A\sqrt{2g\Delta H}$), especially for intrusion through pipe leak orifices, which may take various forms (holes, cracks) by evaluating the applicability of the equation for difference forms.
4. Determine the range of discharge coefficient values to be used in the intrusion flow rate equation for various types of orifices (leaks, air-vacuum valve outlet orifices, meter orifices-if needed).

Suggested Approach:
This project area involves pilot-scale experiments:

- Synthesize the following information obtained from surveys or pressure-related project areas to recreate conditions under pilot-scale experiments:
    - Characteristics of pipe leaks (shape, diameter)
    - Height of groundwater above pipes
    - Size of outlet diameters of air-vacuum valves installed in DSs
    - Height of water above submerged air-vacuum valve orifice
    - Meter orifice sizes that could allow water in pipe if submerged
    - Height of water above submerged meters
    - Number of pipe leaks (i.e., holes, cracks, etc.)
    - Relative locations of leaks
    - Ranges of leak sizes
    - Duration, magnitude of low/negative pressure events
- Perform pilot-scale experiments recreating real-system conditions and compute intrusion flow rate for pipes with several orifice shapes and diameters; Validate the exponent value and determine if the use of the orifice equation (exponent of 0.5) is adequate under realistic negative pressure conditions (pipe internal pressures and external heads).
- Conduct validation experiments with air-vacuum valve vault outlet orifices and meter orifices to confirm whether the use of an exponent value of 0.5 is adequate for these orifices.
- Calculate the discharge coefficient values of the various leak forms.

Results and Application:
- Research in this project area will confirm the adequacy of or need to modify the equation used for the calculation of intrusion flow rates when modeling is used (e.g., transient models).
- The project area results will provide input to fate and transport/risk models which can be used to estimate the exposure/health risk associated with intrusion.
- This will improve our ability to estimate the impacts of intrusion on contaminant volumes and concentrations.

Decision Relevance:
How does research in this project area inform the evaluation of the magnitude of public health risk?
Research in this project area will provide assessments of the adequacy of the orifice equation to compute intrusion flow rates through pipe leaks in distribution system. Intrusion volumes, which are obtained from multiplying the intrusion flow rate by the duration of the event, constitute a fundamental piece of information need to conduct a risk assessment of the public health impacts associated with intrusion events.

How is research in this project area likely to inform opportunities for mitigation and risk reduction?

These are theoretical investigations of the basic mechanisms used to estimate intrusion flow rates (and subsequently, volumes) into orifices found in distribution systems. The results are not likely to directly inform the effect of mitigation strategies. However, the results will increase the reliability of model results and data on subjects such as leak detection/reduction and inspection programs for underground vaults in distribution systems. This information can be used to mitigate and reduce risks by minimizing water loss and contaminant entry into distribution systems.

What types of distribution system decisions could be supported by research in this project area?
Research in this project area will inform the possible need to: (i) establish inspection programs for underground vaults in distribution systems, (ii) establish guidance, technical assistance or requirements for installation/retrofitting of air-vacuum valves in distribution systems, and (iii) emphasize the need for application of leak detection/reduction strategies. Research in this project area supports these decisions by providing information to help determine how important of a contamination pathway intrusion represents.

Project Area Constraints and Timing:

What factors influence the timing of research in this project area? Research in this project area could start immediately, but could also benefit from additional data obtained from RisM2. This is a relatively simple stand-alone project area.

What are potential constraints to the implementation of research in this project area?
Research in this project area requires a working space large enough to accommodate a pilot-scale system built to simulate actual distribution system conditions, especially in terms of pressure conditions. The investigators would also need tested pipes (with leaks) from water utilities that would agree to remove leaking pipe sections as part of repairs.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas or what will be used in follow-on project areas)**
This project area depends on. . .	No other project areas.		N/A
Project areas that this project area builds on	RisM2	Improving hydraulic models for distribution systems	Determination of appropriate orifice equation developed by Con5 will enhance hydraulic models.
Project areas that	None.		N/A

build on this project area		

Relevance to the Agreement in Principle:
Research in this project area will provide information relevant to needs identified in Section 4.2.b of the AIP "Conceptual Framework for Knowledge Gaps", and specifically the following items:

- Exposure and vulnerability of the public
  - Identify situations that may result in contamination of public health significance.
  - Characterize the contamination or conditions of public health significance that are introduced during those situations.
  - Assess the exposure to contaminants (considers occurrence, pathway and host susceptibility).

Research in this project area is highly relevant to the Tier One priority topic area, namely intrusion, and could provide some informative value for cross connections and backflow.

Key References:

Lambert, A. 2001 What do we know about pressure-leakage relationships in distribution systems. In *Proceedings of IWA System approach to leakage control and water distribution systems management*, Brno, Czech Republic.

Greyvenstein, B. & van Zyl, J.E. 2007 An experimental investigation into the pressure-leakage relationship of some failed water pipes. *Journal of Water Supply Research and Technology–Aqua*. **56**(2), 117-124.

Project Area Document Code: Con6

Project Area Title: Understanding the Growth Potential within Distribution Systems of Indigenous Bacterial Pathogens (*Legionella* and *Mycobacterium*)

Goal: To provide quantitative data on both the physical/chemical characteristics of distribution systems, and the distribution of various potentially pathogenic *Legionella* and *Mycobacterium* spp within biofilms in distribution systems. Correlations between these data will be useful in developing predictive risk assessment models.

Rationale: *Legionella* and *Mycobacterium* are bacterial genera that include species that are pathogenic for humans. While there are other potential sources of these pathogens (food, soil), their documented presence in drinking waters is evidence that consumption of or exposure to treated finished water after it has been distributed could pose a risk of infection to humans in the US. Their presence in water that has been specifically treated to remove pathogens is explained by the high resistance of *Mycobacterium* to halogen disinfectants and to the observation that *Legionella* can survive ingestion by protozoan amoebae and thus be protected from disinfection.

While these pathogens have been isolated from drinking water, both from bulk water and biofilm samples, it has not been established under what conditions *Legionella* or *Mycobacterium* are most likely to occur and grow. There appears to be some association with organic carbon levels and perhaps geography and *Mycobacterium* occurrence; and little association with chlorine residuals and *Mycobacterium* occurrence. But difficulties in isolating *Mycobacterium* from water and biofilm samples due to interference from background microflora has prevented a comprehensive picture of occurrence in a wide variety of water systems.

Because of the potential for growth and virulence enhancement, drinking water biofilms will be analyzed in this study. There have been few systematic surveys of water biofilm samples to determine occurrence of these pathogens in distribution systems. From these studies, few clues are available of the important distribution system characteristics that must exist for *Legionella* and *Mycobacterium* to occur at significant levels to impact human health. The significance of varied operational practices, such as switching from free chlorine to monochloramine residuals, as well as the competing microbial composition of the biofilm (including specific amoeba hosts) are expected to influence the selection for virulent pathogens within these genera. It is expected that better management of opportunistic *Legionella* and *Mycobacterium* is reliant upon understanding the differences in distribution system biofilm communities located in different climatic regions of the U.S., along with the impacts of different secondary disinfectants, source water chemistry and management practices.

Objectives:

1. Determine the occurrence of potentially pathogenic *Legionella* and *Mycobacterium* spp. in distribution system biofilms and the diversity of potential amoebae hosts, versus non-pathogenic species of these genera.

2. Quantify the density of potential *Legionella* and *Mycobacterium* pathogens within biofilms and growth rates by water temperature and disinfectant residual type/concentration.
3. Evaluate interrelationships between the presence of specific amoeba host species, water quality parameters and operational regimes and the occurrence of potentially pathogenic *Legionella* and *Mycobacterium* spp.
4. Identify biofilm community characteristics associated with the occurrence of either *Legionella* or *Mycobacterium* pathogens and their amoebae hosts.

Suggested Approach:
This project area includes field studies on biofilm samples collected from a variety of distribution systems and is a companion project area to the occurrence and risk management monitoring project areas.

- Conduct surveys of utilities to determine those which might provide opportunities for biofilm samples and which differ in the following respects:
    - -source water chemistry characteristics and treatment resulting in different levels of carbon/nutrient levels;
    - -types of primary and secondary disinfection;
    - -types of pipe materials used;
    - -temperature/pH/corrosion control program
- Choose utilities that are willing to supply biofilm samples and which represent
    - -low (<100ug/L) and high (>200ug/L) AOC levels in finished water;
    - -free chlorine primary and secondary residual
    - -monochloramine primary and residual
    - -monochloramine primary and free chlorine residual
    - -ozone primary and chlorine/monochloramine residual
    - -those which are located in more temperate zones, which experience four distinct seasons and those from consistently warmer zones.
    - -other management practices which may influence biofilms.
- Assess water meters as sources of biofilm samples and use available cultural and molecular methods to analyze for *Legionella*, *Mycobacterium* and protozoan amoebae.
- Characterize the microbial and protozoan biofilm communities from different systems such that differences in biological composition can be determined (e.g. T-RFLP analysis, Sanger sequencing of amplified DNA fragments to determine predominant genera, pyrosequencing).
- Determine statistical significance of the presence of pathogens, amoebae and physical/chemical characteristics of the source water and distribution system.
- Research in this project area would lead to lab- or pilot- scale studies designed to test hypotheses relating to what conditions are ideal for the growth of these pathogens in distribution systems.

Results and Application:
Research in this project area will provide assessments of the occurrence of these pathogens in U.S. distribution systems using state of the art methodologies that will enable a more comprehensive picture of this occurrence than has been generated in past studies. Culture only

studies have provided an inaccurate picture and have not included the larger community in which these pathogens exist and grow. Especially useful information would include associations demonstrated between specific operational parameters of distribution systems and the occurrence of these specific pathogens or their protozoan hosts, in that this information could result in management changes leading to lower risks from these pathogens. Occurrence/growth/survival data of *Legionella* and *Mycobacterium* pathogens would be important inputs into drinking water quantitative microbial risk assessments. Field data could be complementary to proposed epidemiology studies.

Decision relevance:

How is research in this project area likely to inform the evaluation of the magnitude of public health risk? Previous studies have used methods which provide a limited view of the magnitude of the occurrence of these pathogens, as well as providing no information that could be used to evaluate the risks due to increased virulence of these pathogens. A better understanding of conditions that favor the growth and enhance virulence of indigenous biofilm pathogens will aid in predictive model development which could provide quantitative assessments of risk.

How is research in this project area likely to inform opportunities for mitigation and risk reduction?

Information that allows us to understand better the association between the occurrence of these pathogens, their protozoan hosts and distinguishing characteristics of the distribution system might allow utilities to alter their treatment, flushing activities and/or pipe replacement practices to reduce the potential for these organisms to grow.

What types of distribution system decisions could be supported by research in this project area? Decisions related to the use of chlorine vs monochloramine as a residual; the need for additional treatment to remove a greater proportion of carbon from source water; more informed choices when considering types of new replacement pipes.

Project Area Constraints and Timing:

What factors influence the timing of research in this project area? We are just now seeing more reports on the use of metagenomics in environmental studies. There are a variety of hierarchical approaches for community composition analysis. The methods chosen for these studies would incorporate the latest methods. Research in this project area could be informed by the results of proposed epidemiology studies on *Mycobacterium* infections. There would be advantages to targeting distribution systems from which others are gathering clinical data and isolates from treated drinking water consumers.

What are potential constraints to the implementation of research in this project area? The primary constraint will be finding utilities willing to participate in these studies, as they involve the collection of information on pathogen occurrence in treated drinking water. Other constraints include having access to biofilm samples that can be transported to analytical laboratories under conditions where there is no degradation of the sample, and the fact that genomic analyses, especially large-scale pyro-sequencing, requires a significant investment of money.

Research in this project area is not dependent on any other RICP project areas. See the table below for information about project areas that research in this project area builds on.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas or what will be used in follow-on project areas)**
This project area depends on. . .	None		NA
Project areas that this project area builds on	Sur1	Survey of Large Drinking Water Utility Distribution Systems	Identify pools of utilities with varied infrastructures, distribution system conditions, and/or water quality conditions.
	Sur2	Survey of Small and Medium Drinking Water Utility Distribution Systems	Identify pools of utilities with varied infrastructures, distribution system conditions, and/or water quality conditions.
Project areas that build on this project area	None		NA

Relationship to WaterRF projects:

Project Number	Project Title
4092	The Role of Amoebae in the Protection and Proliferation of Pathogens in Distribution Systems Will determine the extent to which amoebae shelter pathogenic organisms and enable proliferation of pathogens such as *Legionella* and *Macobacterium avium* complex in distribution systems. Research partner: UKWIR.

Relevance to the Agreement in Principle:

Research in this project area will provide information relevant to needs identified in Section 4.2.b of the AIP "Conceptual Framework for Knowledge Gaps", and specifically the following items:

- Exposure and vulnerability of the public
  - Assess the exposure to contaminants (considers occurrence, pathway and host susceptibility).
- Effectiveness of mitigation measures:
  - Characterize preventative measures or steps to minimize or prevent exposure.

Research in this project area is relevant to the Tier One priority topic area, storage; and the Tier Two priority topic areas, biofilms and nitrification.

Key References:

Falkinham et al. (2001) Factors influencing numbers of *Mycobacterium avium*, *Mycobacterium intracellulare* and other mycobacteria in drinking water distribution systems. *Applied and Environmental Microbiology* **67(3):** 1225-31.

Lau, H.Y. and Ashbolt, N.J. (2009) The Use of *Acanthamoeba* as a tool for understanding *Legionella* pathogenesis: Implications for drinking water. *Journal of Applied Microbiology* **10**7: 368-78.

Project Area Code: Con7

Project Area Title: Understanding the Survival of Enteric Pathogens and Ammonia-Oxidizing Organisms under Different Distribution System Conditions and Disinfection Practices

Goal: To provide data to better predict health risks associated with the impacts of water distribution and storage system biofilms on the survival of microbial populations (including enteric pathogens and ammonia oxidizing bacteria) that enter distribution systems through pathways including intrusion, cross-connections, storage breaches, and during main replacement/repair/rehabilitation.

