A HOLISTIC APPROACH TO CONDITION ASSESSMENT OF PRESSURE WATER MAINS

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1 ABSTRACT

The recent development of real-time direct leak monitoring fills a vital gap in the Condition Assessment-Pipeline Replacement process. Now, once a main or section of main has been identified as requiring possible replacement and/or is likely to undergo short term failure, the insertion of a Real-Time Monitoring System (RTMS) allows for cost-effective management of the pipeline, while the evaluation process is completed.

The system has been used in Sydney for sections of pipelines where failures have occurred. RTMS has been easy to install and has allowed the water authority to continue to operate the main (or specifically a high-risk section) whilst condition assessments and/or pipeline replacement evaluations are being conducted.

Moreover, RTMS is seen as also being useful in both cost-effectively (lowering risk) managing sections identified from proactive condition assessment program, and allowing smaller lengths of pipes to be identified for repair. A Water Authority may for example, have a couple of thousand kilometres of pressure pipelines classified as Critical. An Informed Desktop could reduce this length to a few hundred kilometres, and an In-depth Condition Assessment Program would provide an even greater reduction, to say, less than 25 kilometres. Utilisation of RTMS and/or Detailed In-line Inspection Tool (DILIT), may identify a small number of pipe lengths in need of subsequent repair and/or replacement. This is possible due to the large variation of condition of individual pipes in even old, poorly performing pipelines.

KEYWORDS

condition assessment, leak detection, asset management

2 INTRODUCTION

2.1 PCA-ECHLOGICS BACKGROUND

PCA-Echologics (PCA), and its predecessors, has provided pipeline condition assessment (PCA) services since 1996, using a variety of methodologies and techniques. Major contracts have been performed in Sydney, Newcastle, Hong Kong and Singapore, and more than 3500kms of critical water and wastewater mains (greater than DN300) have been surveyed.

Figure 1 PCA introduced DN375 in-line inspection tool into Australia in 1998

2.2 CRITICAL PIPELINES

As mentioned in the previous section, PCA has provided specialist assessment and consultancy services for Critical Mains. These are mains which a failure can cause significant costs (both direct and indirect), and even a single failure is undesirable. Risk associated with the main may be determined by multiplying Consequences ($) by the Likelihood or Probability of Failure.

2.2.1 TYPE OF MATERIALS

For the most part, the vast majority of critical mains assessed have been Grey Cast Iron (CI) and Mild Steel (MS). Other significant lengths of materials assessed include Asbestos Cement (AC), Ductile Iron (DI) and Glass Reinforced Plastic (GRP).

Material	Method of Manufacture	Abbreviatio n	Diameter Range	Type of Material	General Comments
Grey Cast Iron	Static Casting	CI	80-1200mm	Brittle	Eccentric wall. Lead joint. Originally unlined
Grey Cast Iron	Spun Cast	CI	80-750mm	Brittle	Lead/rubber ring joints. Spun cement lined
Ductile Iron	Spun Cast	DI	100-750mm	Ductile	Rubber ring joints. Some polysleeved. Spun cement lined
Asbestos Cement	Autoclaved	AC	100-600	Brittle	Rubber ring couplings. Some externally coated
Steel	Locking Bar	MS	150-900	Ductile	Lead joints. Longitudinal bars. Originally unlined
Mild Steel	Welded	MS	100-2000	Ductile	Lead joints/welded joints/rubber ring joints

Table 1 Summary of Major Pipe Materials Investigated

3 BACKGROUND

Pipelines are constructed from a number of smaller elements – pipes and fittings, in a linear array.

This concept was presented and discussed in a paper presented in Hong Kong in 2009.

3.1 HOW PIPELINES PERFORM

The factors leading to failure of individual pipes is depicted in the following figure.

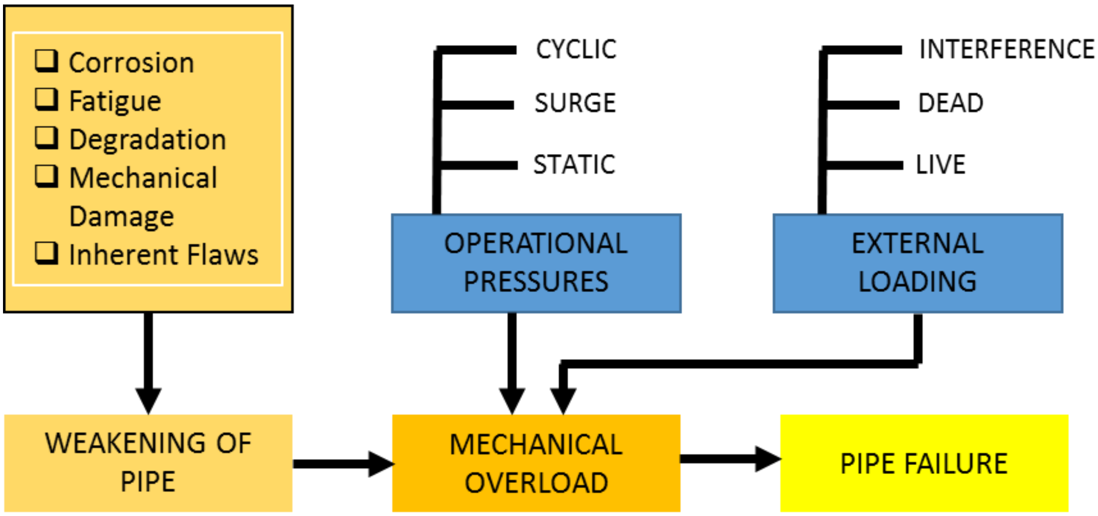

Figure 2 Factors Causing a Mechanical/Physical Pipe Failure

Of the hundreds of pipe failures investigated by PCA group, a very large percentage (>75%) involve significant corrosion (>100%) of pipe wall. A small percentage of metallic pipes investigated exhibited no deterioration or corrosion. Most purely mechanical failures for large diameter CI pipes were attributed to influence of significant surge pressures.

