REDUCING CONTAMINATION RISKS FROM PIPELINE REPAIR AND RENEWAL WORKS

Natalie Crawford [1], Dr Annalisa Contos [1], Claire McInnes [2]
1. Atom Consulting, NSW, Australia
2. Water Research Australia, South Australia, Australia

ABSTRACT

This paper documents the findings from the Water Research Australia project 'Assurance measures to manage potential contamination risks from pipeline repair or renewal (Stage 1)'.

This research will help to identify and assess the extent of microbiological contamination risk from pipeline renewal and repair works and identify measures to manage these risks.

INTRODUCTION

Renewing and repairing water mains, valves and hydrants regularly occurs in water distribution networks. Renewals and repairs includes all planned and unplanned interruptions (including bursts) to the drinking water supply; for the context of this project it excludes installation of new supply mains.

There is evidence in the literature of increased microbial risk associated with mains bursts and repairs, although there is little Australian data. Applicability of some of this research may not be directly relevant to Australian conditions and control measures (e.g. combined sewers, water and sewer mains laid in the same trench).

Water utilities across Australia currently have access to limited information regarding the contamination risks associated with renewal and repair work on water mains. Water Research Australia identified an industry need to gain a better local understanding of the contamination risk of renewals and repairs, including possible impacts from current management practices.

The project aims to:

- Compile the range and nature of risks to consumers from contamination events associated with supply interruptions, and water main repairs and renewals, in Australia.
- Identify scenarios where the risks to consumers from contamination associated with supply interruptions, and water main repairs and renewals, are material.
- Provide guidance to water utilities on control strategies to minimise the likelihood of contamination, and how to monitor the effectiveness of these control strategies, in order to ensure that consumers are not exposed to unacceptable levels of risk.

METHODOLOGY

Project methodology was developed to gain an understanding of the risk factors that contribute to contamination and to identify and assess current management practices for pipe repair and renewal works.

Range and nature of contamination risk

To identify the range and nature of risks to consumers a literature review and industry engagement session were undertaken. The industry stakeholder engagement workshop was held in Melbourne, Australia in July 2016, with representatives from eleven water utilities in attendance from across four states (NSW, Victoria, Tasmania and South Australia).

Extent of Australian current practices for pipe repair and renewal works

To identify current management practices for pipe repair and renewal work, Australian water utilities were surveyed and case studies developed.

An online survey was distributed to Australian water utilities in November 2016. The survey asked utilities questions on the frequency and contributing factors for pipe break events, as well questions on the extent of their pipe repair and renewal work procedures and practices.

A number of case studies were developed for utilities across Australia. Case studies were developed to illustrate a number of areas, including:

- Governance
- Compliance
- Hygiene
- Operator involvement
- Disinfection

Case studies were developed in conjunction with the utility, either through a site visit, teleconference or though review of relevant documentation.

A de-identified comparative assessment of industry control strategy approaches identified gaps in current practices and pathways for improvement and inclusion of a control framework.

Control framework
Utilising the results of the literature review, information gathered from the industry survey and case studies, a draft framework of control strategies has been developed to minimise the risk of contamination in pipe repair and renewal works.

Risk evaluation
Framework elements were assessed to determine the effectiveness of different elements through the following methodology:

- Development of risk criteria
- Desktop risk assessment evaluating barrier effectiveness
- Determine the preferred elements to form the draft control strategy framework

The methodology for evaluating draft framework components was undertaken using risk management processes of ISO 31000:2009 and in line with the Australian Drinking Water Guidelines (NHMRC, NRMMC 2011) risk assessment process.

Risk analysis was undertaken using bow-tie methodology. Bow-ties provides a clear graphical illustration to demonstrate that hazards are being controlled, and that there is a direct link between the controls and elements of the management system. Controls to the hazardous event and the consequence can be depicted on the bow-tie diagram and colour coded for effectiveness.

To evaluate the effectiveness the controls, each control was assessed for viability and impact and a ranking of control effectiveness applied.