Rationale:
Naturally occurring microorganisms found in treated drinking water will attach to and colonize exposed internal surfaces (e.g., pipe walls, storage tank walls, sediment particles) within a DS, forming biofilms. These biofilms are generally thought to be composed of a wide variety of bacteria, protozoa and fungi and are characterized by carbohydrate-rich extracellular polymers that serve to bind cells together. The specific microbiological and chemical properties of biofilms in a specific DS will likely be determined by such parameters as the chemical composition of the source water, the chemistry of the treated water in the DS, disinfectants used, any chemical additions to the water (e.g. corrosion control agents), presence of contaminants organisms that can enter through contamination pathways (e.g., intrusions), temperature, pipe material and flow characteristics. Biofilm microorganisms will be released into the bulk water at rates determined by physical, chemical and biological conditions.

Water utilities rely on residual disinfectants in their DS to inactivate harmful microorganisms that make it through the treatment regime, as well as to guard against and inactivate any contaminants that gain entry into the DS post-treatment. In addition residual disinfectants are relied upon to control biofilm build up and help in preventing the growth of bacterial pathogens in DS. Free chlorine and monochloramine represent the most commonly used residual disinfectants. It is well established in the published literature that free chlorine is far less effective in inactivating microorganisms that are part of a biofilm, as opposed to the same organisms freely floating in water and this is especially true of biofilms formed on iron-containing surfaces, as opposed to other commonly used materials such as copper or PVC. It is generally acknowledged that this difference in disinfectant effectiveness is largely due to the fact that free chlorine reacts to a wider variety of chemical compounds compared to monochloramine. And so the oxidizing power of free chlorine is spent quickly in a biofilm, reacting with the carbohydrate polymers, while the bacterial cells remain unaffected. Monochloramine on the other hand, is less reactive chemically with polysaccharides and thus is able to penetrate biofilms with enough oxidizing power to inactivate the microbes present. However, monochloramines are less effective than chlorine at inactivating microbial contaminants that enter the distribution system bulk water through breaches. The presence of ammonia in the DS, through the production of monochloramine can support the growth of ammonia-oxidizing bacteria, which in turn can lead to elevated levels of nitrate and nitrite.

Situations that allow contaminated water to enter a DS, through cross-connections, backflows, intrusions through cracks during low pressure events and pipe repair operations, will involve the exposure of pipe biofilms to pathogenic microorganisms, as well as creating large disinfectant demands that use up added residuals. Because of the porous nature of biofilms, these microorganisms can become entrapped, shielded from disinfectants and possibly released back into the bulk drinking water through shearing or erosion of the biofilms. Reports exist that document the adsorption and release of pathogenic bacteria from distribution system biofilms following incidents such as wastewater cross-connections. In a pilot-scale study designed to investigate this scenario under controlled conditions, a 2 month long simulated wastewater cross-connection documented the adsorption of bacterial pathogens to the biofilms and re-released back into the water column in a more concentrated 'parcel'.

A better understanding of the role of biofilms as contaminant reservoirs is needed in identifying management practices to reduce the potential for survival of enteric pathogens in distribution systems.

Objectives:

- Determine the relative biofilm uptake and survival kinetics for reference enteric bacterial, viral and protozoan pathogens, and ammonia-oxidizing organisms associated with biofilms on DS pipe and storage internal surfaces and in accumulated sediments, with varying types and concentrations of secondary disinfectants.
- Describe the biological and physical mechanisms and extent to which enteric pathogens are released into the bulk water from the biofilms.
- Evaluate relationships between ammonia oxidizing bacteria and other microbial flora resident in distribution and storage system biofilms and factors that influence survival and die-off.

Suggested Approach:

These are laboratory studies of biofilms on pipe walls and sediments developed from different source waters and surface materials;

- Develop laboratory-scale biofilms on pipe materials which span the range of those currently used, including new materials being proposed as resisting biofilm growth.
- Develop biofilms using pure cultures of selected bacterial strains, ammonia-oxidizing organisms, and wastewater inocula.
- Study adsorption of enteric pathogens (including bacterial, protozoan and viral pathogens) and appropriate indicator organisms to biofilm and quantify microbial viability/infectivity over time.

  > target pathogens will include *Salmonella typhimurium* strains, *Shigella* spp., *Giardia* cysts, norovirus (or best surrogates), enterovirus (echo-coxsackie virus.)
- Conduct parallel tests of alternative secondary disinfectants to evaluate impacts of free chlorine and monochloramine on pathogens/indicators viability/infectivity and activity of ammonia oxidizing bacteria. Include source water quality considerations.
- Evaluate pathogen/indicator release from biofilms and sediments under a variety of simulated distribution system operational modes; and

- Investigate whether the use of mathematical models, such as those that describe the adsorption of particles to surfaces (Langmuir Isotherm), could be useful in predicting attachment/release of specific pathogens from biofilms.

Results and Application:
Sorption, survival and release kinetics for a range of enteric pathogens and indicators are key input parameters required to model the interaction of pathogens with surfaces as pathogens make their way through distribution systems, and ultimately provide densities for input into quantitative microbial risk assessments. Data could be useful in refining existing and modified EPANET models to include the modeling of the movement and fate of both chemical and biological reactive contaminants that interact with biofilms throughout distribution systems. Field data will be complementary to proposed epidemiological studies and to the refinement of best operating practices for distribution systems.

Decision relevance:
How is research in this project area likely to inform the evaluation of the magnitude of public health risk?
Published reports to date have been limited in the conditions under which adsorption/release of pathogens from biofilms have been conducted. More comprehensive studies will provide information on the extent to which specific pathogens adsorb to biofilms generated under commonly observed DS conditions. These studies, focusing on the differences in the chemical nature of the biofilms and the adsorption characteristics of different pathogen types could highlight conditions which favor survival of specific pathogens and aid in predictive model development which could provide quantitative assessments of risk.

How is research in this project area likely to inform opportunities for risk mitigation and risk reduction?
If associations can be found between DS conditions and opportunities for introduced pathogens to survive and even replicate in biofilms, then utility operators could establish best management practices that would reduce these opportunities. It is likely that many operators are unaware of the potential for introduced pathogens to evade disinfection if entrapped in biofilms. And it is also likely that many operators would be unaware that such biofilms will form on any internal surfaces- pipe walls, storage tanks, sediment particles, etc. Increasing the awareness of operators as to the possibilities for pathogens to exist in their systems should provide the impetus for some systems to seek ways to avoid these risks, such as when they are deciding on secondary disinfectants, when they decide on what pipes to use when replacements are needed and perhaps other operational parameters under their control.

What types of distribution system decisions could be supported by research in this project area?
Research in this project area could provide information on the ability to control biofilm formation and sediment accumulation on DS internal surfaces by managing pipe and storage materials, operations, finished water chemistry, and type of primary and secondary disinfectants.

Project Area Constraints and Timing:

What factors influence the timing of research in this project area?
Because these are largely laboratory studies, they are not dependent on other research in project areas being proposed. However, information from fate and transport components of Hea2 could inform the specific parameters in the lab experiments.

What are potential constraints to the implementation of research in this project area?
There are possible technical issues associated with growing and determining viability of certain pathogens, including certain viral pathogens (e.g., noroviruses) without current effective viability assays. Another possible technical constraint is the identification of a representative wastewater.

See the table below for information about project areas that research in this project area builds on.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas or what will be used in follow-on project areas)**
This project area depends on. . .	None.		NA
Project areas that this project area builds on	Hea1	Quantitative Microbial Risk Assessment (QMRA) to evaluate exposure to pathogens through drinking water distribution systems	Fate and transport models and results.
Project areas that build on this project area	None.		NA

Relationship to WaterRF projects:

Project Number	Project Title
4116	Microbial Ecology in Distribution Systems
4165	Microbial Ecology during Nitrification Events,

Relevance to the Agreement in Principle:
Research in this project area will provide information relevant to needs identified in Section 4.2.b of the AIP "Conceptual Framework for Knowledge Gaps", and specifically the following items:

- Exposure and vulnerability of the public:

    - Characterize the contamination or conditions of public health significance that are introduced during those situations.
    - Assess the exposure to contaminants (considers occurrence, pathway and host susceptibility).
- Effectiveness of mitigation measures:
    - Characterize preventative measures or steps to minimize or prevent exposure.
    - Identify and implement remediation steps when contamination occurs.

Research in this project area is relevant to the Tier One priority topic area, storage facilities; and the Tier Two priority topic areas, biofilm, nitrification and contaminant accumulation.

Key References:

Gibbs et al. (2004). Evaluation of the ability of chlorine to inactivate selected organisms from the biofilm of a drinking water distribution system simulator following a long-term wastewater cross-connection. *Journal of Environmental Engineering Science* **3:** 97-105.

LeChevallier et al. (1988) Inactivation of biofilm bacteria. *Applied and Environmental Microbiology* **54(10):** 2492-99.

Project Area Code: Con8

Project Area Title: Baseline Data on Episodic Release/Mobilization of Chemical Contaminants from Biofilms and Accumulated Solids in Distribution and Storage Systems

Goal: Obtain data documenting levels of selected chemical contaminants in drinking water distribution systems collected under "normal" conditions.

Rationale:
A number of researchers have reported that trace contaminants in water can accumulate in solids found in drinking water distribution systems. Studies have shown, for example, that arsenic, radium, uranium and vanadium can accumulate to significant levels on iron and lead corrosion by-products and other solids in the distribution system (Lytle et al. 2004; Valentine and Stearns 1994; Snoeyink et al. 2003; Schock 2005; Schock et al. 2008; Morris and Lytle 2007). Given the likelihood that contaminants have accumulated in some distributions systems, the possibility that an event (such as a pressure fluctuation) could trigger the release of the contaminant back to the water resulting in elevated levels in the consumer's tap water exists. Physical, chemical and biological factors can result in intermittent, episodic, or continuous release of contaminants from solids into the bulk water. These contaminants can be chronic, sub-chronic or acute in nature. Although the potential for contaminants to be released back to the water from distribution systems exist, very little real data documenting levels of released contaminants in the distribution system exists. Regulatory sampling requirements for most regulated contaminants are at the point of entry into the distribution system. Research in this project area will identify levels of contaminants (such as arsenic, nitrite and uranium) in drinking water distribution systems in real communities when no events that could trigger major release episodes are occurring or under "normal" conditions. The data will serve as a "baseline" to compare how levels of contaminants of concern differ from the water entering the distribution system. The data can also be used to compare how contaminant levels change when an "event" occurs that could impact contaminant release (RisM4).

Objectives: Research in this project area establishes a baseline for occurrence of some contaminants of concern in drinking water at consumer's taps and other locations in the distribution system. The research will include intensive field investigations of consumer's tap water and other locations for water quality parameters of concern and corresponding treated water chemistries.

1. Establish baseline levels of contaminants at consumer's taps and elsewhere within the distribution system.
2. Evaluate the impact of finished water quality on water quality at consumer's taps and other locations such as storage tanks under "normal" operation.
3. Evaluate the impact of distribution system materials (iron, cement, etc.), on water quality at consumer's tap.

Suggested Approach:
The team will coordinate with utility participants to identify locations that currently have or in the past had measureable levels of contaminants (such as arsenic, radium, and uranium) in their source water. Also, communities with specific materials in the distribution system that can contribute to elevated levels of contaminants will be targeted. Complete water quality monitoring programs of sites in the distribution system, source water and finished water will be initiated. The research will:

- Develop distribution system sampling protocols designed to collect samples at consumer's taps and other locations in distribution systems under "normal" operating conditions. Researchers should take into account routine distributions system operations that could lead to release of contaminants.
- Analyze samples for potential contaminants of concern and indicator parameters (e.g. iron, color, TSS, metals, carbonates, phosphates, silicates, pH, alkalinity, ORP, TDS, conductivity, chloride, sulfate, coliforms, HPC, turbidity, chlorine residual, nitrite).
- Compare source and finished water parameters with distribution samples and interpret data to identify relationships.

Results and Applications:
Results will provide a baseline for comparing water quality, particularly contaminants of concern, in the distribution system under "normal" operating conditions. In some cases, some of the contaminants may increase in concentrations in distribution systems to levels above the MCLs, even under "normal" conditions. The utilities may be unaware of this increase since the monitoring occurs before distribution. Therefore, the results of the studies will provide baseline data to help determine whether changes to monitoring locations need to be considered.

Decision relevance:
Research in this project area will support risk management decisions targeted at controlling health risks associated with chemical contaminants that are released from biofilms and accumulated solids in distribution and storage systems.

How does research in this project area inform the evaluation of the magnitude of public health risk?
Research in this project area will yield new data carefully collected in targeted systems and scenarios, to enhance the understanding of effects of risk management practices on stability or release of selected chemical contaminants from distribution system biofilms and accumulated solids.

How does research in this project area likely inform opportunities for mitigation and risk reduction?
Research in this project area will provide data from actual systems that can be used as a baseline for making changes toward mitigation of system contamination risks. Levels of contaminants measured and patterns of release can help inform potential exposures and risk.

What types of distribution system decisions could be supported by research in this project area?

Research in this project area will enhance the understanding of the range possible consequences of risk management actions aimed at minimization of sediment accumulation- or biofilm-related chemical contamination. As such, research in this project area will inform the need for consideration of revisions to current regulatory monitoring strategies for inorganic contaminants.

Project Area Constraints and Timing:

This project area does not depend on any other RICP project areas. Project area timing has been projected as 2 – 5 years.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas or what will be used in follow-on project areas)**
This project area depends on. . .	None.		NA
Project areas that this project area builds on	None.		NA
Project areas that build on this project area	None.		NA

What are the potential constraints to the implementation of research in this project area?

- Investigator knowledge of complex operational conditions and factors affecting accumulation potential, access to analytical resources and qualified sampling staff.
- Access to and assimilation of findings from R&ICP project areas upon which this project area builds.
- Sampling protocols to accommodate sample integrity and analytical processing needs and to collect water and sediments under clearly described conditions.
- Willingness of utilities to participate by facilitating or taking samples and providing metadata.