External soil corrosion was also considered to account for a large proportion of "corrosion" only failures.

3.1.1 STRATA

The concept of stratum or strata was also presented in Hong Kong in 2009. In simple terms, a stratum is defined as a collection of pipes exhibiting the same characteristics all exposed to the same environment. There will be natural variability of soils within the same stratum. This can be appreciated by referring to the following condition profile of a pipeline buried in essentially the same stratum along the shores of Lake Macquarie.

3.1.2 LIFE OF PIPELINES

The service life is dependent upon the service requirements that the regulator (such as OFWAT, IPART etc.) have imposed upon the water authority. These requirements will include water quality requirements (usually based on WHO guidelines), and limitations on number of planned and unplanned interruptions, and their duration.

3.1.3 DISTRIBUTION OF CONDITION

The following figure depicts the variability of individual pipe condition of unprotected CI pipes exposed to the same corrosive soil stratum.

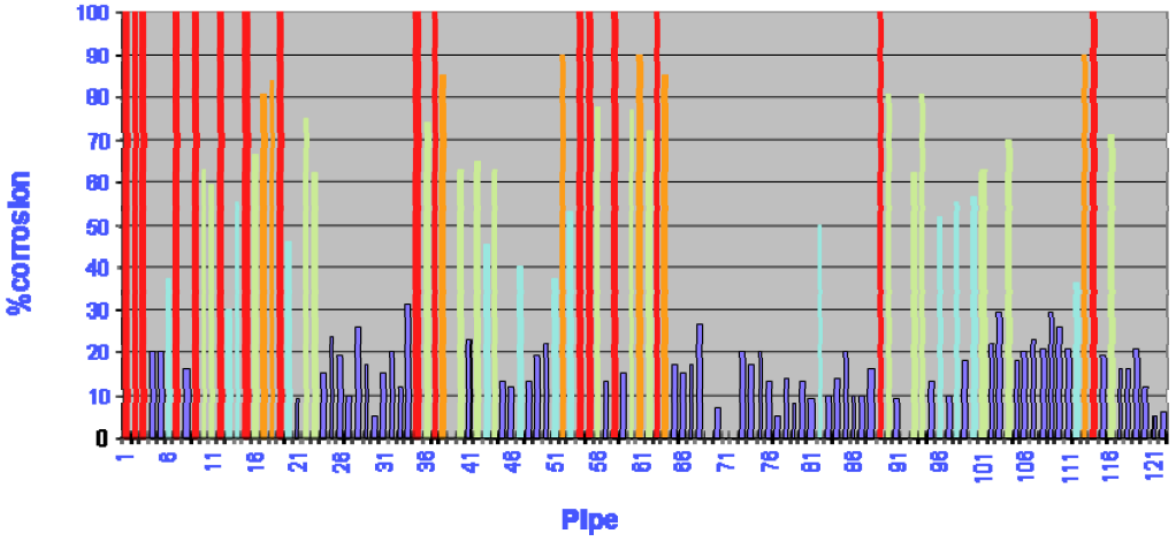

Figure 3 Variability of condition of 450m 45 years old CI pipe near Lake Macquarie

This data can be presented in terms of distribution of category as shown in the following diagram.

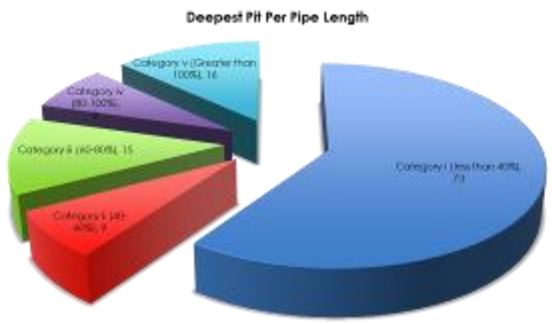

Figure 4 Distribution of Condition Category

4 METHODOLOGY OF CONDITION ASSESSMENT

4.1 STAGED APPROACH

Due to all of the factors previously described, a Staged Approach is considered to form the basis of a Cost-Effective Condition Assessment Investigation. Important outcomes of the process are Probabilities of Failure and Failure Regimes.

4.1.1 INFORMED DESKTOP

The initial stage of a Condition Assessment is to conduct an Informed DeskTop. This would follow an Audit DeskTop, which merely provides an initial identification of the attributes of nominated assets. The following diagram depicts Informed DeskTop, which quantitatively models performance of the pipeline, showing inputs, factors considered, and Final Outcomes.

