p-CAT™

Pipeline Condition Assessment Technique for Water and Sewer Mains

Dr Young-il Kim
Project Director of Detection Services Pty Ltd

Water NZ 2017

p-CAT™ pipeline condition assessment

DETECTION SERVICES
PIPELINE INSPECTION AND ANALYSIS

Pipe Condition Assessment

For accessing
the remaining life
of ageing pipelines:

are a key area

when developing
a future maintenance plan

p-CAT™

Previously, there have been little to no technologies that could assess and calculate wall thickness over long distances.

p-CAT™ fills this void as a long-distance, non-invasive scanning tool that can split pipelines into 10 meter sections with pipe wall thicknesses of 0.2 mm resolution, and provide localized faults.

p-CAT™ - Advantages and Performance

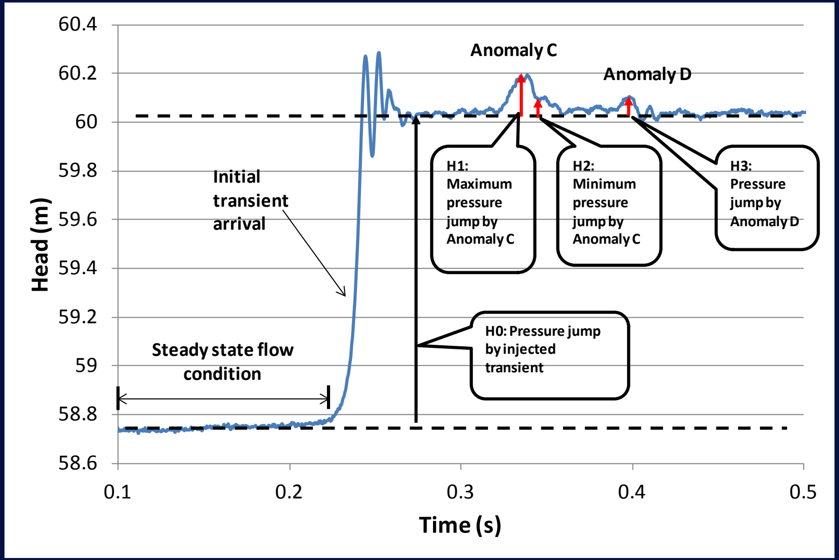
- Cost effective pipeline condition assessment method for relatively long distance pipeline section (over 2 km) with +/- 10 m spatial accuracy.
- Sub-sectional pipeline condition assessment with various resolutions from 10 m using only one set of tests both between measurement points and out of the boundary.
- Identification of pipeline anomalies (localized fault detection)
- Detects pipeline characteristics and anomalies which can be confirmed using a point sampling technique. Saving a lot of time and money.
- Various pipe diameters and materials (metallic, concrete and AC).

Fundamental Physical Mechanisms

- There is a correlation between changes in the thickness of metal and cement mortar lining forming a pipeline wall and the speed with which a wavefront from a hydraulic transient propagates along the pipeline.

- Changes in this thickness give rise to reflections which can be theoretically interpreted to obtain a distribution of damage in the pipe.

- Pipe wall damage or lining loss has a visible impact on a resultant transient pressure wave trace