Relevance to the Agreement in Principle:

As stated in section 4.2.a, accumulation and release of contaminants from distribution system scales and sediments was identified by the TCRDSAC as being one of the seven issues most relevant to protecting public health and maintaining the integrity of distribution systems.

Research in this project area helps address multiple issues across the AIP priority topic areas in Section 4.2 of the AIP (e.g., storage facilities, nitrification and contaminant accumulation). This

project area, as part of a phased R&ICP project area approach also addresses AIP directives to conduct *focused and coordinated* research and information collection to inform potential additional risk management actions (e.g. regulations, guidance).

Key References:

Lytle, D.A.; Sorg, T.J.; Frietch, C. 2004. "The Accumulation of Arsenic in Drinking Water Distribution Systems." *Environ. Sci. Tech.* 38:20:5365-5372.

Valentine, R.L.; Stearns, S. 1994. "Radon Release from Water Distribution System Deposits." *Environ. Sci. Technol.* 28(3):534-537.

Snoeyink, V.L.; Schock, M.; Sarin, P.; Wang, L.; Chen, A.S.C.; Harmon, S. 2003. "Aluminum-Containing Scales in Water Distribution Systems: Prevalence and Composition." *Journal of Water Supply: Research and Technology*. 52(7):455.

Schock, M.R. 2005. Distribution Systems and Reservoirs and Reactors for Inorganic Contaminants (Chapter 6). In: *Distribution System Water Quality Challenges in the 21st Century*. AWWA. Denver, CO.

Schock, M. R.; Hyland, R.N.; Welch, M.M. 2008. "Occurrence of Contaminant Accumulation in Lead Pipe Scales from Domestic Drinking-Water Distribution Systems." *Environ. Sci. Tech.* 42(12): 4285-4291.

Morris, E. and Lytle, D.A., "The Accumulation of Radium and Other Radionuclides in Drinking Water Distribution Systems." Presented at AWWA Water Quality Technology Conference, Nov. 4-8, 2007, Charlotte, NC. 2007.

Project Area Document Code: Hea3

Project Area Title: Response Teams to Prepare Case Studies on Adverse Public Health Effects from Distribution System Events

Goal: To deploy trained response teams to collect and analyze information on any reported public health consequences associated with distribution system events where the introduction and/or mobilization of one or more contaminants is known or believed to have resulted in human population exposures at levels presenting potential public health risks.

Rationale:
Real-time data linking adverse public health consequences to distribution system contamination events are limited. Contamination events such as intrusion, main breaks, cross connections and backflow may cause harm to individuals consuming tap water. The purpose of the response teams and case studies is to compile information in a coordinated and systematic way to describe associations between observed distribution system events and adverse health effects. Activities in this project area will involve close collaboration with CDC and other federal, state, or local entities and EPA Regional offices as appropriate. It is envisioned that this project area will involve a large number of systems with evidence of a contamination event. The investigations will occur as close in time to the actual contamination event and will focus on the population most likely to have experienced the elevated exposure levels during the contamination event. This project area will augment the data obtained from more comprehensive long-term epidemiological studies that tend to focus on a limited number of specific systems where the occurrence of distribution system events may or may not be observed. Results from these studies may also inform the design and data collection needs in epidemiological studies that are focused on distribution systems. In addition to characterizing the extent and severity of adverse health effects among the exposed population, researchers will document differences in public health consequences associated with various response and intervention measures implemented by water system managers to address those distribution system events.

Objectives:

- Establish, train, and maintain the readiness of response teams of public health professionals to deploy to locations where a significant event has occurred in public water distribution systems (e.g., a major main break, significant pressure loss due to power outages, storage related events) to study potential resulting adverse public health effects.
- Collect and analyze data on: illnesses or other adverse health effects following documented distribution system contamination events; relevant information on distribution system characteristics, operations, and water quality; and supporting demographic data.

- Prepare case study reports that characterize the nature of the distribution system contamination events (including relevant conditions leading up to the event), the water

system response to addressing / controlling that event, and the incidence and severity of any illnesses occurring among exposed populations following those events.

Suggested Approach:
This research effort will involve three main phases.

- The first phase would be to identify representative sets of water systems (in terms of types of water systems and geographic distribution) and enter into advance agreements with them (and with relevant local public health agencies) to notify the response teams when events occur and to allow them access to the information needed for conducting the case studies (e.g. security clearances for viewing sensitive DS characteristic information).

- The second phase would be to select and train the response team members for this effort, to provide on-going training and support to ensure their readiness, and to provide all needed logistical support for the teams to deploy when events occur that will be studied.

- The third phase is the actual mobilization of the teams into the field to collect information from drinking water supply customers or local public health agencies concerning gastrointestinal (GI), respiratory and other diseases, in the period following a significant disruption in normal service at public water systems as well as the associated information on the events themselves. This third phase will also include the preparation and dissemination of the case study analysis results to EPA and the research partners for their use in assessing the health risks and risk reduction potential from those events.

- It should be noted that the purpose of these response teams is gathering information about the events, and not to provide the type of emergency response support that is the responsibility and purview of a range of federal, state and local entities (see, for example, HHS 2007). However, it is anticipated that there would be considerable cooperation with those entities and that the training and deployment logistics would be modeled to some extent on those developed by such emergency response groups.

Results and Application:

- The key products from the case studies are expected to be characterizations of the extent and severity of public health risks associated with the actual occurrence of different types of distribution system events.

- The application of this information is expected to contribute to an understanding of the potential health benefits to be gained from implementing risk mitigation strategies through technical assistance, industry guidance, policy statements, or technical guidance and/or regulations developed locally, at the State level or nationally.

Decision Relevance:
How is research in this project area likely to inform evaluation of the magnitude of health risk? Research in this project area will directly inform the potential magnitude and severity of public health risks associated with different types of distribution system events, including major main breaks, significant pressure loss due to power outages, and storage related events.

How is research in this project area likely to inform opportunities for mitigation and risk reduction? Research in this project area could identify differences in public health outcomes for similar events where systems have important differences in operating characteristics or event response strategies. This would inform the relevant risk mitigation and reduction strategies.

What types of distribution system decisions could be supported by research in this project area? The results of these studies will help inform the basis to determine whether the current risks and risk reduction potential regarding various types of distribution system events merit regulatory action, technical guidance, both, or neither.

Project Area Constraints and Timing:
Research in this project area can begin without dependence on any other effort. As indicated in the suggested approach section, research in this project area does depend upon establishing advance agreements with public water systems, and possibly with other local public health agencies, to deploy to those locations and have access to needed information.

The completion of this information collection project area may influence several other project areas. See the table below for information on the project areas under consideration by the DS RICP that build on Hea3.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by the DS RICP)**	**Information needs (what will be used in follow-on project areas)**
This project area depends on. . .	No other project areas.		NA
Project areas that this project area builds on	None.		NA
Project areas that build on this project area	RisM1	Decision support for managing potential distribution systems public health risks from potential contamination events and daily operations	Information from the case study reports (e.g., relevant conditions leading up to the contamination event) may aid in refining the project area designs of RisM1 and Pres4.
	Pres4	Toolkit for pressure management	

Note: Although research in this project area does not explicitly build on other project areas, nor do other project areas depend on it, it is possible that this project area and Hea2 (Epidemiological Studies of Low Pressure Events) may be mutually informative of one another with respect to improving their respective methodologies for gathering information and identifying health effects end-points and subpopulations on which to focus.

Relevance to the Agreement in Principle: Research in this project area will provide information relevant to needs identified in Section 4.2.b of the AIP "Conceptual Framework for Knowledge Gaps", and specifically the following items:

- Health Effects and Risk to the Public
    - Measure health consequences from exposure to contaminants
    - Monitor for situations that pose a public health concern
    - Measure and track the national significance of the described situations
- Effectiveness of mitigation measures
    - Characterize preventative measures or steps to minimize or prevent exposure
    - Identify and implement remediation steps when contamination occurs
    - Quantify the national significance of additional mitigation measures

Research in this project area is highly relevant to all of the Tier One priority topic areas: main construction/repair, storage, cross-connection and backflow and intrusion (e.g., from significant pressure loss due to power outages).

Key Reference:

HHS 2007. U.S. Department of Health and Human Services. Public Health Emergency Response -- A Guide for Leaders and Responders. Office of the Assistant Secretary for Public Affairs. http://www.hhs.gov/emergency (August 2007).

Project Area Document Code: Hea4

Project Area Title: Molecular Epidemiology of Distribution System Associated Pathogens

Goal: Evaluate potential linkages between distribution system characteristics and disease transmission by comparing the molecular signatures of distribution system-associated pathogens and clinical samples from hospitals and clinics. A key focus will be comparing distribution system samples of biofilm-associated pathogens including *Legionella* and *Mycobacteria* with samples from patients with suspected cases of *Legionella*-like respiratory disease or infection by non-tuberculous mycobacteria.

Rationale:
Various *Mycobacterium* and *Legionella* spp. and other pathogens are known to colonize drinking water biofilms. A recent study using genomic analyses of household showerhead water and biofilm samples found that 78- 90% of the samples were positive for *M. avium*, by either qPCR or sequence analysis of rRNA clone libraries. Another study found *Legionella spp* present in 22% of household hot water samples. However, data are lacking on the extent to which these opportunistic pathogens colonize water distribution and storage systems. These pathogens can persist under ambient disinfectant conditions in drinking water distribution systems, either through protection by amoebal ingestion (*Legionella* and *Mycobacterium*), through resistance to inactivation by halogen disinfectants due to an unusually protective cell wall (*Mycobacteria*), or through the microbial ecology of biofilms. In fact, numbers of mycobacteria are higher in water systems that use some disinfectant (as opposed to untreated groundwater systems), likely due to the fact that mycobacteria are extremely slow growing and cannot compete with other halogen-sensitive bacteria found in water.

Drinking water is not the only possible source of these pathogens. *Mycobacteria* are present in many household environments, including food and soils. And *Legionella* were originally recognized as pathogens that came from aerosols from air-conditioning units. So the link between municipally treated drinking water and exposure is unclear.

By using molecular epidemiology to compare high-resolution molecular fingerprints of environmental sample isolates with isolates/molecular fingerprints directly from infected patients, it can be determined if drinking water is a possible source of pathogens causing human respiratory illness. Such an approach has provided evidence for drinking water as a potential source of *Mycobacterium avium* complex (MAC). Here we seek to investigate a wider selection of clinical and environmental strains and link the microbiological findings to distribution system water quality and operating parameters to identify plausible control and management strategies.

Objectives:

1. Develop culture and direct molecular fingerprint approaches to apply to lung/sputum samples and environmental isolates.

2. Work with clinicians and local utilities at patients' households to collect paired samples.
3. Conduct molecular identification of isolates and then appropriate high-resolution fingerprinting for the different species identified.

Suggested Approach:

Phase 1:

- Research in this project area will depend on access to hospitals and clinical patients suffering from *Legionella* and *Mycobacterium* respiratory disease and the isolates from these patients. Therefore medical practices/clinics which cater to these patients will need to be identified and enrolled in the studies.
- Institutional Review Board approval for human subject research must be obtained.
- Once households are identified for analysis, a sampling plan must be developed for each house. The plan should include both water and biofilm samples from as many taps as there are in the house and include how samples will be collected and how frequently samples are to be taken. In addition, plans must be developed to receive clinical isolates of *Legionella* and *Mycobacterium* from targeted patients.
- Information on the drinking water systems should be collected, including the source water, treatment regime, location of the house in the distribution system, physical characteristics of distribution system (pipe material, storage facilities, dead ends), distribution system operational and management parameters and in premise plumbing water quality parameters.

Phase 2:

- Tap water and biofilm samples will be processed for recovery of *Legionella* and *Mycobacterium* using current best practices (including enrichment culturing.)
- Samples should also be processed for recovery of DNA targets for molecular analyses for these pathogens.
- All isolates, both clinical and water, should be analyzed by amplified fragment length polymorphism analysis (AFLP) to determine if the pairs (isolates from the patient and from his/her home environment) are clonal, indicating that the home tap water is the source of the clinical infection.
- Based on the culture/molecular identifications, fingerprinting and distribution system parameters, identify potential covariates in characterizing risk and system vulnerability.

Results and Application:

These studies should add to the understanding of drinking water as a transmission vehicle for *Legionella* and *Mycobacterium* infections. In addition, these studies should yield critical information needed to determine whether the occurrence of *Legionella* and *Mycobacterium* strains, those which are the causative agent of human infections, can be predicted based on the physical and chemical characteristics of particular distribution systems. It is likely that if such predicted associations can be determined for these pathogens, then there are likely to be present other pathogens in water inhabiting the same ecological niches as the pathogens targeted in these studies. Preventing the survival and/or the growth of *Legionella* and *Mycobacterium* will also serve to decrease exposure to other pathogens. Data from these studies could be useful in refining quantitative microbial risk assessment models to include the risks from exposure to

these biofilm pathogens, evaluate potential management strategies to reduce distribution-system associated respiratory disease and enable estimation of the national significance of drinking water respiratory pathogens.

Decision relevance:

How does research in this project area inform the evaluation of the magnitude of public health risk?

Because there are other potential sources of *Legionella* and *Mycobacterium* other than home water taps, a better understanding of role of distribution systems and household premise plumbing in supporting the survival/growth of these pathogens will enable a more accurate evaluation of the magnitude of the public health risk.

How is research in this project area likely to inform opportunities for mitigation and risk reduction?

If it can be established that specific parameters of the distribution system or premise plumbing are associated with exposure to *Legionella* or *Mycobacterium* pathogens, then altering distribution system management practices or consumer actions in the home could provide meaningful opportunities for mitigation and risk reduction.

What types of distribution system decisions could be supported by research in this project area?

The choice of secondary disinfectant could be informed by the results of these studies. The use of monochloramine introduces potential public health risks (nitrification) and the lack of inactivation of intruded contaminants due to lack of necessary contact time in the DS, balanced by the potential for more effective disinfection of biofilm pathogens. These studies could provide further evidence that the use of monochloramine is associated with lower levels of biofilm pathogens. Also any water quality parameters or physical characteristics of distribution systems that are found to be associated with the occurrence of these human pathogens could form the basis for identification of how/where possible management activities could be focused to reduce the disease burden.