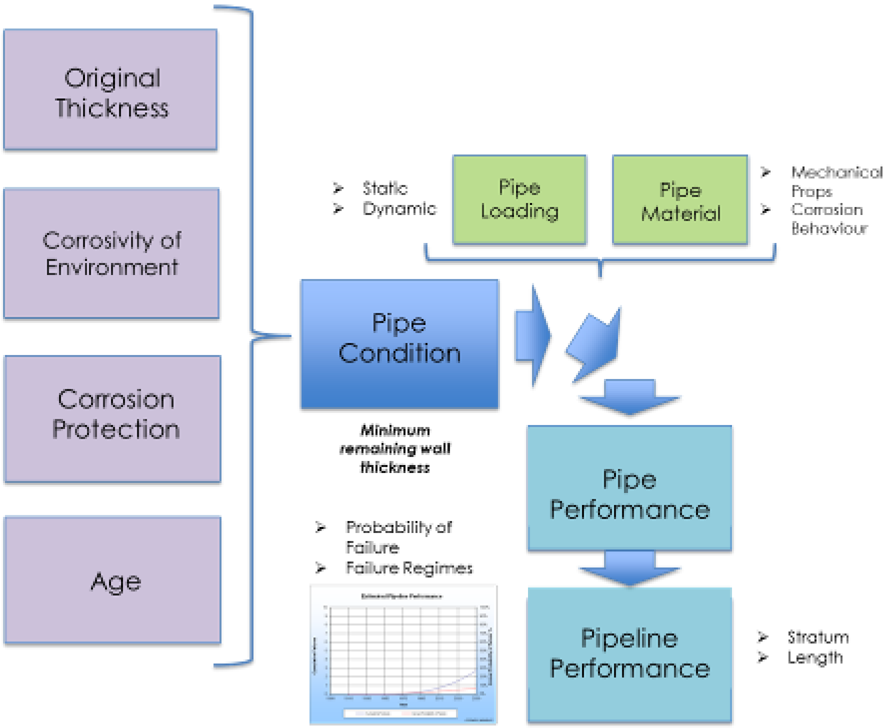

*Figure 5 Modelling of Pipeline Performance (Informed DeskTop) using **PipeForm***

4.1.2 GENERAL/PRELIMINARY SURVEY

Following an Informed DeskTop, a methodology capable of broadly classifying the condition and likelihood of failure within a pipeline or section of pipeline should be employed – these include ***SoilCorr***, ***ePulse*** and ***PipeFail***. For brittle pipe materials, such as asbestos cement and grey cast iron, this must include pressure monitoring, and for welded steel pipelines can include Pipe Coating Survey.

The outputs from this survey are presented in the following figures.

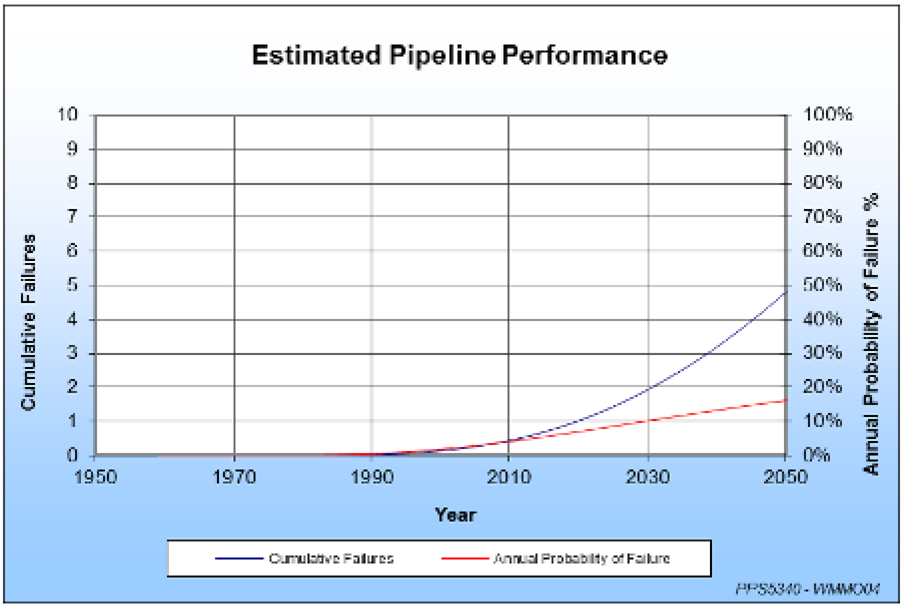

Figure 6 Estimated Performance of 480m 60 year old pipeline section

This result will allow further refinement of Risk Analysis, by providing an updated Probability of Failure. Further actions, such as pipeline/section replacement, will depend on level of risk the operator/owner is prepared to take, number of pipes in very poor and poor condition and potential for lowering Likelihood of Failure (such as pressure/surge reduction).

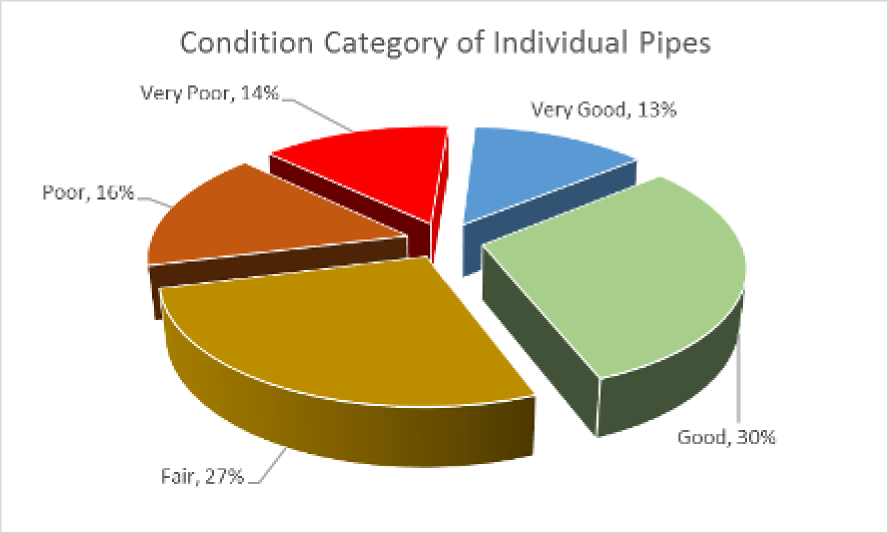

Figure 7 Example of Condition Category of a Section

As a general comment, pipes in Very Poor condition are more likely to leak for some time before failure. Typically, a Preliminary Survey reduces the length from 10km to 1.5km, a reduction of approximately 85%.

4.1.3 DETAILED/FOCUSED SURVEY

Following identification of a section with an unacceptable level of Probability of Failure, the following options are available to the client.