Fundamental Physical Mechanisms

$$a = \sqrt{\frac{K/\rho_W}{1 + \left(K/E_m\right)\left(ID/e_{eq}\right)\psi}}$$

a = speed of propagation of hydraulic transient pressure wave

K = bulk modulus of water

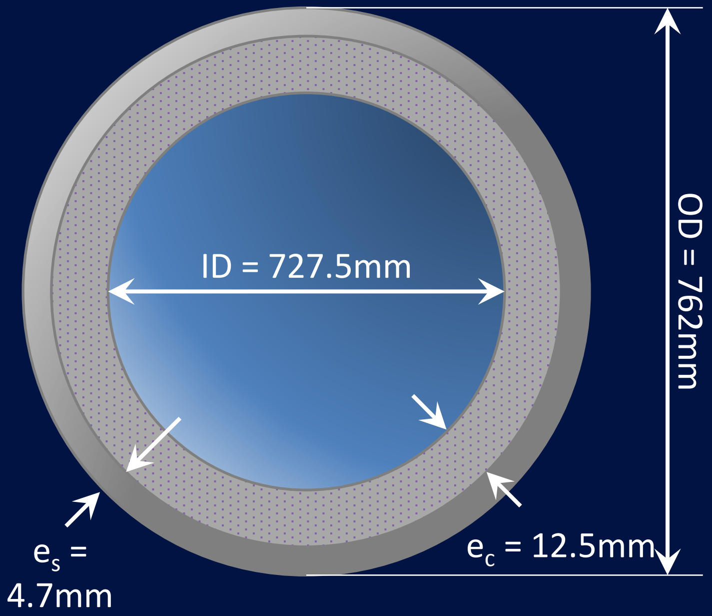
ρ = density of water

E = Young's modulus of elasticity of the pipeline wall material

D = internal diameter of the pipeline

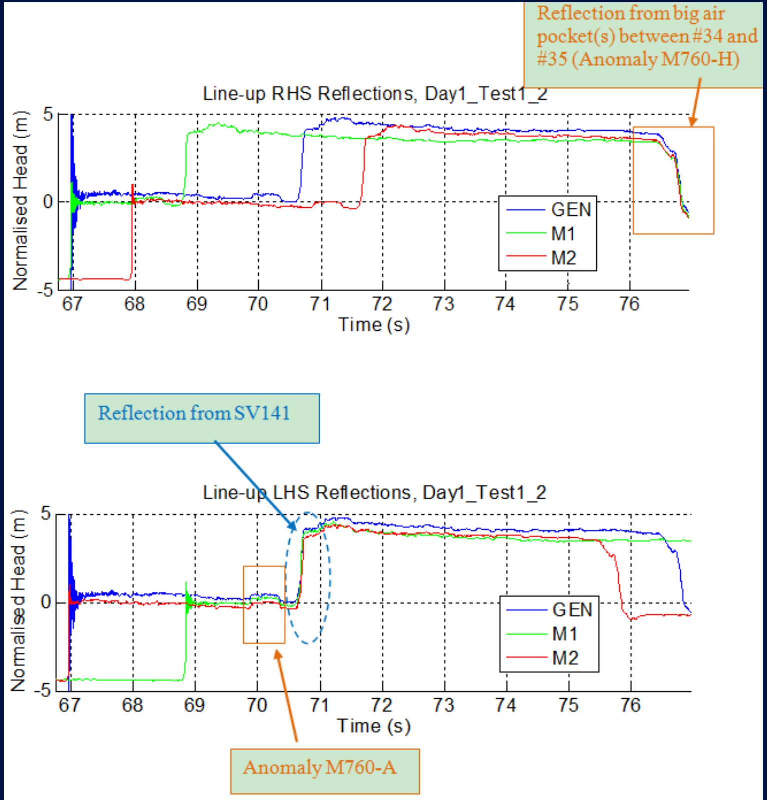
e_{eq} = wall thickness of a single material pipe
or
the total equivalent wall thickness of the composite material pipe