Project Area Constraints and Timing:

What factors influence the timing of research in this project area? While research in this project area is not dependant on any other project areas, research in this project area would build on the successful completion of Con 6- Understanding the growth potential within distribution systems of indigenous bacterial pathogens (*Legionella* and *Mycobacterium*).

What are potential constraints to the implementation of research in this project area?

Finding clinics willing to participate in the study and receiving IRB approval could be a time-consuming and lengthy process. Also it will be difficult to gain access to homes for sample collection or to rely on patients or their family to take samples. Shipping of samples to lab will need to be accomplished such that any target organisms remain viable. And, it is likely that most clinical cases will be from either exposure to pathogens in other matrices or that the water exposure occurred in the past and the pathogens are no longer present in the household water taps.

Relationship to other RICP project areas	Project area document code	RICP project area document title (under consideration by DS RICP)	Information needs (what will be learned from the predecessor project areas)
This project area depends on. . .	None		NA
Project areas that this project area builds on	Con6	Understanding the growth potential within distribution systems of indigenous bacterial pathogens (Legionella and Mycobacterium)	Information would inform sampling plan.
Project areas that build on this project area	None		NA

Relevance to the Agreement in Principle:
Research in this project area will provide information relevant to needs identified in Section 4.2.b of the AIP "Conceptual Framework for Knowledge Gaps", and specifically the following items:

- Exposure and vulnerability of the public
  - Assess the exposure to contaminants (considers occurrence, pathway and host susceptibility).
- Effectiveness of mitigation measures:
  - Characterize preventative measures or steps to minimize or prevent exposure.

Research in this project area is relevant to the Tier One priority topic area, namely storage; and the Tier Two priority topic areas, biofilms and nitrification.

Key References:

Falkinham et al. (2001) Factors influencing numbers of *Mycobacterium avium*, *Mycobacterium intracellulare* and other mycobacteria in drinking water distribution systems. *Applied and Environmental Microbiology* **67(3):** 1225-31.

Feazel et. al. (2009) Opportunistic pathogens enriched in showerhead biofilms. *PNAS* **106(38):** 16393-399.

Lau, H.Y. and Ashbolt, N.J. (2009) The Use of *Acanthamoeba* as a tool for understanding *Legionella* pathogenesis: Implications for drinking water. *Journal of Applied Microbiology* **107:** 368-78.

Project Area Document Code: Mon1

Project Area Title: Collection of Distribution System and Storage Monitoring Data for Nitrite, Nitrate, and Related Physical and Chemical Constituents

Goal: To establish a national perspective on the levels of nitrite, nitrate, and other contaminants in distribution and storage systems (water and sediments) and their relationship with system characteristics, water chemistry, disinfection approaches, and operating practices, etc.

Rationale:
Federal drinking water regulations require monitoring of nitrate and nitrite at the entry point to the distribution system. However, nitrification can occur within distribution systems and excess nitrate and nitrite can lead to significantly higher levels in distribution systems. These high levels could exceed maximum contaminant levels (MCLs).

Objectives:

- Develop programs to monitor distribution system mains, storage tanks, and premise plumbing for nitrite, nitrate, ammonia, disinfection residuals (including organic and inorganic chloramines). Consider issues such as source water quality, time of year, treatment methodologies, and distribution system hydraulics in developing monitoring procedures.
- Evaluate relationships between system characteristics, source water characteristics (including blending), disinfection approaches, operating practices, consumer complaints, and monitoring results to identify possible causes of the contamination and if contaminant detection outcomes result.

Suggested Approach:
This is an information collection project area for monitoring of water in distribution systems and sediments in storage tanks. Research in this project area will proceed in three sequential phases:

- Phase 1 - Identify participating utilities and review available data and information.
- Phase 2 - Develop sample collection and processing methods.
- Phase 3 - Develop and conduct utility specific monitoring programs, and collect and analyze samples.

Phase 1 - The first phase includes the identification of utilities to participate in the monitoring programs, representing systems with a variety of distribution and storage system characteristics: size, age, sources of water, disinfection approaches, and geographical and climate distribution. After utility identification, comprehensive analyses of the available utility data will be conducted.

Phase 2 - The second phase will be the development of new sample collection and processing methods required to conduct the proposed sampling (e.g. methods related to sediment analysis from storage tanks).

Phase 3 - Based on the results of the previous phases, utility specific monitoring plans will be developed. Following the development of the monitoring plans sample collection will take place. After collection, the data will be analyzed and interpreted to identify relationships between system properties and monitoring results.

Results and Applications:
Research in this project area will develop a national perspective on nitrite, and nitrate in distribution and storage systems. Results may also lead to alternative monitoring approaches. In addition, sample collection and processing methods will be developed.

Specifically, the data to be collected includes:

- Distribution system influent levels and occurrence of ammonia, nitrite, nitrate, and chloramines (inorganic and organic).
- Distribution system levels and occurrence of ammonia, nitrite, nitrate, and chloramines (inorganic and organic).
- Premise plumbing levels and occurrence of ammonia, nitrite, nitrate, and chloramines (inorganic and organic).
- Storage tank sediment analyses to determine sediment accumulation rates.

Decision Relevance:
Research in this project area could inform new monitoring strategies for regulation, such as revising monitoring requirements for nitrate/nitrite. Research in this project area could also inform the need for potential guidance or policies relevant to nitrification.

How is research in this project area likely to inform evaluation of the magnitude of public health risk?
Research in this project area will provide a national perspective of the levels of nitrite and nitrate in distribution and storage systems. This will inform the extent and frequency at which various potential public health vulnerabilities are occurring on a national basis.

How is research in this project area likely to inform opportunities for mitigation and risk reduction?
Research in this project area will provide an initial understanding of the degree to which nitrite and nitrate occur in distribution and storage systems.

What types of distribution system decisions could be supported by research in this project area?
Research in this project area would inform the local, state and national policies on distribution system issues, including monitoring requirements for nitrite/nitrate. It will also support monitoring decisions undertaken at individual utilities.

Project Area Constraints and Timing:

Factors that may influence the timing of project area completion include:

- Identification and willingness of utilities to participate.
- Participation by enough (and sufficiently diverse) utilities to provide meaningful results between system characteristics, source water characteristics (including blending), operating principles, disinfection approaches, consumer complaints, and monitoring results.
- Issues associated with providing potentially sensitive information (data confidentiality).
- The complexity and scope of monitoring plan design and data analysis.
    - Lack of information in utility files.
    - Lack of utility resources (personnel-time, computer expertise, sampling expertise) to complete the monitoring plan.
    - Identification of relevant sampling points.
    - Development of required sample collection and processing methods.

Research in this project area does not depend on the completion of other project areas. See the table below for information on project areas that research in this project area builds on and project areas that build on research in this project area.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas or what will be used in follow-on project areas)**
This project area depends on. . .	None.		NA
Project areas that this project area builds on	Sur1	Survey of Large Drinking Water Utility Distribution Systems	Candidate utilities where to conduct research based on information such as: source water ammonia levels, secondary disinfectants used and distribution system attributes.
	Sur2	Survey of Small and Medium Drinking Water Utility Distribution Systems	Candidate utilities where to conduct research based on

			information such as: source water ammonia levels, secondary disinfectants used and distribution system attributes.
Project areas that build on this project area	RisM4	Tracking how water quality modifications and distribution system O&M impact stability and release of chemical contaminants from accumulated solids and biofilms in distribution and storage systems	Identification of candidate utilities that could be studied in RisM 4. Identification of areas of potentially increased contaminant concentrations in candidate utilities.

Relevance to the Agreement in Principle (AIP):
The completion of research in this project area is directly relevant to two AIP topic areas listed in section 4.2.a: (1) contamination due to storage facility design, operation, and maintenance and (2) nitrification issues that lead to public health effects. In addition, the analysis of sediments in storage facilities provides information for two additional AIP topic areas listed in section 4.2.a: (1) significance and control of biofilm and microbial growth and (2) accumulation and release of contaminants from distribution system scales and sediments.

Key Reference:

TCRDSAC Agreement in Principle (2008).
http://www.epa.gov/safewater/disinfection/tcr/pdfs/tcrdsac/agreementinprinciple_tcrdsac_2008-09-18.pdf

Project Area Document Code: Pres3

Project Area Title: Develop Strategies to Diagnose and Monitor Pressure Fluctuations in Water Distribution Systems

Goal: To optimize where and how to monitor for low and negative pressure events and to develop a better understanding of the frequency, magnitude and causes of low and negative pressure events.

Rationale:
Distribution systems prone to low or negative pressures are more susceptible to water quality deterioration due to backflow and intrusion. Furthermore, wide pressure fluctuations in distribution systems may increase leakage rates and main breaks, and decreasing service life. Previous research has demonstrated that certain critical locations in the distribution system may be especially prone to low or negative pressures (Fleming et al., 2006). Identification and effective monitoring of these critical locations is necessary for successful distribution system pressure management and optimization. The purpose of research in this project area is to build on previous research (Fleming et al, 2006; Friedman et al, 2004) and available pressure optimization guidance (Ongoing Water Research Foundation project 4109, "Criteria for Optimized Distribution Systems") to refine strategies to identify and monitor critical distribution system locations. Furthermore, limited data exist on the frequency and magnitude of low or negative pressure events. Pressure data loggers will be installed in these critical locations in an effort to capture the frequency and magnitude of low and negative pressure events and pressure events will be investigated to determine their possible causes. The results of this work could lead to improved pressure management, reducing the public health risks that may be associated with low and negative pressure events.

Objectives:

- Refine strategies to identify and monitor critical distribution system locations susceptible to low or negative pressure events.
- Evaluate the effectiveness of passive monitoring strategies for pressure management.
- Develop a greater understanding of the risk and mitigation factors associated with low or negative pressure events by generating field data on the cause, frequency and magnitude of these pressure events across a variety of distribution system attributes.

Suggested Approach:
This research involves full-scale field studies that will be conducted at a minimum of 25 utilities that will be selected to represent the range of conditions prevalent in distribution systems nationally. It is anticipated that some utilities with representative distribution system attributes will have optimized pressure management programs while pressure management at others could be improved.

- Participating systems will be instrumented with high-speed electronic pressure data loggers in areas vulnerable to pressure events. These areas will be identified based on existing pressure optimization guidance from ongoing Water Research Foundation Project 4109 "Criteria for Optimized Distribution Systems." Current guidance suggests

that monitored locations should be selected to be representative of areas of high and low pressure in every pressure zone of a distribution system.

- Control data will also be obtained from analogous distribution system areas expected to be relatively free from risk factors related to pressure events. The comparison of data from vulnerable and control areas will help evaluate the effectiveness of critical location determination based on existing guidance.
- Pressure monitoring will be conducted at relatively short intervals (two to three weeks). Current guidance suggestions that pressure data should be collected at least hourly for a minimum of four days. Pressure monitors are intended to be temporarily installed at utilities for short periods of time to maximize the data collection provided from data loggers used for the research.
- Metadata associated with the distribution system operations will be compiled in parallel with pressure monitoring, allowing pressure events occurring during the monitoring periods to be investigated to document potential causative factors.
- Methods for selection of critical distribution system locations and pressure monitoring at those locations should reflect the current state-of-the industry practice.

Results and Application

The results of this study are expected to:

- Enhance pressure management optimization strategies by testing the effectiveness of passive monitoring approaches.
- Generate a greater understanding of the risk factors associated with low or negative pressure events, therefore providing insights into the cost and applicability of available mitigation strategies.
- Provide improved estimations of the nationwide prevalence of low or negative pressures in distribution systems through extrapolation of the results collected from representative distribution systems.

Decision Relevance:

How does research in this project area inform evaluation of the magnitude of health risk?
Research in this project area does not directly inform the magnitude of public health risk, but the results of this work will help to further inform an estimate of the nationwide prevalence of low or negative pressure events. The research will directly provide information to the participating utilities on the magnitude of risk from low to negative pressure events in those utilities. Understanding the prevalence of these events is an intermediate step in evaluating the national public health risk associated with water quality deterioration due to backflow or intrusion.

How does research in this project area inform opportunities for risk reduction?
The goals of research in this project area are to refine strategies for pressure management. Improved pressure management should directly reduce the risk associated with backflow and intrusion. Furthermore, identification of the causes of low or negative pressure events will allow

the applicability of available mitigation strategies to be evaluated, including how and when to apply them.

What types of distribution system decisions could be supported by research in this project area?
The results of these studies will help determine what type of risk reduction response opportunities associated with low or negative pressure events are warranted on a local, regional, State or national level. The results of research in this project area are also likely to confirm or expand on existing technical guidance related to distribution system pressure management. The research will inform the magnitude of risks from low to negative pressure events in the participating utilities.

Project Area Constraints and Timing:
What factors influence the timing of research in this project area? Research in this project area could move forward without dependence on other project areas. However, more benefit may be gained if it is implemented after the Survey of Large Drinking Water Utility Distribution Systems (Sur1), the Survey of Small and Medium Drinking Water Utility Distribution Systems (Sur2) and the Survey of Distribution System Pressure Management Practices (Pres1) because these project areas will help identify nationally representative distribution system attributes that could be further understood through work on this new project area.

Surge models may help identify critical distribution system areas and can confirm the choice of critical locations based on other factors. Therefore, information developed through the Characterize Propagation of Pressure Events through Water Distribution Systems to Improve Pressure Management Approaches (Pres2) could be beneficial to this project area though the results are not critically dependent of the Pres2 project area.