Material	Diameter	Pipes in Poor Condition	Option
Grey Cast Iron	All	High Number	Recommend for replacement and provide short term Leak Monitoring
Grey Cast Iron	DN300-DN600 *inclusive*	Small Number	Conduct Detailed In-Line Inspection to identify pipes in poor and very poor condition for Selective Replacement (perform Cost-Benefit analysis)
Mild Steel	All	Small Number	Conduct Coating Defect Location to identify areas of coating defects for subsequent repair. If under asphalt paved roadway provide Permanent Leak Monitoring
Mild Steel	All	Large Number	Provide permanent Leak Monitoring
Ductile Iron	DN300-DN600	Small Number	Conduct Detailed In-Line Inspection to identify pipes in poor and very poor condition for Selective Replacement (perform Cost-Benefit analysis)
Ductile Iron	All	Small/Large Number	Provide permanent Leak Monitoring

Table 2 Options following Preliminary Survey

4.1.4 SELECTIVE REPAIR/REPLACEMENT

This is the final outcome of the process, and will lower the risk for the client, reduce capital budget and allow more cost effective management of the network.

LOWER RISK

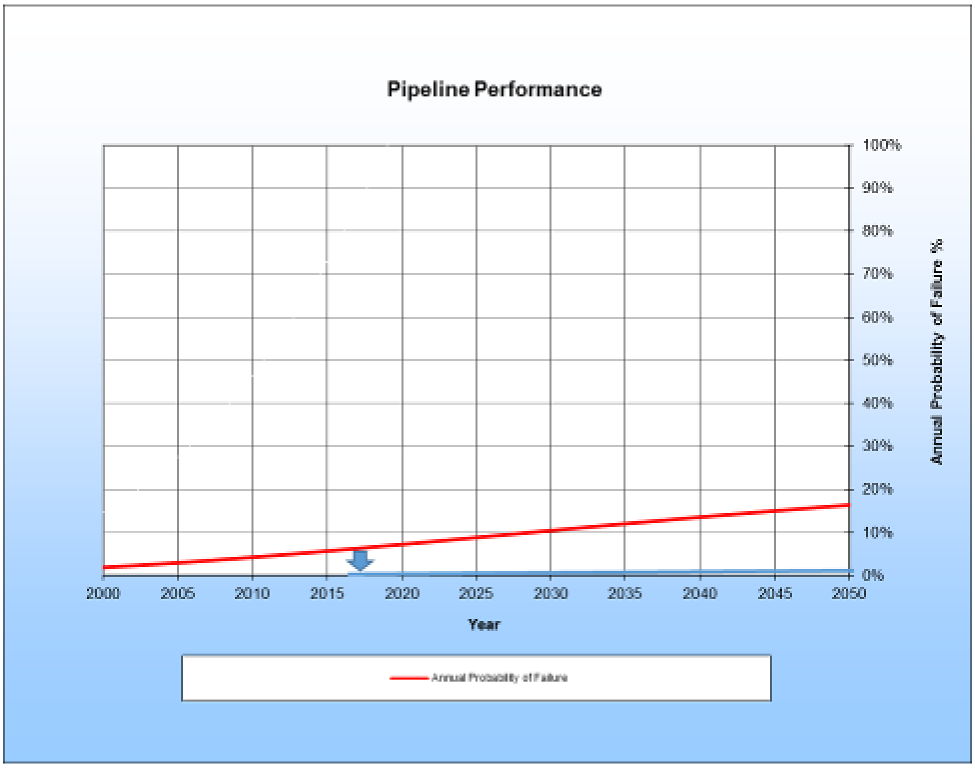

Figure 8 Reduced Probability of Failure

REDUCE CAPITAL BUDGET

Figure 9 Reduction in Costs

Another benefit is the possible compliance with Regulator's Standards of Service, by reduction in number of unplanned interruptions to customers.

4.1.5 SUMMARY

The proposed Step-Wise Methodology is depicted in the following diagram.