Framework components were assessed for a number of scenarios, including:

- Pipe repair under pressure
- Pipe repair loss of pressure

Comparison of industry approaches
A desktop comparative assessment of industry control strategy approaches against the proposed draft control strategy framework will be undertaken. A second national industry engagement session will be held in February 2017 to discuss the results of the framework.

DISCUSSION AND RESULT ANALYSIS

Range and nature of the contamination risk
The literature review compiled known information on contamination risks and control framework measures. Factors identified from the literature and the stakeholder engagement workshop that can contribute to the level of contamination risk experience by consumers are shown in Table 1.

The risk of pathogens entering the distribution system may occur during depressurisation events or pipe repairs. A number of studies have attempted to quantify the contamination risk from such events, however there is limited data and no studies specific to Australia.

Nygard *et. al* (2007) looked at gastrointestinal illness following breaks and maintenance work in the water distribution systems in Norway for seven water works. The results from this study indicated an increased risk of gastrointestinal illness among water recipients, with 12.7% of exposed and 8% of non-exposed households reporting gastrointestinal illness. The results also indicated that flushing and use of chlorination indicated a decreased risk. It should be noted that 80% of the episodes from this study had water and sewer pipes in the same trench. While this practice is not common in Australia, it can occur, including at pipe cross-over location points and is a risk that still needs to be considered. Study limitations included reliance on consumer recall and that reporting of symptoms from pathogens with longer incubation periods may not have been picked up.

A study undertaken by Ryan *et. a*l (2008) used data mining techniques and internet search volume to assess the relationship between pipe breaks and symptoms of gastrointestinal illness for two U.S. cities in the mid-Atlantic area. Pipe breaks were found to positively correlate with internet search volume in both cities, indicating an increased risk of gastrointestinal illness from distribution system disturbances.

A project undertaken by WaterRF (2014) on *Effective Microbial Control Strategies for Main Breaks and Depressurization* assessed the level of microbial risk through risk modelling and laboratory studies. A quantitative microbial analysis (QMRA) built on work undertaken by Yang *et. al* (2011), considering the risk of pathogens infection to consumers from pipe breaks. The study used the worst-case scenario of soil contaminated with sewage. The risk modelling included reductions from raw pathogen concentration, through dilution (3 log reduction), flushing (2-3 log removal) and disinfection (4-5 log for virus and bacteria). The study found that infection from viruses presented the biggest pathogenic risk to consumers and concluded that dilution, flushing and disinfection are all need to reduce infection risks to US EPA acceptable risk levels (1 x 10^{-4}).

Survey and case study
A total of 21 different sized and types of utilities from across Australia responded to the survey, including from Western Australia, Victoria, Tasmania, South Australia, Queensland and New South Wales (Figure 1). Figure 2 shows the breakdown of water supply system types

(e.g. municipal, rural or mixed) and Figure 3 shows the distribution of utility sizes.