What are potential constraints to the implementation of research in this project area? A large number of utilities willing to participate must be identified and convincing poorly optimized systems to participate may be difficult. Systems may have security concerns with making distribution system information available. In addition, for some systems there may be logistical issues associated with accessing parts of the distribution system that may be of interest for research in this project area. The installation of the pressure monitors, which are expensive pieces of equipment, will need to be coordinated to ensure the timeframe of data collection provides the highest value for each utility monitored.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas)**
This project area depends on. . .	None		NA
Project areas that this project area	Sur1	Survey of Large Drinking Water	Identification of nationally

builds on		Utility Distribution Systems	representative distribution system attributes
	Sur2	Survey of Small and Medium Drinking Water Utility Distribution Systems	Identification of nationally representative distribution system attributes
	Pres1	Survey of Distribution System Pressure Management	Identification of nationally representative distribution system attributes
	Pres2	Characterize Propagation of Pressure Events through Water Distribution Systems to Improve Pressure Management Approaches	Understanding of frequency and severity of pressure events
Project areas that build on this project area	None.		NA

Relevance to the Agreement in Principle:
Research in this project area will provide information relevant to needs identified in Section 4.2.b of the AIP "Conceptual Framework for Knowledge Gaps", and specifically the following items:

- Effectiveness of mitigation measures:
    - Characterize preventative measures or steps to minimize or prevent exposure.
    - Identify and implement remediation steps when contamination occurs.
    - Quantify the national significance of additional mitigation measures.

Research in this project area is highly relevant to the following Tier One priority topic areas of the AIP: intrusion and cross connection/backflow. The other Tier One priority topic areas that this project area relates to are storage and main construction/repair.

Key References:

Fleming, et al. 2006. *Susceptibility of Distribution Systems to Negative Pressure Transients.* Water Research Foundation and American Water. Denver, Colorado.

Friedman, et al. 2004. *Verification and Control of Pressure Transients and Intrusion in Distribution Systems.* Water Research Foundation. Denver, Colorado.

Ongoing Water Research Foundation Project 4109. "Criteria for Optimized Distribution Systems," particularly the information on preliminary Distribution System Optimization Self-Assessment Criteria (DOSAC).

Project Area Document Code: Pres4

Project Area Title: Toolkit for Pressure Management

Goal: To develop guidance on the use of tools and operational strategies to minimize low and negative pressure events and to optimize distribution system pressure management

Rationale:
Distribution systems prone to low or negative pressures are more susceptible to water quality deterioration due to backflow and intrusion. Minimization of low and negative pressure events can help reduce the public health risk associated with these events. Furthermore, wide pressure fluctuations in distribution systems may increase leakage rates and main breaks, decreasing service life and providing opportunities for the direct introduction of contaminants into the distribution system. The purpose of research in this project area is to build on previous research (Fleming et al, 2006; Friedman et al, 2004), currently available pressure optimization guidance (ongoing Water Research Foundation Project 4109, "Criteria for Optimized Distribution Systems) and the findings of other project areas developed and executed as part of the Research and Information Collection Partnership (RICP) to synthesize the use of available tools and operational strategies to optimize distribution system pressure management. The results of this work are intended to improve pressure management strategies, reducing the public health risks that may be associated with low and negative pressure events.

Objectives:

- To critically evaluate the effectiveness and cost of various strategies to optimize pressure management based on existing knowledge and information and on information collected through the RICP.
- Support utility decision making by compiling the findings from other work into suites of easy-to-use, practical tools to optimize distribution system pressure management.

Suggested Approach:
The key results from other project areas such as the frequency of low or negative pressures nationwide, the causes of low or negative pressures, the effectiveness of available mitigation strategies, and the use of enhanced hydraulic and surge models and passive pressure monitoring for pressure management will be critically evaluated to determine the most cost-effective and efficient approaches to optimize distribution system pressure management. These critical evaluations will support decision making on the most appropriate approach to optimize pressure management.

Results and Application:

The results of these studies are expected to:

- Integrate the results from previous project areas to provide multiple approaches to improved pressure management.
- Integrate the results from previous project areas to provide a critical evaluation of the costs associated with improved pressure management, and to help identify the most cost-effective and efficient approaches to minimizing low or negative pressures and generally optimizing distribution system pressure management.
- Support decision making on the most appropriate approach for controlling the risks associated with low and negative pressure events.

Decision Relevance:

How is research in this project area likely to inform evaluation of the magnitude of health risk?

Research in this project area does not directly inform the magnitude of public health risk. However, since it does inform the effectiveness of pressure management strategies it could help inform national risk magnitude for utilities already using those strategies.

How is research in this project area likely to inform opportunities for risk reduction?

The goals of research in this project area are to determine the most cost-effective, efficient approaches to distribution system pressure management. Therefore, the research will inform the potential decrease in public health risks through the application of the tools evaluated.

What types of distribution system decisions could be supported by research in this project area?

The results of research in this project area will expand on existing technical guidance related to distribution system pressure management. Research in this project area will also support decision making on the most appropriate approach for addressing risks from low and negative pressures locally, regionally, at the State level and nationally.

Project Area Constraints and Timing:

Research in this project area does not depend on any other project areas. However, the project area could benefit from the completion of other relevant project areas because it builds on their results. The project areas that research in this project area builds on are listed in the table below.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas)**
This project area depends on. . .	None		NA
Project areas that this	Sur2	Survey of Small and Medium	Identification of

project area builds on		Drinking Water Utility Distribution Systems	nationally representative distribution system attributes
	CC1	Best Practices to Minimize Risks Associated with Cross Connections and Backflow	Best practices for addressing cross connections
	Pres1	Survey of Distribution System Pressure Management	Identification of nationally representative distribution system attributes
	Con4	Estimation of contaminated water volumes and contaminant concentrations introduced into DSs from cross-connection contamination events based on model predictions and field and pilot-scale experiments	Total volume and contaminant concentrations introduced during pressure events
	Hea3	Response Teams to Prepare Case Studies on Adverse Public Health Effects from Distribution System Events	Real world examples from pressure related incidents
Project areas that build on this project area	None		NA

Relevance to the Agreement in Principle:
Research in this project area will provide information relevant to needs identified in Section 4.2.b of the AIP "Conceptual Framework for Knowledge Gaps", and specifically the following items:

- Effectiveness of mitigation measures:
  - Characterize preventative measures or steps to minimize or prevent exposure.
  - Identify and implement remediation steps when contamination occurs.

Research in this project area is highly relevant to the Tier One priority topic areas, namely intrusion and cross connection/backflow. The project area is also relevant to the Tier One priority topic areas, storage and main construction/repair.

Key References:

Fleming, et al. 2006. *Susceptibility of Distribution Systems to Negative Pressure Transients.* Water Research Foundation and American Water. Denver, Colorado.

Friedman, et al. 2004. *Verification and Control of Pressure Transients and Intrusion in Distribution Systems.* Water Research Foundation. Denver, Colorado.

Ongoing Water Research Foundation Project 4109. "Criteria for Optimized Distribution Systems," particularly the information on preliminary Distribution System Optimization Self-Assessment Criteria (DOSAC).

Project Area Document Code: RisM1

Project Area Title: Decision Support for Managing Potential Distribution System Public Health Risks from Potential Contamination Events and Daily Operations

Goal: To understand advantages and disadvantages of current risk management practices and to identify the best risk management strategies

Rationale:
Water utilities currently have a wide range of options to manage and mitigate distribution system risks, including those listed in industry standards, utility-specific practices, and state and local guidelines. However, in a given situation, it is not always easy for utilities to identify the best option and to fully understand the implications of the options. Because distribution systems are interconnected, risk management practices in one area can negatively impact another area. For example, flushing to increase chlorine residual may cause pressure fluctuations or contaminated sediment re-suspension. Therefore, the need exists to better understand the risk management practices used across the country, the effectiveness, and barriers to implementation of risk management strategies for different types of utilities. A decision support system that synthesizes national practices and outlines steps for utilities to follow in various situations is a critical resource for public health protection, which directly depends upon effective risk management.

Objectives:
1. Synthesize survey data from project areas Sur1, Sur2, Sur3, and Sur4 to develop a comprehensive understanding of how different risk management practices are used to address distribution system risks, differences in best management practices, factors that affect differences, and barriers to implementation.

2. Identify some of the possible unintended consequences of applying the best management practices from the survey information.

3. Identify ways to avoid situations where management practices intended to mitigate one specific problem may result in other unintended negative consequences, including political/managerial consequences (e.g., public concern over the use of chloramines).

4. Suggest monitoring programs that may be used to generate data to inform how to best address the possible problems anticipated, and to avoid unintended consequences of changed management schemes.

5. Develop decision support products on how to select the best risk management option to prevent, predict, diagnose, and/or respond to contamination under specific scenarios.

Suggested Approach:
Research in this project area should proceed in four sequential phases: Phase 1 – Compile and synthesize risk management strategies currently being implemented as observed in Sur1, Sur2,

Sur3, and Sur4, identify key differences in risk management practices, and develop lists of optimized risk management practices; Phase 2 – Evaluate information compiled in Phase 1 and identify possible unintended consequences that could result from implementation of the risk management practices; Phase 3 - Suggest monitoring programs that may be used to generate data to inform how to best address the possible problems anticipated, and to avoid unintended consequences of changed management schemes; and Phase 4 - Develop decision support products on how to select the best risk management options to prevent, predict, diagnose, and/or respond to contamination under specific scenarios

Phase 1 – The first phase is compilations of survey data from project areas Sur1, Sur2, Sur3, and Sur4 and summarization of existing industry standards (e.g., ANSI/AWWA G200-09, Ten State Standards). From the compiled data, identify key differences in risk management practices along with factors that affect differences and lessons learned regarding barriers to implementation (including political/managerial) and suggest ways current risk management practices may be optimized to better protect public health. The outcomes should be short lists of optimized risk management practices and how they can overcome implementation barriers.

Phase 2 - For the optimized risk management practices, identify and evaluate the possible negative consequences that could result. Where it is not possible to fully avoid negative consequences, use cost/benefit analyses to clearly document the situations where the given risk management practice should still be used.

Phase 3 – Evaluate existing monitoring programs that may provide early warning of possible problems that may occur when implementing risk management practices and suggest which monitoring programs may be appropriate for systems with different characteristics (e.g., size, location, etc.) to avoid unintended consequences of changed management schemes.

Phase 4 - Build decision support systems that incorporate the findings on risk management practices in a comprehensive manner. The decision support systems should be easy to use tools that systems can use to help make optimal decisions concerning their risk management practices. The systems should be developed to incorporate all relevant factors including system size, prevalence and type of vulnerabilities for which risk management strategies are lacking, ease of implementation, potential barriers to implementation, and additional criteria identified throughout the project area.

Results and Applications:
Research in this project area provides a critical link between the fundamental understanding of contamination events and the field-based application of practices for intervention and public health protection. The anticipated products are decision support systems that can be used by utilities and regulators to better select the appropriate risk management practices, allowing for quicker response to events and minimization of adverse public health outcomes. Pulling from data collected from Sur1, Sur2, Sur3, and Sur4 will allow for a comprehensive perspective on risk management within the context of real-world distribution system operation.

Decision Relevance:

How is research in this project area likely to inform evaluation of the magnitude of public health risk?
Research in this project area will not provide a direct evaluation of the magnitude of public health risk. However, as the understanding of the implications, particularly the unintended negative consequences, of different risk management options is increased, the information learned will also provide insight into the magnitude of public health risks, particularly when those risks are related to distribution system operations.

How is research in this project area likely to inform opportunities for mitigation and risk reduction?
The primary focus of research in this project area is to identify the best risk management practices so that water utilities can make solid decisions about risk mitigation and reduction. Quick and effective intervention is important in reducing the potential public health risks and for sustained public health protection.

What types of distribution system decisions could be supported by research in this project area?
A variety of important decisions regarding distribution system operation and selection of risk management practices will be directly supported by research in this project area through the creation of the decision support systems.

Project Area Constraints and Timing:
Research in this project area is dependent on the findings of Sur1, Sur2, Sur3, and Sur4. The design of the survey questions related to risk management practices within project areas Sur1, Sur2, Sur3, and Sur4 should be coordinated with research in this project area to ensure that the correct data are collected. In addition, there are other project areas that research in this project area could build on. These project areas are summarized in the table below.

Relationship to other RICP project areas	Project area document code	RICP project area document title (under consideration by DS RICP)	Information needs (what will be learned from the predecessor project areas)
This project area depends on. . .	Sur1	Survey of Large Drinking Water Utility Distribution Systems	Data on risk management practices from representative subsets of large systems
	Sur2	Survey of Small and Medium Drinking Water Utility Distribution Systems	Data on risk management practices from a representative subset of small and medium systems
	Sur3	Field Survey to Collect Information on Risk Management Practices Employed in Water Distribution Systems	Information on the effectiveness of risk management practices and information on challenges related to

			implementing certain risk management practices
	Sur4	Targeted surveys to obtain information on state and local regulations, policies, manufacturing practices and guidelines for distribution systems	Information on risk management and mitigation strategies as listed in industry standards, utility-specific practices, and state and local guidelines
Project areas that this project area builds on	Con2	Distribution system contamination associated with repair of water main leaks and breaks	Extent of contamination due to main repairs. Effectiveness of mitigation strategies
	Con3	Contaminant entry from breaches in storage facilities	Effectiveness, costs and barriers to implementation of storage related risk mitigation measures
	Con4	Estimation of contaminated water volumes and contaminant concentrations introduced into DSs from cross-connection contamination events based on model predictions and field and pilot-scale experiments	Total volume and contaminant concentrations introduced during pressure events
	RisM4	Tracking how water quality modifications and distribution system O&M impact stability and release of chemical contaminants from accumulated solids and biofilms in distribution and storage systems	Extent of the mobilization/release of contaminants as a result of various DS actions
Project areas that build on this project area	None		NA

Factors that might influence the timing of completion of research in this project area include:

- Need to supplement the data collected in Sur1, Sur2, Sur3, and Sur4 project areas. Sur1, Sur2, Sur3, and Sur4 must have adequate detail to ensure they will capture the type of information needed/anticipated.
- Coordination with state and local jurisdictions with overlapping regulations/requirements to identify core best management practices.
- Ability to conduct the necessary research to fully understand the potential negative consequences associated with each risk management practice.
- Ability to accurately identify and assess the most significant political/managerial barriers to implementation from regional and local perspectives.

Relevance to the Agreement in Principle:
Research in this project area is relevant to all seven priority topic areas and is cross-cutting in that it addresses the inter-relationships between areas.