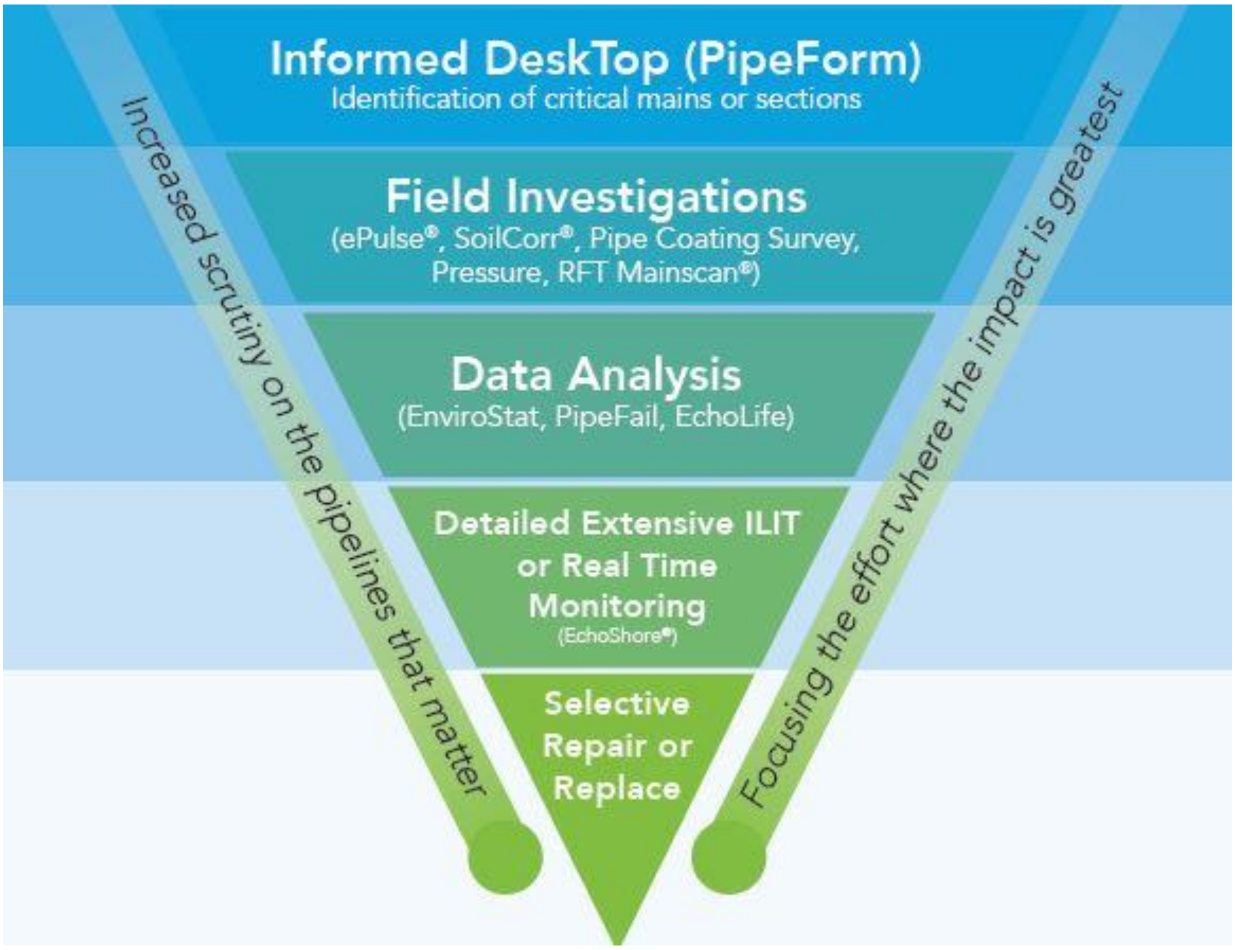

Figure 10 Inverted Pyramid of Condition Assessment Hierarchy

5 REAL-TIME LEAK MONITORING SYSTEMS

5.1 LEAKS PRECEDE A PIPE BURST

The Advanced Condition Assessment & Pipe Failure Prediction Project is a collaborative research agreement between Sydney Water Corporation, UK Water Industry Research Ltd., Water Research Foundation of the USA, Water Corporation (WA), City West Water, Melbourne Water, South Australia Water Corporation, South East Water Ltd, and Hunter Water Corporation. Water Environment Research Foundation of the USA is an affiliate partner. Monash University leads the research supported by University of Technology Sydney and the University of Newcastle. One of the outputs of this project is confirmation that significant leaks precede a burst in a cast iron pipe.