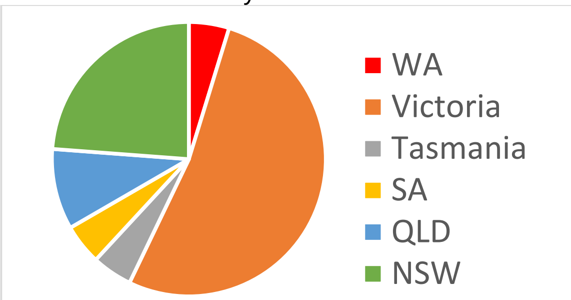

Figure 1. Breakdown of utility survey responses

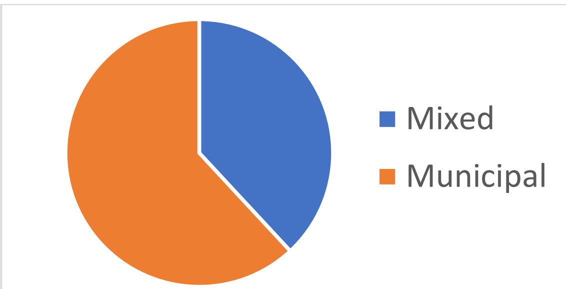

Figure 2. Types of supply systems

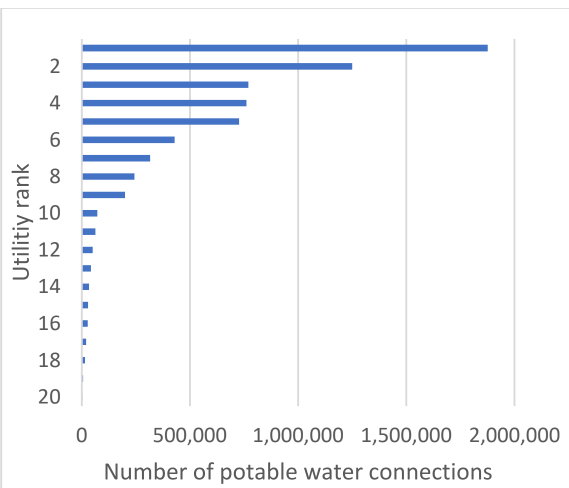

Figure 3. Utilities ranked by potable water connections

The frequency of pipe breaks between utilities varied from 3 to 56 per 100 km/year. No correlation was identified within the data between the frequency of pipe breaks and number of potable water connections, length of potable water main, pipe age, pipe material, environmental or any other contributing factor. Utilities reported that a combination of factors contributed to pipe break frequency.

All utilities that responded to the survey reported they had either informal or documented pipe repair renewal works procedures in place, with 85% documented.

A summary of pipe break contributing factors, identified from the literature review, stakeholder workshop, utility survey and case studies is shown in Table 2.

A summary of the percentage of control framework measures being implemented by surveyed utilities is shown in Figure 4. The most common framework areas include:

- Flushing
- Excavation to below break
- Controlled shutdown
- Repair under pressure where able
- Mains isolation

Site evaluation

90% of surveyed utilities undertake either dynamic risk assessments, prior identification of risks, HAZOPS, SWMS, pre-work checklists or risk assessments that can include environmental / contamination risks. A common practice for any works site is the undertaking of a pre-start risk assessment. While the majority of utilities currently focus on WHS and environmental issues, it would be feasible for these risk assessments to be expanded to consider health risks to consumers from contamination of the water supply. A checklist of potential hazards has been developed for such use.

Key factors identified for effective site evaluation assessments include:

- Training and awareness of staff in potential contamination risks
- Documented dynamic risk assessment process
- Documentation of control measures in place for levels of risk identified on site
- Identified escalation and reporting process

Flushing

Flushing is a common practice used by all surveyed utilities. Flushing was identified within the literature review as a key component in reducing the risk of water supply contamination. Generally, utilities flush to clear based on a visual examination of the water. An area of improvement is in the definition in the criteria at which flushing will provide an effective reduction in the contamination risk.

Hygienic work practices

Prevention of contamination through the use of hygienic work practices is implemented to varying degrees across the surveyed utilities and case studies. The case studies provided good example of implementation of hygienic practices, with one utility developing a water hygiene framework that aims to prevent contamination by ensuring that all activities carried out in the distribution system are carried out in a hygienic matter.

Provision of hygienic equipment or kits (e.g. mats, chlorine solution, hand sanitizers) is key in ensuring that good hygiene practices can be easily implemented.

Disinfection

Disinfection, either from chlorine dosing or ozonation, is used by a number of water utilities primarily only for high risk contamination breaks. Utilities reported constraints to implementation including time off-line needed to achieve C.t and the need for competent and trained staff to undertake this type of work.

Successful use of ozonation was undertaken as described in one of the case studies, when disinfection by ozone was used for a high-risk repair events following contamination by sewerage from damage to an adjacent sewer pipe. Flushing and ozonation were undertaken to manage the contamination risk, with monitoring of ozone disinfection verified through adequate ORP and turbidity.

Monitoring

The majority of utilities undertake some form of monitoring after a pipe break repair, either for all repairs or dependent on the level of risk. The most common type of monitoring was for free chlorine residuals and turbidity.

It is important, when monitoring samples are taken, that there are definable limits and clear actions that should be undertaken if limits are exceeded. Constraints for not undertaking sampling include inadequate operators training and competence in taking samples, system awareness, sampling equipment and meter availability.