Key References:

ANSI/AWWA (2004). Standard G200-04, Distribution Systems Operation and Management, Denver, CO.

Great Lakes Upper Mississippi River Board (2007). Ten States Standards: Recommended Standards for Water Works, Health Research Inc., Albany, NY.

TCRDSAC Agreement in Principle (2008). *http://www.epa.gov/safewater/disinfection/tcr/pdfs/tcrdsac/agreementinprinciple_tcrdsac_2008-09-18.pdf*

Project Area Document Code: RisM 2

Project Area Title: Improving Hydraulic Models for Distribution Systems

Goal(s): To enhance hydraulic modeling software so that it can more accurately simulate pressure transients, pressure management options, and the impact of hydraulics on contaminant fate and transport.

Rationale:
Hydraulic models to simulate distribution system performance are used widely throughout the industry for design and operational evaluations. These models currently rely primarily on empirical pipe flow equations developed in the early 1900s and are best suited for simulating typical operating conditions. There are limited current capabilities for modeling very short duration events like pressure transients, mixing dynamics that are non-uniform, pipe wall interactions with bulk fluid, the impact of certain pressure management devices and contaminant dispersion factors. Research in this project area provides the necessary fundamental research along with the recommendations for using existing modeling options for a broader range of contaminant events to advance the state of hydraulic modeling. Research in this project area will work to improve existing models to provide an excellent tool for design of monitoring and risk management strategies for water utilities.

Objectives:
- Build upon existing knowledge and research about cross-connections, intrusions, and pressure management to enhance existing modeling tools.

- Enable identification of new risk management strategies related to pressure and hydraulics through the application of the enhanced modeling capabilities.

Suggested Approach:
1. Compile and synthesize the findings of fundamental research related to pressure and pressure management strategies from project areas Pres1, Pres2, Sur1 and any other relevant sources. Summarize the current capabilities of hydraulic modeling software and identify data gaps to be filled, which may include data on specific types of contamination events (e.g. intrusions), field practices from water utilities, contaminant dispersion factors, ties to GIS and related case studies.
2. Create algorithms, equations, and supporting model inputs to more accurately simulate the full range of pressure events, fluid dynamics, and contaminant fate and transport that can occur in a distribution system.
3. For the new algorithms and equations, recommend field data collection procedures and develop typical ranges of input parameters based on factors that water utilities can determine from their system characteristics. Conduct sensitivity analyses on the input parameters to assist water utilities in prioritizing data collection to determine parameters.
4. Conduct full-scale field trials to validate the enhanced models.

Results and Applications:
Research in this project area provides enhanced tools that will enable water utilities to better understand pressure management vulnerabilities, contaminant dispersion through the system and mitigation options. These types of tools will play an important role in the development of risk mitigation strategies for distribution system operation. With the inclusion of field verification studies to assist in parameterization of the models developed, the results will be readily usable by water utilities.

Decision Relevance:
How is research in this project area likely to inform evaluation of the magnitude of public health risk?
Research in this project area will provide enhanced tools for individual water utilities to estimate the magnitude of pressure events and the dispersion potential for contaminants introduced during these events for their particular system configuration and operation. In conjunction with related project areas to characterize the magnitude of health risk from pressure events, the health risk can be estimated at an individual system level with these tools.

How is research in this project area likely to inform opportunities for mitigation and risk reduction?
The primary focus of research in this project area is to provide tools to assist with risk identification, mitigation and management strategies. Tools are needed to design appropriate monitoring and management systems for distribution system pressure management and overall operation.

What types of distribution system decisions could be supported by research in this project area?
Decisions related to placement of pressure sensors, adjustments of operational practices related to pumping, identification of vulnerable locations and parts of distribution systems affected, evaluation of the effectiveness of different risk management strategies and response to contamination events can all be supported by research in this project area.

Project Area Constraints and Timing:
Research in this project area will build upon the findings of Sur1, Pres1 and Pres2. The design of the survey questions related to pressure management practices within project area Pres1 should be coordinated with research in this project area to ensure that the correct data is collected.

Relationship to other RICP project areas	Project area document code	RICP project area document title (under consideration by DS RICP)	Information needs (what will be learned from the predecessor project areas or what will be used in follow-on project areas)
This project area	Sur1	Survey of Large Drinking Water	Identification of

depends on. . .		Utility Distribution Systems	nationally representative distribution system attributes
	Pres1	Survey of Distribution System Pressure Management	National data on pressure management practices
	Pres2	Characterize Propagation of Pressure Events through Water Distribution Systems to Improve Pressure Management Approaches	Understanding of frequency and severity of pressure events
Project areas that this project area builds on	None		NA
Project areas that build on this project area	Pres4	Toolkit for pressure management	Hydraulic models could be a tool to assess and improve pressure conditions in the DS

Factors that might influence the timing of completion of research in this project area include:

- Need to supplement the data collected in Sur1, Pres1 and Pres2 project areas
- Ability to conduct the necessary research to fully understand the pressure events
- Ability to field verify the findings and develop a database of parameter values that is broadly applicable
- Modeling complexity

Relevance to the Agreement in Principle:
Research in this project area is most relevant to intrusion, cross-connection, and storage, which are all Tier One priority topic areas. Because pressure is a cross-cutting issue for all distribution system reactions, research in this project area will also have relevance for biofilms, contaminant accumulation, and nitrification.

Key References:

Rossman, L.A. (2000). *EPANET 2 Users Manual*. National Risk Management Research Laboratory, Environmental Protection Agency. Cincinnati, OH.

Walski, T., Chase, D., Savic, D., Grayman, W., Beckwith, S., and Koelle, E. (2003). "Introduction to Water Distribution Modeling." Advanced Water Distribution Modeling and Management, Haestad Method Inc. 1st Ed, Waterbury, CT.

Project Area Document Code: RisM4

Project Area Title: Tracking How Water Quality Modifications and Distribution System O&M Impact Stability and Release Of Chemical Contaminants from Accumulated Solids and Biofilms in Distribution and Storage Systems

Goal: To provide data to support risk management decisions targeted at controlling health risks associated with chemical contaminants that are released from biofilms and accumulated solids in distribution and storage systems.

Rationale:
Risk management decisions require sound data to understand the influence of source water changes, treatment strategies, storage operations, and operation and maintenance (O&M) practices on accumulation and release of chemical contaminants from biofilms and sediments in distribution and storage systems. Biofilms and solids which may form and accumulate in distribution systems can contain toxic chemical substances which may be mobilized at levels of health concern when system hydraulic, physical or chemical conditions (Schock 2005, Lytle 2008, NASNRC 2006). For example, changes to source water quality or treatment can contribute trace levels of chemical contaminants which can accumulate undetected in low flow areas of system piping or storage, or can destabilize existing accumulations or biofilms. System changes which affect pressure or flow affect the likelihood that contaminants will accumulate and/or mobilize (NASNRC 2006).

Several approaches are available to address potential risks from the accumulation of solids and biofilms in distribution systems. In some cases the full effect of these approaches are not completely understood. More research is needed to measure, document and understand systems status and effects of O&M modifications. Specifically, real system data provided through research in this project area will enhance the understanding of the effects of a variety of water quality (treatment or source changes) or O&M-related risk mitigation measures on release of chemical contaminants from biofilms and solids accumulations in distribution systems and storage. Research in this project area will help utilities to better manage system O&M activities by using improved knowledge of factors affecting stability and release of chemical contaminants from solids and biofilms. Data from research in this project area will also assist in identification of obstacles to implementation of good O&M practices and the need for risk management decisions.

Objectives: Research in this project area builds on the baseline data project area (RisM3) and includes intensive field investigations before, during, and after planned modifications to water quality or distribution system O&M.

Suggested Approach:
The project area requires coordination with utility participants to:

- Identify existing or planned actions that could potentially impact the extent to which chemical contaminants are mobilized/released from biofilms or solids including:

    - Changes in source water that impact nutrients, organics, microbial community structure, pH, alkalinity, sulfur, nitrogen, chloride, and other water quality parameters
    - Changes in treatment including disinfectant type/dose/ratio, pH adjustment, corrosion control, coagulant chemicals, reverse osmosis, ion exchange, advanced oxidation
    - O&M activities such flushing, storage cycling, and mixing, storage or pipe cleaning.
    - Short-term or seasonal change to primary or secondary disinfectant (e.g. free chlorine, ozone, chloramines or chlorine dioxide)
- Determine which inorganic, organic, and microbial parameters will be used as indicators in these studies (e.g. iron, color, TSS, metals, carbonates, phosphates, silicates, pH, alkalinity, ORP, TDS, conductivity, chloride, sulfate, turbidity, chlorine residual, nitrite).
- Conduct monitoring before, during, and after planned action using sampling approaches developed in the baseline study (RisM3) to collect representative samples of system biofilms, sediment, bulk water, and associated metadata surrounding the timeframe of the action.
- Analyze samples for accumulated chemical contaminants and indicator parameters and interpret data to identify relationships between baseline conditions, conditions during and after the changes in source water or treatment, operations, maintenance procedures, or structural changes to piping or storage.

Results and Applications:
Results will provide assessments of how system or storage O&M changes impact release of chemical constituents from distribution system biofilms and solids. This will allow for a greater understanding and more effective application of O&M changes studied.

Decision relevance:
This project area will support risk management decisions concerning the most effective O&M activities for controlling health risks associated with chemical contaminants that are released from biofilms and accumulated solids in distribution and storage systems.

How does research in this project area inform the evaluation of the magnitude of public health risk?
Research in this project area will yield new data carefully collected in targeted systems and scenarios, to enhance the understanding of effects of risk management practices on stability or release of chemical contaminants from distribution system biofilms and accumulated solids.

How does research in this project area likely inform opportunities for mitigation and risk reduction?
Research in this project area will provide detailed analyses of data from actual systems making changes toward mitigation of system contamination risks. Levels of contaminants measured and patterns of release can help inform potential exposures and risk.

What types of distribution system decisions could be supported by research in this project area?

Research in this project area will enhance the understanding of the range of possible consequences of risk management actions aimed at minimization of chemical contaminant accumulation and release in sediments or biofilms. The need for risk management decisions that address monitoring within distribution systems will be further informed.

Project Area Constraints and Timing:

Project area timing influences and considerations. Research in this project area has been developed as a companion project area to Con8 "Baseline data on episodic release/mobilization of chemical contaminants from biofilms and accumulated solids in distribution and storage systems." Project area timing is expected to take 2 – 5 years to complete.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas or what will be used in follow-on project areas)**
This project area depends on. . .	Con8	Baseline data on episodic release/mobilization of chemical contaminants from biofilms and accumulated solids in distribution and storage systems	Baseline data on release/mobilization is needed to compare to the situations studied in this project area.
Project areas that this project area builds on	None		NA
Project areas that build on this project area	RisM1	Decision support for managing potential distribution systems public health risks from potential contamination events and daily operations	Extent of the mobilization/release of contaminants as a result of various DS actions

What are potential constraints to the implementation of research in this project area?

- Investigator knowledge of complex operational conditions and factors affecting accumulation potential, and access to analytical resources and qualified sampling staff.
- Access to and assimilation of findings from R&ICP project areas upon which research in this project area builds.
- Identification/selection of water quality and O&M change scenarios/systems to study.
- Sampling protocols to accommodate sample integrity and analytical processing needs and to collect water, biofilm and sediment samples under clearly described conditions.

- Willingness of utilities to participate by facilitating, conduction and/or allowing sampling, and providing metadata.

Relevance to the Agreement in Principle:
As stated in section 4.2.a, accumulation and release of chemical contaminants from distribution system scales and sediments was identified by the TCRDSAC as being one of the seven issues most relevant to protecting public health and maintaining the integrity of the distribution system.

Research in this project area helps address multiple issues described in Section 4.2 of the AIP (e.g., storage facilities, biofilms, nitrification and contaminant accumulation). Research in this project area, as part of a phased R&ICP project area approach also addresses AIP directives to conduct *focused and coordinated* research and information collection to inform potential additional risk management actions (e.g. regulations, guidance).

Key References:

Schock, M.R. 2005. Distribution Systems and Reservoirs and Reactors for Inorganic Contaminants (Chapter 6). In: *Distribution System Water Quality Challenges in the 21st Century*. AWWA. Denver, CO.

Lytle, D.A. 2008. "Additional USEPA Accumulation and Release Studies" Presented at AWWA Water Quality Technology Conference, Nov. 16-20, 2008, Cincinnati, OH.

NASNRC 2006. National Academies of Science National Research Council Report. *Drinking Water Distribution Systems: Assessing and Reducing Risks*. The National Academies Press. Washington, DC, USA.

Project Area Document Code: RisM 5

Project Area Title: Develop Next Generation Models for Informing Distribution System and Storage Water Quality Including Episodic Release/Mobilization of Chemical Contaminants from Accumulated Solids and Biofilm

Goal(s): Develop computer-based models that can be used to identify vulnerable portions of distribution systems and optimize risk management activities associated with controlling chemical contaminants that are released from biofilm and accumulated solids in distribution and storage systems.

Rationale:
Water quality models currently in use are first-generation simulations that are built upon a hydraulic model of flows and pressures. Research continues to advance regarding the fundamental mechanisms of distribution system reactions; particularly those that are least understood which include biofilm and solids accumulation reactions. There is a need to apply the findings to better simulate water quality dynamics in real distribution systems. Current capabilities to model complex, multi-phase and multi-species phenomena within distribution systems are limited. Most models rely on the use of simplified first-order reaction equations and segmented pipe wall reactions. Research in this project area applies the findings of fundamental research on accumulation of solids and biofilms to modeling frameworks and develops tools to support design of monitoring and risk management strategies for water utilities.

Objectives:

- Develop mechanistic representations and input parameters to enable water quality models to incorporate biofilm attachment and detachment, particle transport and deposition, and adsorption/desorption reactions.

- Conduct field studies to test, validate and optimize these advanced water quality models in distribution and storage systems.

- Develop modules to link these advanced water quality models to existing hydraulic models.

Suggested Approach:

- Compile and synthesize the findings of fundamental research related to biofilms and solids accumulation from project areas RisM3 and RisM4. Supplement where necessary with data from laboratory studies, water utilities, and related case studies.