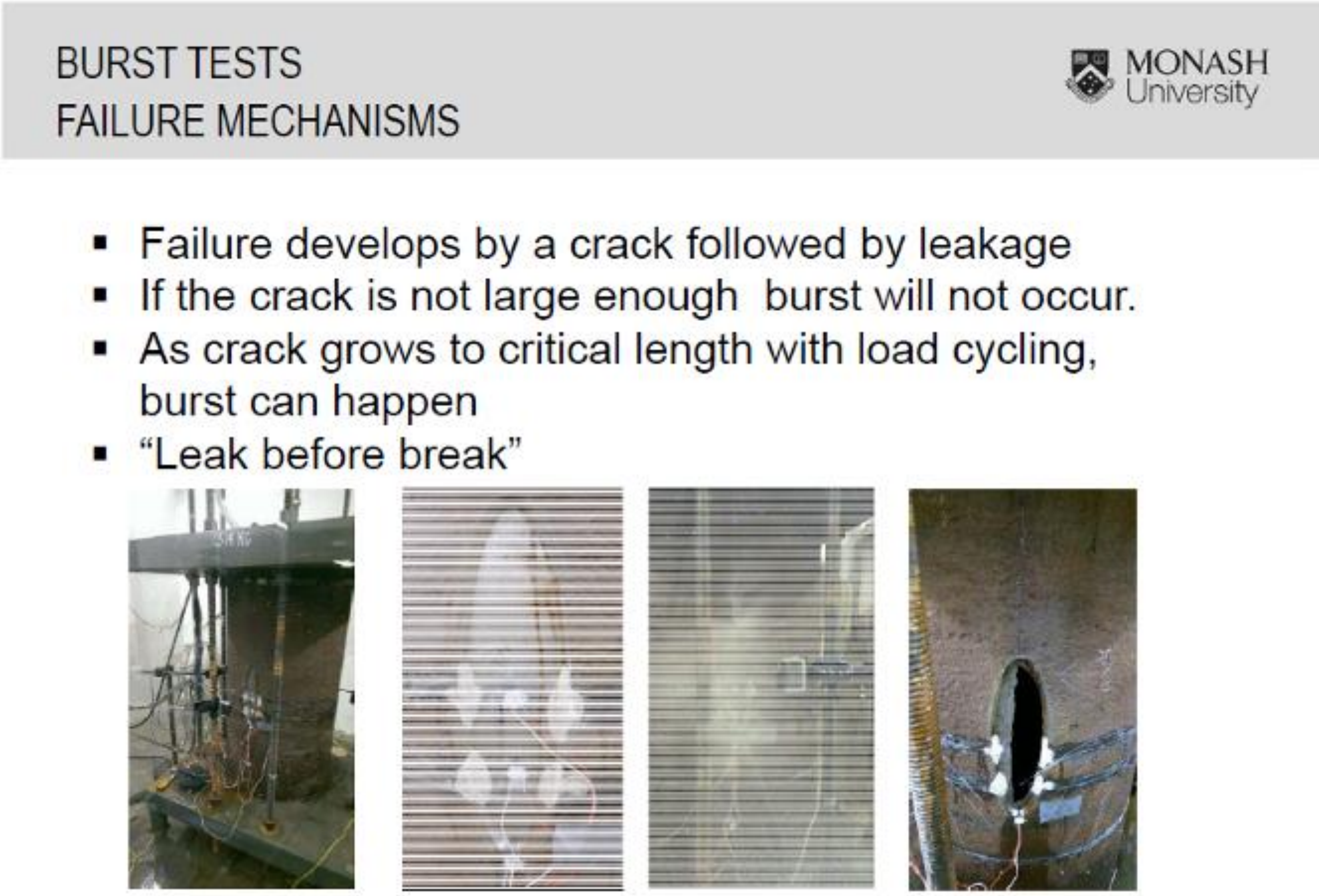

Figure 11 Physical test results from Monash University research project

5.1.1 LEAK DETECTION APPROACHES

Knowing that leaks precede a burst, it could be deduced that monitoring for the emergence of a leak could give one the ability to proactively respond and undertake a repair before a pipe burst occurs.

There are multiple different approaches to proactive leak detection and Table 3 presents a comparison of the more common approaches.

Type	**Description**	**Pros**	**Cons**
Visible	Eyes on the pipe	Low cost	Limited to visibility
Sounding	Electronic listening equipment to detect the sound of leaks	Catches leaks that can't be seen	Doesn't locate
Infrared/Thermal	Multispectral and thermal aerial photographs of ground temperatures	Capable of large surveys	Limited to warm, dry climates, many limitations
Metering	Active monitoring of metered flow and pressure in a zone	Quantifies the loss	Doesn't locate
Insertion	Insertion of microphone into the pipe. Microphone to the leak	High sensitivity	Potential for contamination; service disruption
Correlation	Analysis and correlation of acoustic data	Non-invasive, non-disruptive, works with existing fittings	Will not find very small leaks (<5L/min)

Table 3 Comparison of common leak detection approaches used by water utilities

Both *Insertion* and *Correlation* type leak detection are acoustic-based technologies. Based on both efficacy and economic factors, these are popular technology choices for water utilities.

5.1.2 LEAK MONITORING

Development of acoustic leak correlators have occurred such that they can operate remotely (e.g. battery-powered and cell phone connectivity) and be permanently installed on large diameter pipelines to provide real-time monitoring and accurate location of leaks as they occur.

The National Research Council Canada has been at the forefront of work in this field and some years ago developed a new method for detecting and locating leaks in water pipes. The patented technology, called LeakFinderRT, was subsequently licensed to Echologics Engineering, who has offered the technology to municipal markets around the world. This technology was then further developed by Severn Trent Water in the UK, who with Echologics created the LeakFinderST. In collaboration with Dr. Osama Hunaidi, the developer of LeakfinderRT, the NRC project has now extended the technology to offer a continuous leak monitoring system.

The new system employs a wireless network of battery-powered vibration sensors, either inserted into the water column, or attached to the outside of pipes, fire hydrants or valves. These sensors contain embedded software to ensure reliable and power-efficient operation. The sensors are programmed to wake up at programmable times, when ambient noise is at a minimum, to listen for and record vibration (or noise) signals. The signals are processed, encoded and transmitted wirelessly to a central server, where they can be analyzed using special software.

The segment of transmission main to be monitored is bracketed by a pair of leak detection nodes. A distance of up to 1000 metres, depending on pipe material and diameter, can be monitored by a pair of nodes. A leak detection node arrangement is shown in Figure 11. The location of the leak can be detected to an accuracy of +/- 2 metres.

Figure 12: An example of a node installed in an existing air valve chamber

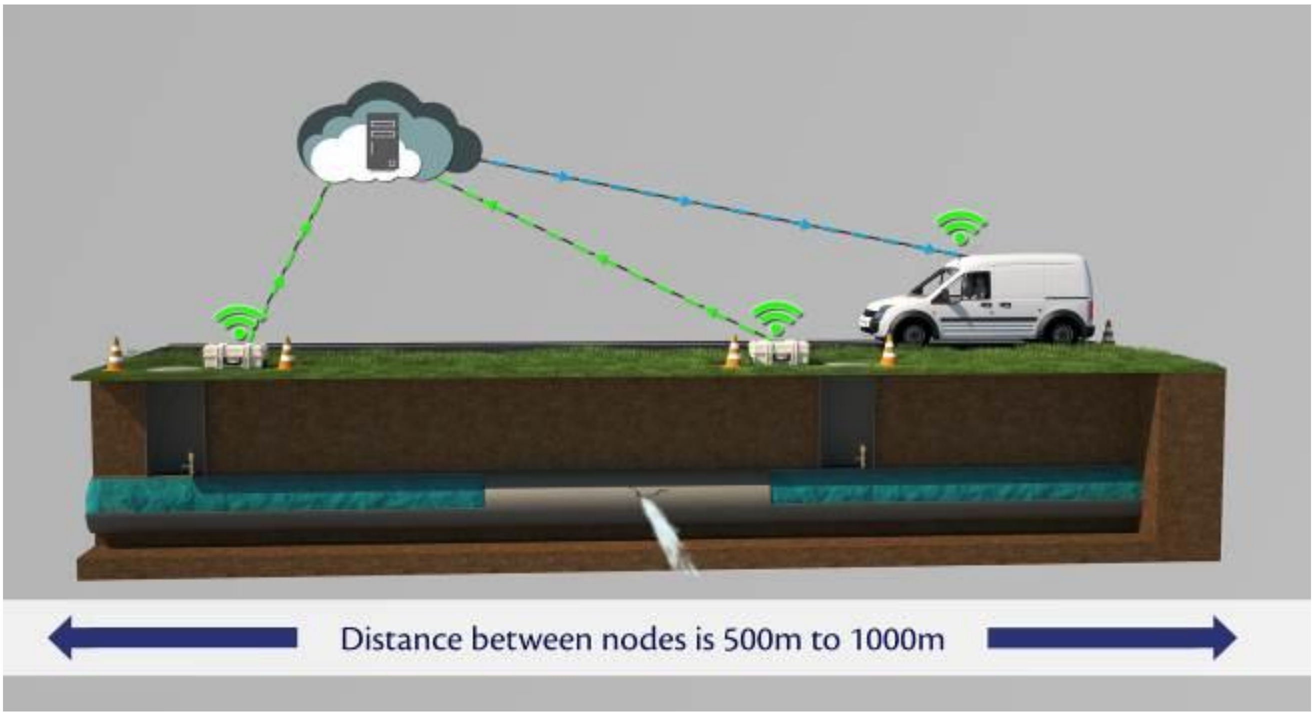

Figure 13: The location of the leak is achieved by correlating the data from each node