Governance

Over half of utilities surveyed use sub-contractors to undertake pipe repair and renewal works. Governance and compliance are key in assuring contamination risks are being adequately managed. Governance through a collaborative relationship between utility and contractor was shown to encourage innovation and best practice. In one of the case studies an outcome based quality requirement in the contract (to provide safe water that meets the requirements of the Australian Drinking Water Guidelines) was used to manage quality expectations.

Compliance audits can also be used to provide assurance that contamination risks are being appropriately managed. Data collected as part of the audit process provides measurable indices that can be used to track compliance and measure areas of improvement or needs for further training. Compliance audits can also be a good mechanism for ongoing awareness training of crews.

Training

The case studies highlighted the importance of training and operator competence in the implementation of successful pipe repair and renewal work procedures.

Key factors to success were identified as:

- Inclusion of staff in the development of procedures
- Importance of trialling procedures, reviewing and continual improvement.
- Importance of operator input and buy-in
- Awareness training to ensure need for procedure implementation is understood

Research and development activities

A number of utilities are implementing preventative pressure reduction programs either to reduce the frequency of pipe breaks or to control when pipe breaks occur. Constraints to implementation include geography and zone size. Analysis of pipe break data allowed for ongoing improvements to be identified and managed.

CONCLUSION

A number of studies have attempted to quantify the increased microbial risk associated with mains bursts and repairs, however there is limited data and no studies specific to Australia.

A preventative risk management approach in line with Australian Drinking Water Guidelines (NHMRC, NRMMC, 2011) has been developed and evaluated against Australian industry needs. The case studies and literature review highlighted the importance of supporting framework areas in the development of a control framework. A summary diagram of the draft control framework is shown Figure 5 and draft control elements in Table 3, key elements include:

- Onsite components (e.g. dynamic risk assessment, repair under pressure, flushing, hygienic work practices etc.)
- Governance (e.g. contractual arrangement and compliance auditing)
- Supporting process (e.g. training, documentation, research and development)

Industry engagement on the proposed framework is ongoing. A second industry engagement session will be held in late February 2017

ACKNOWLEDGMENT

The authors thank the Water Research Australia, Coliban Water, Goulburn Valley Water, Sydney Water, SouthEast Water, SA Water, TasWater, UnityWater, Water Corporation, Western Water, WIOA, Yarra Valley Water for their input into the project.

<u>REFERENCES</u>

AS/NZS ISO, 2009, AS/NZS ISO 31000*: Risk management - Principles and guidelines*

ISO/IEC, 2009, ISO/IEC 31010 *Management – Risk Assessment Techniques*, Geneva, Switzerland

NHMRC, NRMMC, 2011, *Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy*. Version 2 Updated December 2013, National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra.

American Water Works Association (AWWA), 2015, *AWWA Standard Disinfecting Water Mains*, ANSI/AWWA C651-14. Effective date 1 February 2015.

Baker E., 2014, *Public Health depends on proper water main repair and disinfection"* Baker, Water Works Nov 2014; 7-9

Ercumen A., Gruber j. and Colford H., 2014 "*Water Distribution System Deficiencies and Gastrointestinal Illness: A Systematic Review and Meta-Analysis*" Environmental Health Perspectives 2014.

Friedman, Melinda J & AWWA Research Foundation & Keuringsinstituut voor Waterleidingartikelen (Netherlands) 2003, *Establishing site-specific flushing velocities*, AWWA Research Foundation, Denver, COA

Huang L., Wang Y., Liu C., Trong-Neng W., Chang-Hung C., Fung-Chang S., 2011, *Water outage increases the risk of gastroenteritis and eyes and skin diseases.* BMC Public Health. 2011; 11: 726.