- Create algorithms, equations, and supporting model input parameters to more accurately simulate the processes of biofilm attachment and detachment, particle deposition, transport and re-suspension, pipe wall reactions such as adsorption/desorption and associated water quality dynamics affecting contaminant fate and transport in a distribution system.
- For the new algorithms and equations, recommend field data collection procedures and develop typical ranges of input parameters based on factors that water utilities can determine

from their system characteristics. Conduct sensitivity analyses on the input parameters to assist water utilities in prioritizing data collection to determine parameters.

- Conduct full-scale field trials to validate the enhanced models and develop databases of input parameters that can be used in individual applications of the advanced water quality models.

Results and Applications:
Research in this project area provides enhanced tools that enable water utilities to better understand the full dynamics and inter-relationships among factors that govern water quality reactions in distribution systems. These models will provide a more realistic understanding of conditions in real distributions systems and will therefore allow utilities to have more complete information with which to make decisions. These tools that represent water quality reactions in a mechanistic manner can then be used by individual water utilities to develop risk mitigation strategies and guidance for the characteristics of their particular distribution system and its operation. With the inclusion of field verification studies to assist in parameterization of the models developed, the results will be more readily usable by water utilities.

Decision Relevance:
How is research in this project area likely to inform evaluation of the magnitude of public health risk?
Research in this project area will provide tools for water utilities to simulate a wide range of important water quality reactions for their individual system configuration and operation. In conjunction with related project areas to characterize the magnitude of health risk from different chemical contamination events, the health risk can be estimated at an individual system level with these tools. In addition, a national perspective on distribution system conditions can be informed from case studies conducted using these improved models.

How is research in this project area likely to inform opportunities for mitigation and risk reduction?
The primary focus of research in this project area is to provide tools to assist with risk identification, mitigation and management strategies at individual utilities. Additional tools are needed to design appropriate monitoring and management systems for distribution system management.

What types of distribution system decisions could be supported by research in this project area?
Decisions related to adjustments of operational practices, identification of vulnerable locations, evaluation of the effectiveness of different risk management strategies and response to contamination events can all be supported by research in this project area.

Project Area Constraints and Timing:
Research in this project area will build upon the findings of project area RisM4. While research in this project area is intended to be a later application of the findings of several project areas, the researchers conducting RisM4 should consider the modeling application desired as they design

and carry out their studies so that the findings will support this desired modeling end products as much as possible.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas)**
This project area depends on. . .	RisM4	Tracking how water quality modifications and distribution system O&M impact stability and release of chemical contaminants from accumulated solids and biofilms in distribution and storage systems	Fundamental understanding of biofilm and solids accumulation processes, field data on these processes
Project areas that this project area builds on	Con3	Contaminant entry from breaches in storage facilities	Information on storage related pathogens that may be found in distribution systems
Project areas that build on this project area	None		NA

Factors that might influence the timing of completion of research in this project area include:

- Need to supplement the data collected in RisM4
- Availability of sufficient research to fully understand the complex series of reactions affecting biofilms and solids accumulation
- Ability to field verify the findings and develop a database of parameter values that is broadly applicable

Relevance to the Agreement in Principle:
Research in this project area is most directly relevant to biofilms, contaminant accumulation, and nitrification. However, robust water quality modeling tools will have wide range of applications with relevance to most topic areas.

Key References:

Rossman, L.A. (2000). *EPANET 2 Users Manual*. National Risk Management Research Laboratory, Environmental Protection Agency. Cincinnati, OH.

Project Area Document Code: Stor2

Project Area Title: Assess Distribution Systems Characteristics that May Lead to Storage Related Problems and Potential Health Risks

Goal(s): To better understand the potential public health risks and the magnitude of the health risks related to storage contamination events.

Rationale:
Finished water storage facilities have been associated with a range of health risks that can include acute or fatal illness from exposure to waterborne pathogens, exposure to intermittent, chronic, or persistent contamination that can result from breaches in tank integrity or internal reactions including nitrification, solids accumulation and mobilization, and release of pathogens from biofilms. In addition, aesthetics concerns (taste and odor) may be linked to perturbations in storage operations and associated water quality variations. Due to large volumes of water in storage, and often limited monitoring of storage, undetected storage breaches and/or contaminant accumulations could potentially impose health risks that impact large areas of the system and associated consumer populations. Finished water storage facilities have been directly linked to reported waterborne disease outbreaks. For example, a well-documented, extensively studied, drinking water storage-related *Salmonella typhimurium* disease outbreak occurred in December 1993 in Gideon, Missouri. This outbreak resulted in more than 650 illnesses and seven deaths. It was ultimately determined that system-wide hydrant flushing distributed contaminated water from a bird-infested elevated storage tank. While high profile events such as the outbreak in Gideon have pointed to finished water storage as a potential public health risk, more work is needed to fully understand the national implications of storage on public health.

Research in this project area will examine distribution system characteristics that may contribute to contamination due to storage related events. In particular, the research will examine the potential frequency at which the convergence of three distribution system characteristics exist that must simultaneously occur for storage contamination. The three factors that must occur are the presence of a contaminant in storage or in proximity to storage, the presence of pathways or mechanisms for contaminant entry to the distribution system, and the failure of a barrier to prevent contamination. To estimate the potential public health impacts from storage related events, research in this project area will examine data on these characteristics from other RICP project areas, as well as existing data.

Objectives:

1. Collect and synthesize information that may inform the frequency and magnitude of potential health risks related to storage contamination events
2. Conduct additional targeted literature searches, if needed, that may provide information on the magnitude of potential health risks related to storage events

Suggested Approach:

This project area has two suggested approaches to obtain information needed to assess distribution system characteristics that may lead to storage problems and potential health risks

1. Collect and synthesize information from completed RICP project areas related to storage and that may inform the magnitude of potential health risks related to storage events. This includes determination of the extent to which barriers to contamination (e.g., disinfection) exist and the causes and frequencies of barrier failure.

- Presence of a pathway for contamination
- Number and types of storage facilities (Sur1)
- Populations served by storage facilities (Sur1)
- Number and size of systems with floating storage tanks (Sur1)
- Storage tank operation/configuration information (Sur1)
- Location of storage relative to supply source (Sur1)
- Volume of storage relative to piping (Sur1)
- Characterization of breaches in storage tanks (including causes, sizes, durations, and frequencies) (Con3)

- Failure of a barrier
- Storage disinfection practice information (including type, usage, frequency, dosage and application point)
-Number of pressure zones and storage facilities per pressure zone (Sur1)
-Practices for removal of solids accumulated in storage (amount and percent removed, frequency of removal) (Sur1)

- Presence of a contaminant
- Number and types of storage facilities with specific types of internal coating (Sur1)
- Frequency of pathogen occurrence in storage tanks (Con3)
- Extent to which accumulation, amplification or die-off of pathogens occurs due to storage conditions or operations (Con3)

2. Conduct additional targeted literature searches, if needed, for existing information that may provide information on the frequency and magnitude of potential health risks related to storage contamination events. These searches would fill in any gaps in the areas of knowledge that are listed in section 1, but were not able to be obtained from RICP project areas. Evaluate resulting information to estimate the frequency and magnitude of potential public health risks resulting from storage.

Results and Applications:
The results of research in this project area will inform the magnitude of potential public health risks associated with distribution system contamination from storage related events. Specifically, the research will assess information from other RICP project areas and, if needed, information from research and information collection efforts outside of the RICP to determine the frequency at which various distribution system characteristics occur which contribute to storage related contamination. The estimated occurrence of contamination from storage from these data will provide information to support local and national risk management decisions.

Decision Relevance:

How is research in this project area likely to inform evaluation of the magnitude of public health risk?

Research in this project area will evaluate information on the prevalence, frequency, and magnitude of occurrence of distribution system characteristics that lead to storage related contamination. The characteristics evaluated are those that lead to contamination of distribution systems from storage, and the resultant public health risks from the contamination. These pieces of information are essential inputs to a calculation of risk from storage related contamination.

How is research in this project area likely to inform opportunities for mitigation and risk reduction?

Increased understanding of the risk factors associated with contamination due to storage events will lead to better decisions on how to mitigate those risks.

What types of distribution system decisions could be supported by research in this project area?

Research in this project area will support future decisions regarding the need for regulation, guidance, policy statements, or other actions be taken to control potential public health risks from storage.

Project Area Constraints and Timing:

The focus of research in this project area is to analyze information generated through other research and information collection project areas, including some conducted as part of the RICP. Therefore, research in this project area cannot be completed until the information generated from those other RICP project areas is available. These project areas are listed in the table below.

Relationship to other RICP project areas	**Project area document code**	**RICP project area document title (under consideration by the DS RICP)**	**Information needs (what will be learned from the predecessor project areas or what will be used in follow-on project areas)**
This project area depends on	Sur1	Survey of Large Drinking Water Utility Distribution Systems	The presence of distribution system characteristics that contribute to contamination from storage.
	Con3	Contaminant entry from breaches in storage facilities	Extent of contamination of storage tanks.

Project areas that this project area builds on	Con8	Baseline data on episodic release/mobilization of chemical contaminants from biofilms and accumulated solids in distribution and storage systems	Frequency and extent of release of accumulated contaminants, especially from storage.
Project areas that build on this project area	Stor1	Best practices for minimizing risks associated with storage facilities	The problem identification assessment from Stor2 may be used to evaluate the effectiveness of existing best practices.
	RisM1	Decision support for managing potential distribution systems public health risks from potential contamination events and daily operations	Information on barriers to implementation of storage contamination mitigation activities.

Factors that might influence the timing of completion of research in this project area include:

- Completion of preceding RICP project areas listed in the table above
- Quality and completeness of information in the preceding project areas
- Availability of supplemental information from sources other than RICP project areas

Relevance to the Agreement in Principle:
Research in this project area is relevant to storage topic area described in the Agreement in Principle, which is a Tier One priority area. Research in this project area focuses on the analysis of information on storage to inform local and national risk management decisions by the drinking water community. Support for these risk management decisions through the RICP was a recommendation in the Agreement in Principle.

Key References:
TCRDSAC Agreement in Principle (2008).
http://www.epa.gov/safewater/disinfection/tcr/pdfs/tcrdsac/agreementinprinciple_tcrdsac_2008-09-18.pdf

EPA. (2001) Potential Contamination Due to Cross-Connections and Backflow and the Associated Health Risks. Distribution System White Paper. *www.epa.gov/safewater/disinfection/tcr/pdfs/issuepaper_tcr_crossconnection-backflow.pdf*.

Project Area Document Code: Sur2

Project Area Title: Survey of Small and Medium Drinking Water Utility Distribution Systems

Goal(s): To identify the characteristics of drinking water distribution and storage systems that serve ≤ 50,000 people.

Rationale:
Information collection in this project area will evaluate the current status of distribution system conditions and practices. It will provide data on the type, condition, and vulnerabilities of small and medium systems infrastructure; inform potential risk implications; and characterize the use of risk management strategies. This could also identify opportunities and impediments to mitigate and manage risks pertinent to systems that serve ≤ 50,000 people.

Objectives:

- Use relevant data sources to identify drinking water distribution and storage systems to target for these surveys.
- Identify key variables related to the type, quantity, and condition of distribution system infrastructure elements that may contribute to increased public health risks.
- Assess the prevalence and use of various risk management strategies on distribution systems.
- Provide baseline information on medium and small drinking water distribution and storage systems.
- Compare results to findings from large system survey(s) (see Sur1).
- Identify additional research and information collection needs.
- Identify pools of utilities with varied infrastructure, distribution system conditions, and/or water quality conditions to assist in construction of a representative sample for subsequent distribution system related research and information collection project areas.

Suggested Approach:
Information in this project area will proceed in two sequential phases: Phase 1 - Review and analyze available, and Phase 2 - Survey targeted medium and small utilities based on findings in Phase 1.

Phase 1 - The first phase is comprehensive reviews of literature and available data relevant to water distribution systems that serve small communities. Examples of data sources include the Community Water System Survey (CWSS), the 2007 Drinking Water Infrastructure Needs Survey (DWINS), and the 2006 Water Research Foundation Study – Susceptibility of Distribution Systems to Negative Pressure Transients. Implementation data from sanitary survey for drinking water regulations (e.g., Surface Water Treatment Rule, Total Coliform Rule, etc.)

may also provide information. Key variables will be identified and these data sources will be mined to compile, synthesize, and evaluate the available data.

Information collected will be analyzed to determine characteristics of drinking water distribution and storage systems, and identify information gaps.

Phase 2 - Based on the results of Phase 1, survey instruments will be developed targeted at utilities that serve populations $\leq$ 50,000. Systematic methods will be developed to collect data from representative utilities that serve medium or small-sized populations. All terms used in the surveys will be carefully and explicitly defined in order to ensure there is no confusion between the survey respondents and those using the results. Because smaller systems tend to have fewer staff members with less specialized training, it is anticipated that the desired level of detail will require considerable follow up effort on the part of the researchers. States may be able to provide assistance in these survey processes due to their familiarity with the small systems within their jurisdiction. Supplemental information could be collected through workshops or meetings with groups of utility representatives.

Results and Applications:
The survey results will be used to identify distribution system characteristics including the prevalence of specific infrastructure components, perceptions of infrastructure condition in medium and small systems, and the extent to which specific risk management practices are employed. The survey results are expected to help explain and estimate the prevalence of risk factors, and the degree of use and effectiveness of specific risk management strategies, as well as barriers to implementation.

Specifically, the data from these surveys may help in better understanding:

- Number of high-hazard cross-connections and degree of implementation of various cross-connection control program elements,
- Potential for intrusion through leaks and other orifices,
- Degree of implementation of surge control strategies,
- Types of storage facilities and the degree to which storage facilities are configured/operated for good cycling/mixing, breach avoidance, etc.
- Frequency and characteristics of planned and emergency main installations and repairs.