A series of interconnected nodes can be used to monitor longer length mains or a network. The network arrangement is shown in Figure 14.

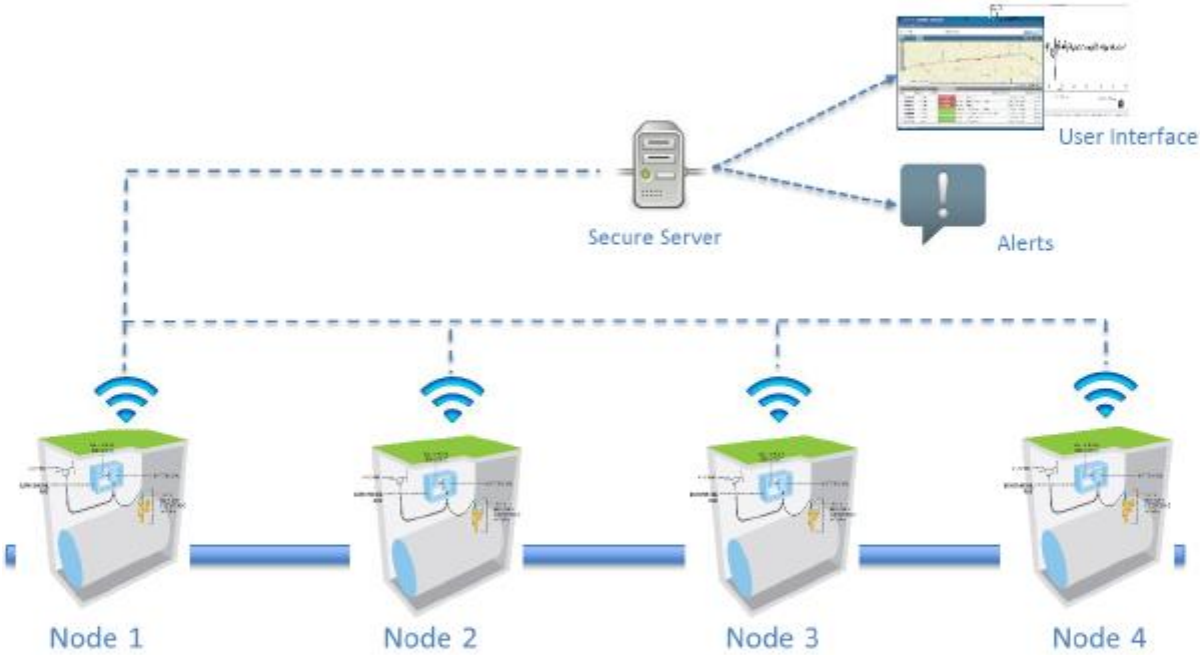

Figure 14: Network of interconnected leak detection nodes monitoring a service area.

Figure 15: example of a leak in a buried water pipeline and the damage caused by a pipe burst

6 IN-LINE INSPECTION TOOLS

6.1 OVERVIEW

These essentially are only available for metallic (ferrous metal) pipelines, in a limited range of sizes. They utilize electromagnetic properties of the metal as a consequence in decrease in metal thickness at some locations. The resolution of the tools are influenced by number of sensors (sensor spacing) and extent of lift-off. Tools utilizing Remote Field Technique (RFT) are considered the best performing of ILIT's.

6.2 RFT TOOLS

These range of tools have been operating since mid-1990's and involve changes in the magnetic field as a consequence of wall loss as depicted in the following diagram.

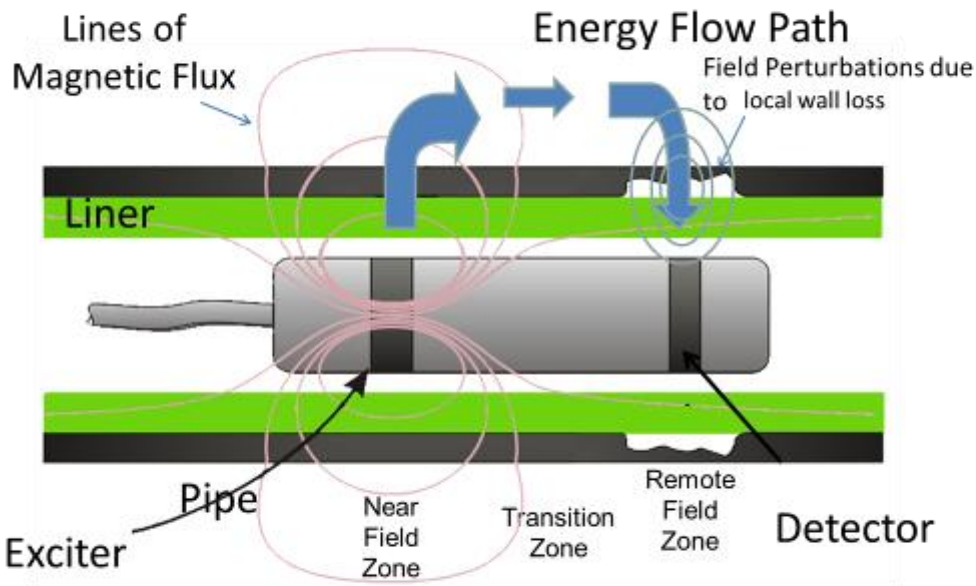

Figure 16: Schematic of RFT Tool (provided by PICA)

The tools are available in a variety of forms applicable to a range of sizes.