Malm A., Axelsson G., Barregard L., Ljungqvist J., Forsberg B., Bergstedt O. and Pettersson T., 2013, *The association of drinking water treatment and distribution network disturbances with Health Call Centre contacts for gastrointestinal illness symptoms*, IWA Water Research 47 (2013)

Shortridge J. and Guikema S., 2014, *Public health and pipe breaks in water distribution systems: Analysis with internet search volume as a proxy*, IWA Water Research 53 (2014) 26-34

Nygaard K., Wahl E., Krogh T., Tveit O., Bohleng E., Tverdeal A, and Aavitsland P., 2007, *"Breaks and maintenance work in the water distribution systems and gastrointestinal illness: a cohort study"* International Journal of Epidemiology 2007 p873-880

Ryan G, Mathes P., Haylock G., and Jayaratne A., Wu J., Noui-Mehid N., Grainger C. and Nguyen B.., 2008, Research Report 33, Particles in Water Distribution Systems, The Cooperative Research Centre for Water Quality and Treatment, CRC WQT Report 33

Tescke K, Bellack N, Shen H et al., 2010, *Water and sewage systems, socio-demographics, and duration of residence associated with endemic intestinal infectious diseases: A cohort study,* BMC Public Health. 2010; 10: 767.

Tinker SC, Moe CL, Klein M et al. *Drinking water residence time in distribution networks and emergency department visits for gastrointestinal illness in Metro Atlanta, Georgia*. J Water Health 2009; 332-344.

United States Environmental Protection Agency (US EPA), 2002, *New or Repaired Water Mains*, Prepared by AWWA for the United States Environmental Protection Agency (US EPA)
Water Services Association of Australia (WSAA), 2011, *Water Supply Code of Australia*, Version 3.1, WSA 03-2011

WaterRF, 2014, *Effective Microbial Control Strategies for Main Breaks and Depressurization*, Report #4307a, Water Research Foundation, Effective date February 2015.

Water UK, 2015, *Principles of water supply Hygiene and technical guidance note,* Water UK, Londo*n.*
WaterRF, 2014, *Good Practices for Preventing Microbial*

World Health Organization (WHO), 2004, *Contamination of Water Mains – Field pocket guide* , *Safe piped water – Managing Microbial Water Quality in Piped Distribution Systems,* Chapter 5 by Richard A and David H

Yang J., LeChevallier M.W., Teunis P.F., Xu M., 2011, *Managing risks from virus intrusion into water distribution systems due to pressure transients,* J Water Health. 2011 Jun;9(2):291-305.

Table 1 Contamination events high risk factors

Factor	**Details**
Areas of known contamination	Contaminated soil e.g. petrol stations
	Septic tanks e.g. leaching
	Water and sewer pipes in parallel in same trench
	Water and sewer pipe cross over (separation distances)
	Adjacent recycled water systems
	Adjacent raw water systems
	Adjacent storm water systems
Biofilm	Disturbing of the biofilm during repair works
Cleaning methodology	Greater contamination risk reported from cleaning pipes by swabbing
Contaminated equipment	Contaminants entering the system from repair equipment or materials
Duration of repair/water shutoff	Longer duration of repair increases period of exposure
Environmental conditions	Wetland areas
	Rain events
	Amount of water lost and mud around the site
Increased flow	Higher volumes of contaminated water entering the system
Loss of pressure	Allows contaminants to enter the system
Operational staff	Insufficient training or competency
	Insufficient knowledge
	Human errors
	Common water and sewer repair crews, introducing contaminants on their clothing
Pipe size	Larger pipes greater population served
Pipe materials	Age, condition, quality and type of material
System failure during repair	Contaminated water entering the system
Type of system	Open systems have a higher risk to contamination than closed systems

Table 2 Pipe break contributing factors

Factor	Details
Environmental conditions	Soil type e.g. clay soils drying out, acid sulphate soils
	Ground movement (saturated or drying out)
	Climatic conditions e.g. high/low temperatures, drought/flood
	Seasonal variations e.g. summer, seasonally between years
	Geography
Pipe failure	Pipe age e.g. asbestos cement & ferrous mains where a trench environment is wet
	Pipe material
	Condition of fittings
	Installation practices
	Pipe layout
Physical interactions	Excavation works e.g. direct hit
	Maintenance works
	Tree roots
System pressure	High pressure