The results of these surveys may provide a baseline for follow-up research or information collection project areas that inform the magnitude of public health risks or the effectiveness of risk management strategies. The survey results are expected to provide baseline information on distribution system conditions, operations, and management practices. The surveys are expected to provide information on practices already in use to help utilities make informed decisions about distribution system operations, maintenance, rehabilitation, or replacement. The information can provide a reference point of current conditions from which the effectiveness of potential actions such as guidance, regulations, or policies that arise from the RICP process may be assessed.

The results of these surveys may also identify pools of utilities with varied infrastructures, distribution system conditions, and/or water quality conditions to assist in construction of representative samples for subsequent distribution system related research and information collection project areas. Screening of survey participants and associated responses will identify potential candidate utilities for follow-up field research or information collection project areas.

Decision Relevance:

How is information collection in this project area likely to inform evaluation of the magnitude of public health risk?

Information collection in this project area will provide a perspective of the quantity, type and condition of existing distribution system infrastructure. This information coupled with information from RisM1 and Hea2 is expected to inform the frequency at which various potential public health vulnerabilities are occurring throughout the nation.

How is information collection in this project area likely to inform opportunities for mitigation and risk reduction?

Information collection in this project area will provide an initial understanding of the degree to which various risk management practices are used across the nation. This information can help the water supply community (PWSs, States, EPA) determine whether and what type of policies would be prudent to reduce risks.

What types of distribution system decisions could be supported by information collection in this project area?

Information from this project area could be used to inform national policies on distribution system issues. Possible policy outcomes that could be supported may include guidance, regulation, or other options.

Project Area Constraints and Timing:

The completion of information collection in this project area may influence several other project areas. In most cases, the baseline data from Phase 1 will improve design of follow-on project areas or be used to identify appropriate subpopulations for in-depth sampling, field work, or modeling. See the table below for information on the project areas that build on Sur2.

Relationship to other RICP projects	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas or what will be used in follow-on project areas)**
This project area depends on. . .	Sur1	Survey of large drinking water utility distribution systems	Lessons learned from Sur1 will help determine the extent of Sur2.

Project areas that build on this project area	Con4	Estimation of contaminated water volumes and contaminant concentrations introduced into DSs from cross-connection contamination events based on model predictions and field and pilot-scale experiments	Survey results may provide insightful information that may aid in refining the design of Con4.
	Con6	Understanding the growth potential within distribution systems of indigenous bacterial pathogens (*Legionella* and *Mycobacterium*)	Survey results may aid in refining the project area design of Con6.
	Pres3	Develop strategies to diagnose and monitor pressure fluctuations in water distribution systems	Survey results may provide insightful information that may aid in refining Pres3.
	RisM1	Decision support for managing potential distribution systems public health risks from potential contamination events and daily operations	Survey results could be used to refine the menu of risk management strategies.
	Sur3	Field survey to collect information on risk management practices employed in water distribution systems	Baseline conditions and inventory; identify pools of utilities to select for Sur3. Survey results could perhaps reduce or eliminate elements of Sur3.

Factors that might influence the timing of completion of this project area include:

- Familiarity of investigators with distribution system concepts and survey design and data analyses
- Complexity and scope of survey design and survey data analyses
- Survey response/data quality review
- Ability of surveyors to solicit or require sufficient responses
- Willingness of recipients to participate
    - Issues associated with providing potentially sensitive information (data confidentiality)
    - Lack of information in utility files

    - Lack of utility resources (personnel-time, computer expertise) to complete survey responses
- Participation by enough (and sufficiently diverse) recipients to provide meaningful results
- Communication/approvals for survey data use in follow-on project areas

Relevance to the Agreement in Principle:
The AIP specifically recommends in section 4.1.e that the RICP explore several mechanisms for collecting and analyzing data, including surveys implemented through research project areas or by interested organizations such as EPA, AWWA, AMWA, NRWA, WaterRF, and others. The completion of this project area is relevant to all seven priority topic areas.

Key Reference:

TCRDSAC Agreement in Principle (2008).
http://www.epa.gov/safewater/disinfection/tcr/pdfs/tcrdsac/agreementinprinciple_tcrdsac_2008-09-18.pdf

Project Area Document Code: Sur3

Project Area Title: Field Survey to Collect Information on Risk Management Practices Employed in Water Distribution Systems

Goal(s): To develop a detailed understanding of the types of risk management practices (that are used to control distribution systems against contamination events and maintain water quality), the extent of their use, their perceived effectiveness, and challenges related to implementation.

Rationale:
Conducting field surveys of representative subsets of Sur1 (Survey of large drinking water utility distribution systems) and Sur2 (Survey of small and medium drinking water utility distribution systems) participants provides an opportunity to systematically collect more detailed information with regard to use and effectiveness of risk management practices without imposing undue costs on the larger population of systems.

These surveys build on Sur1 and Sur2. Certain types of information being requested in Sur1 and Sur2 may not be readily available from all participating systems. Sur3 will try to collect such information. Additionally, there are information collection needs that cannot necessarily be fully captured using a paper or electronic survey formats.

Objectives:

- Collect information on risk management practices that are used to control pressure, intrusion, cross-connections and backflow, main repair contamination, storage facility contamination, excess biofilm formation and release, nitrification, and solids accumulation.
- Collect information on the effectiveness of risk management practices and identify challenges in implementing them.

Suggested Approach:
This project area will proceed in two sequential phases: Phase 1 - Review results of Sur1 and Sur2 to assess additional information collection data gaps identified in Sur 1 and Sur2, and to identify potential survey participants for these surveys; and Phase 2 – Develop and implement follow-up field surveys of subsets of Sur1 and Sur2 participants.

Phase 1 – The first phase of this project area is detailed reviews of the Sur 1 and Sur 2 results to assess the degree to which those project area objectives were fulfilled, and areas in which more in-depth data collection, field observations, interviews, etc. are needed to more fully and accurately estimate the prevalence of risk factors, the degree of use of specific risk management strategies, as well as barriers to implementation. Systematic processes will be developed to select respondents from Sur1 and Sur2 for participation in Sur3. Factors such as system size, type, location (state), level of detail and consistency of responses, perceived willingness to participate and share information, etc. will be considered to maintain representativeness. The

survey developers will need to define categories of participation (e.g., representing which physical, chemical, or high/low risk conditions) and appropriate justifications. While participation will need to be broad enough and comprehensive enough to allow for extrapolation to other systems, the purpose of Sur3 is to provide more detailed information from a smaller number of "representative" systems.

Phase 2 – Once the information gaps have been assessed and participant pools have been identified, Sur3 will be developed and implemented. Sur3 will likely involve a combination of targeted phone interviews, field investigations, requests for additional information collection and evaluation, modeling, and follow-up. Utilities could be asked to identify critical distribution system challenges and then queried on methods used to prevent, diagnose, predict, respond, and manage water quality problems generated within their distribution systems. They could also be asked for information on the types of monitoring that are used routinely, how they document and respond to distribution system issues, and how they gauge the effectiveness of risk management strategies. A key issue for consideration as Sur3 is being carried out is to determine how, whether, and to what degree the results can be extrapolated nationally.

Other information that may be collected includes the following:

- Level of training provided to staff,
- Asset management,
- Assessment of costs of risk mitigation and prevention, and
- Perceived barriers to implementation of various risk management strategies (cost, public relations, conflicting requirements, lack of authority, political barriers, etc).

Results and Applications:
The survey results will be used to develop a more detailed perspective on the use, effectiveness, and barriers to implementation of risk management practices relevant to managing distribution system water quality. Sur1 and Sur2 results will be used to develop identify distribution system characteristics including the prevalence of specific infrastructure components, perceptions of infrastructure condition in large systems, and the extent to which specific risk management practices are employed. Specific information gaps that may be addressed by the Sur3 participants include but are not limited to the following:

- Additional field surveys (including site visits by surveyors) and review of existing cross-connection surveys to better estimate the number of cross connections per service connection and the number of cross-connections with health hazards
- Frequency of valve operations by valve type and crew type (e.g., utility vs. fire department, etc.)
- Frequency of hydrant operations and type of operations (e.g., fire flow testing, flushing, fire department practice, maintenance, etc.)
- Distance (horizontal/vertical) between sewer mains and drinking water mains
- Effect of increasing water pressure on current infrastructure condition in low pressure area
- Ability to maintain sanitary conditions during main installations and repairs

- Use and effectiveness of existing risk management strategies and intervention options
- Economic impacts of implementing various risk management options
- Impacts of storage facility set points on mixing and turnover
- Impacts of storage facility inlet/outlet configurations on mixing and turnover

Decision Relevance:

How is information collection in this project area likely to inform evaluation of the magnitude of public health risk?

Information collection in this project area will support development of a more in-depth understanding of the occurrence and magnitude of potential health risks for the systems surveyed in Sur3 by identifying aspects of systems' risk management practices and the prevalence of risk factors across the nation.

How is information collection in this project area likely to inform opportunities for mitigation and risk reduction?

Information collection in this project area will provide a substantially greater understanding of the degree to which various risk management practices are used across the nation. It will also help to probe more deeply into understanding barriers to implementation of risk management strategies that are already known to be effective, but perhaps under-utilized. This information can help the drinking water community (PWSs, States, EPA) determine whether and what type of actions might be appropriate for reducing potential risks.

What types of distribution system decisions could be supported by information collection in this project area?

Information collection in this project area would inform local, regional, State and national policy on distribution system issues. Possible policy outcomes that could be supported may include the need for technical assistance, guidance, or regulation, or other options.

Project Area Constraints and Timing:

Ideally, this information collection will build on the findings Sur 2, and therefore will occur sequentially with Sur2. In most cases, the baseline data obtained from Sur 2 will improve the design of Sur 3, and can be used to identify a subset of representative systems for in-depth sampling, field work, or modeling. However, there may be good opportunities to recruit utilities prior to the completion of Sur 2.

Relationship to other RICP projects	**Project area document code**	**RICP project area document title (under consideration by DS RICP)**	**Information needs (what will be learned from the predecessor project areas or what will be used in follow-on project areas)**
This project area	No other project areas.		NA

depends on. . .			
Project areas that this project area builds on	Sur2	Survey of small and medium drinking water utility distribution systems	Baseline data, identification of additional information gaps, pools of potential participants.
Project areas that build on this project area	RisM1	Decision support for managing potential distribution systems public health risks from potential contamination events and daily operations	Survey results could be used to refine the menu of risk management strategies.

Factors that might influence the timing of completion of this project area include:

- Complexity and scope of survey design and survey data analyses
- Survey response/data quality reviews
- Technical capability of respondents
- Ability of surveyors to solicit "representative" participants so that the ability to extrapolate can be determined
- Willingness of recipients to participate
    - Issues associated with providing potentially sensitive information (data confidentiality)
    - Lack of utility resources (personnel-time, expertise) to complete survey responses
- Communication/approvals for survey data use

Relevance to the Agreement in Principle:
The AIP specifically recommends in section 4.1.e that the RICP explore several mechanisms for collecting and analyzing data, including surveys implemented through research project areas or by interested organizations such as EPA, AWWA, AMWA, NRWA, WaterRF, and others. The completion of this project area is relevant to all seven priority topic areas, and will use multiple data collection mechanisms including phone interviews, field inspections and surveys, use of hydraulic models, more detailed review of databases, plus others.

Key References:

TCRDSAC Agreement in Principle (2008).
http://www.epa.gov/safewater/disinfection/tcr/pdfs/tcrdsac/agreementinprinciple_tcrdsac_2008-09-18.pdf

Appendix D – Scoring System Description and Initial Results

How the Scoring System Works

The partners completed the scoring by assessing the ability of the project area documents to fill the needs identified, and by applying the appropriate weighting to the Tier One and Tier Two issues, as recommended by the SC. For each of the seven topics areas each project area document received two scores, one for magnitude of risk and one for mitigation of risk. Therefore each project area document received a total of 14 scores, which were then summed to obtain the final score. Scores of 0, 5 or 10 were used. The standards used to assign these scores were:

10 – The project area is critical to informing risk magnitude/risk mitigation for this framework topic.

5 – This project area provides some information relevant to risk magnitude/risk mitigation but is not considered to be critical for this framework topic.

0 – This project area provides no information relevant to risk magnitude/risk mitigation for this framework topic.

Once the partners completed the scoring, they provided an initial ranking for each project area based on the sum of the weighted scores. The partners then provided this initial ranking to the SC for review and discussion.

Initial Scoring Results

The following are the results of the scoring and ranking process executed by the partners. The partners presented this information to the SC for their final review.

Project Area Document Code	Score
Sur1	155
Sur2	155
Sur3	120
Pres1	120
Pres2	120
Hea1	120
RisM1	110
Hea2	95
Sur4	90

Project Area Document Code	Score
Hea3	55
Con7	55
RisM5	50
Con3	50
Con4	50
Mon1	45
CC*	40
Stor*	40
Hea4	25

Pres3	90		RisM3	25
Con1	65		RisM4	25
Con2	65		Con6	25
Pres4	60		Con5	20
RisM2	60			

* At the time of the scoring, only the CC1 and Stor1 project area documents had been completed, so the scores here reflect the partner scores of those projects. Subsequently, the partners included two additional projects, CC2 and Stor2, that served to compliment the CC1 and Stor1 projects. While CC2 and Stor2 did not undergo the formal scoring process described above, they would have likely received similar scores to CC1 and Stor1 based on the scoring criteria used.

Appendix E – First Generation Project Area Documents

Project Area Document Code	Project Area Title
CC1	Best Practices to Minimize Risks Associated with Cross Connections and Backflow
Con3	Contaminant Entry from Breaches in Storage Facilities
Hea1	Quantitative Microbial Risk Assessment (QMRA) to Evaluate Exposure to Pathogens through Drinking Water Distribution Systems
Hea2	Epidemiological Studies of Health Effects Associated with Low or Negative Pressure Events in Distribution Systems
Hea3	Response Teams to Prepare Case Studies on Adverse Public Health Effects from Distribution System Events
Pres2	Characterize Propagation of Pressure Events through Water Distribution Systems to Improve Pressure Management Approaches
Stor1	Best Practices for Minimizing Risks Associated with Storage Facilities
Sur1	Survey of Large Drinking Water Utility Distribution Systems