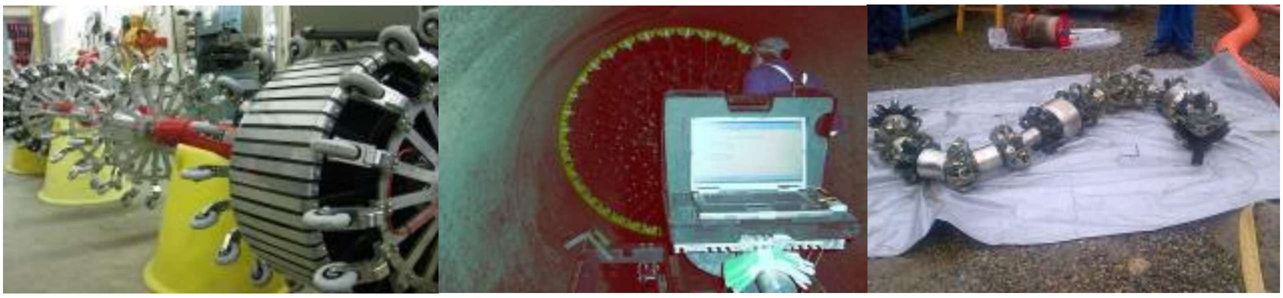

Figure 17: Range of PICA ILIT's

The table summarises the availability (from left to right in above figure)

Type of ILIT	Diameter Range (mm)	Comments
Chimera style SeeSnake	400-900	
EMIT style SeeSnake	>1200	Man-entry – shut down required
SeeSnake	150-600	SeeSnake

Table 4 Range of PICA ILIT's

6.3 OUTPUT

A typical output from an RFT in-line inspection is shown in the following diagram.

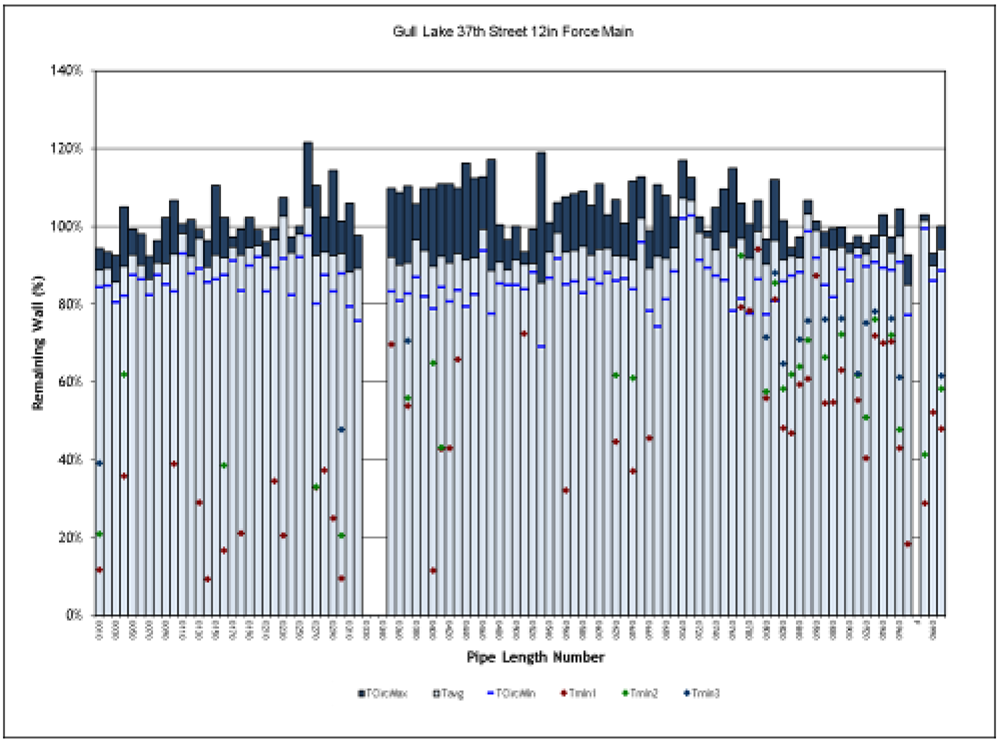

Figure 18: Wall Thickness Results for ILIT of 3km 30yo DN300 DICL SRM (courtesy of PICA)

7 CONCLUSIONS

1) A variety of pipeline materials are used in critical mains – Cast Iron, Ductile Iron, Steel, Asbestos Cement;
2) Condition Assessment is a Staged Approach;
3) Informed DeskTop provides a good start for a successful campaign by considering the mode of failure of the nominated pipeline material;
4) Brittle materials are also susceptible to rapid loading, and can fail with little or no deterioration;
5) There is a distribution of conditions of pipes along/within a Stratum;
6) An appropriate Preliminary Survey can identify the Sections/Mains with High Likelihood of Failure;
7) A Preliminary Survey reduces the length of Detailed Inspection by approximately 85%;
8) Further investigation may be cost effective using Real Time Monitoring and/or Detailed Inspection using ILIT;
9) The outcomes of a successful condition assessment campaign will be lowering of capital budget and lowering of risk;
10) Real Time Monitoring can identify leaks before they reach critical size and cause failure.

ACKNOWLEDGEMENTS

Critical Pipe Project Activity 1: Failure modes and loadings (How, where and when do critical pipes fail?)

Prof. Jayantha Kodikara

PICA Corporation, Private Communication, July 2016

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