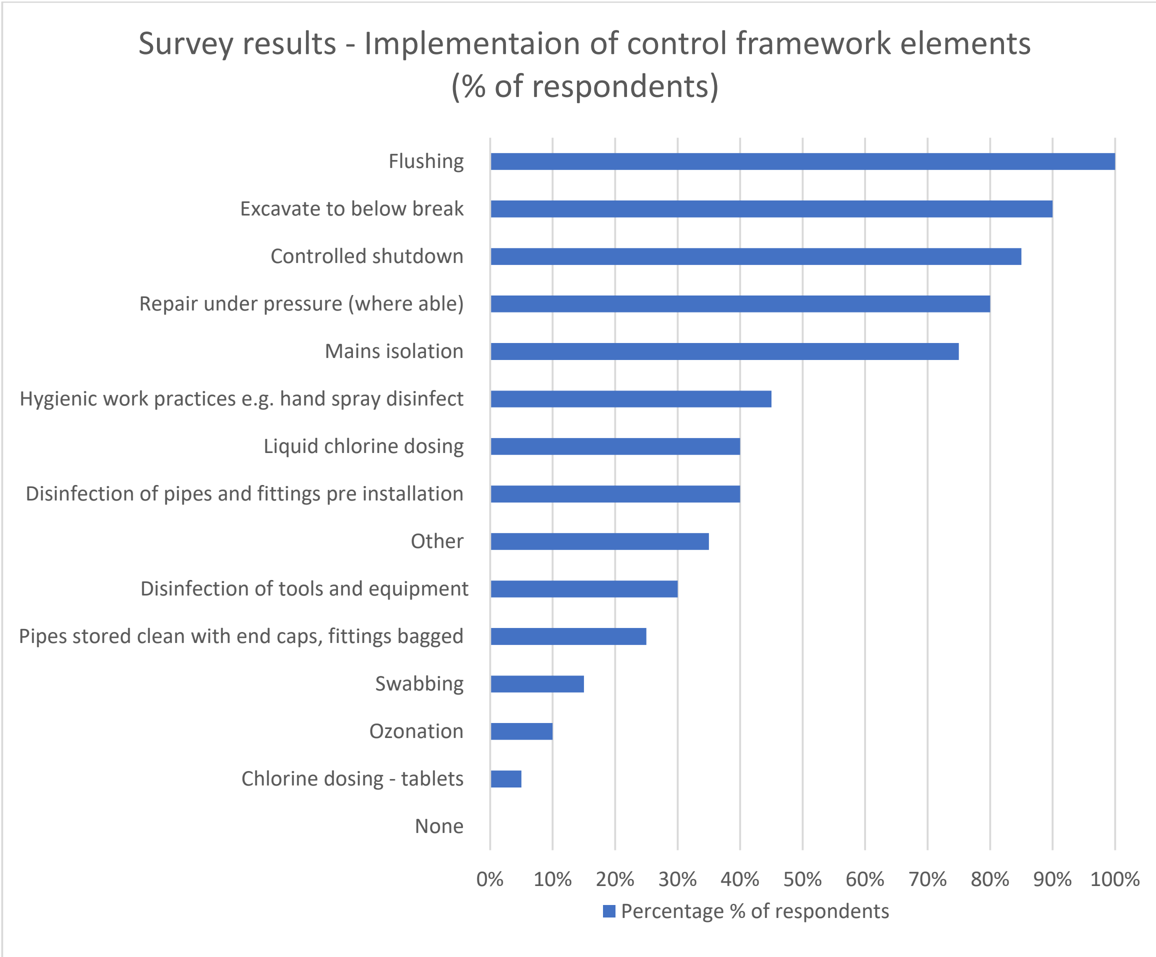

Figure 4. Control framework elements being implemented by survey respondents

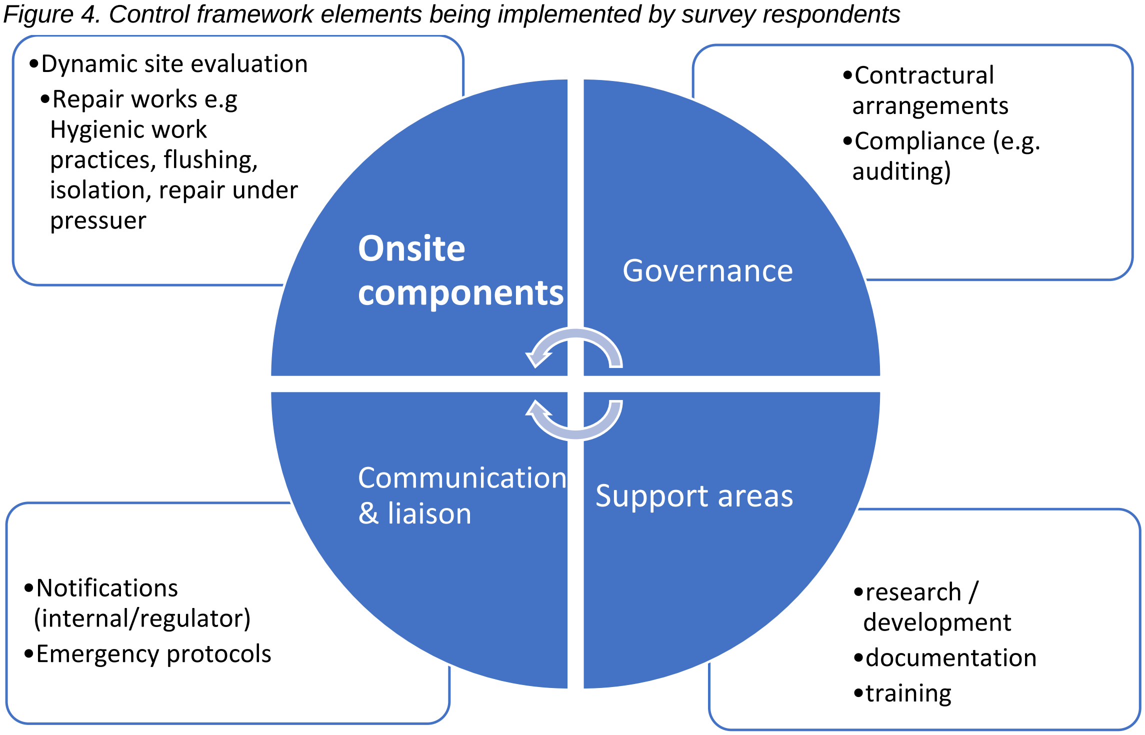

Figure 5. Draft control framework

Table 3 Control framework elements

Draft framework areas	**Component**	**Details**
Site evaluation	Dynamic on site risk assessment to identify appropriate repair work components	Site specific evaluation of risk and severity
		Identification of areas of known contamination
		Contamination pre-start hazard assessment
Repair works	Excavation	Excavate to below break
	Water level	Maintain pit water level below break
	Repair	Repair under pressure where able
		Controlled shutdown
		Mains isolation
		Cut out repair
	Disinfection of parts	Chlorination (Use of C.t for different scenarios)
		Ozone
	Flushing	Flushing (three volume changes or flush till clear)
	Cleaning	Air scouring and swabbing
	Disinfection	Chlorine liquid dosing
		Chlorine tables
		Ozonation
	Crews	Use of separate crews for water and sewer
	Equipment	Disinfection of equipment
		Separate sets of kit for water and sewer works
		Hygienic practices e.g. equipment placed on mats
	Fittings	Capping of pipes
		Use of new fittings
	Hygiene	Hand spray disinfect
		Hygiene scheme
	Testing	Chlorine residual testing
		Microbiological testing (before and after a break)
		Turbidity testing
Communication & liaison	Community notifications	Boil water notice
		Website showing pipe repair
		Door knocking
		Text messages
	Regulator	Incident reporting
Governance	Compliance	Compliance audits
	Contract	Water quality requirements
Support areas	Prevention programs	Pressure reduction programs
	Documentation	Documentation of any potential contamination
	Training	Ongoing engagement with field staff
		External training programs
		Target internal training
		Inductions
		Ongoing training through compliance audits