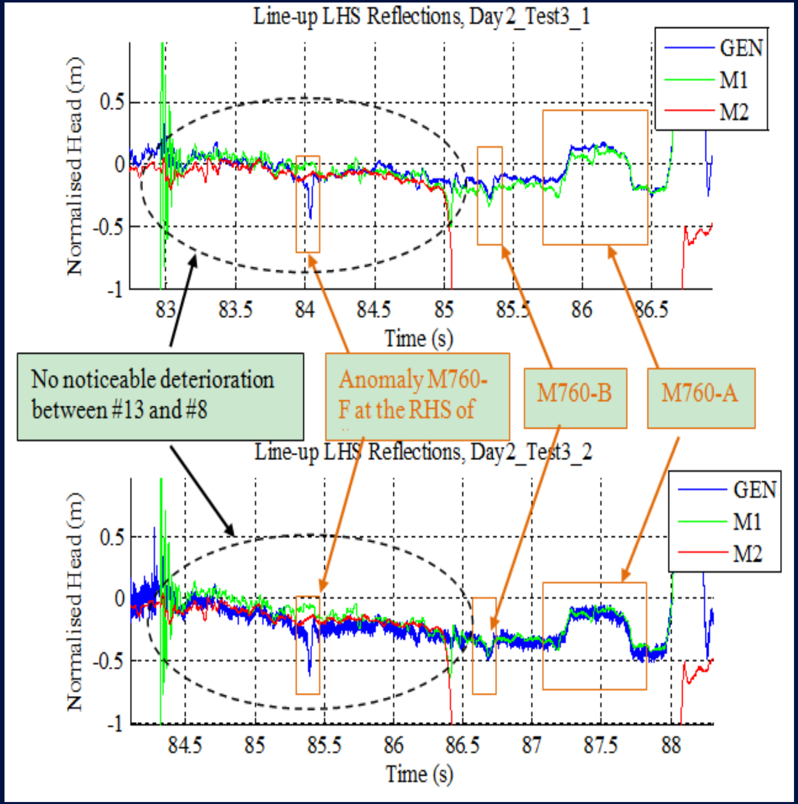
ψ = pipeline restraint factor.

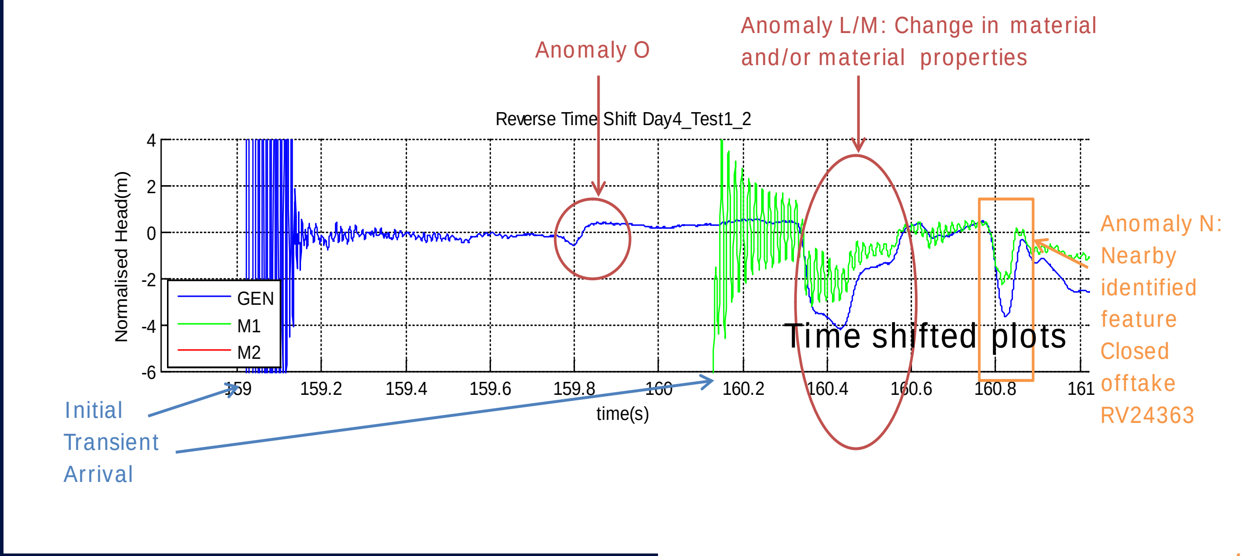


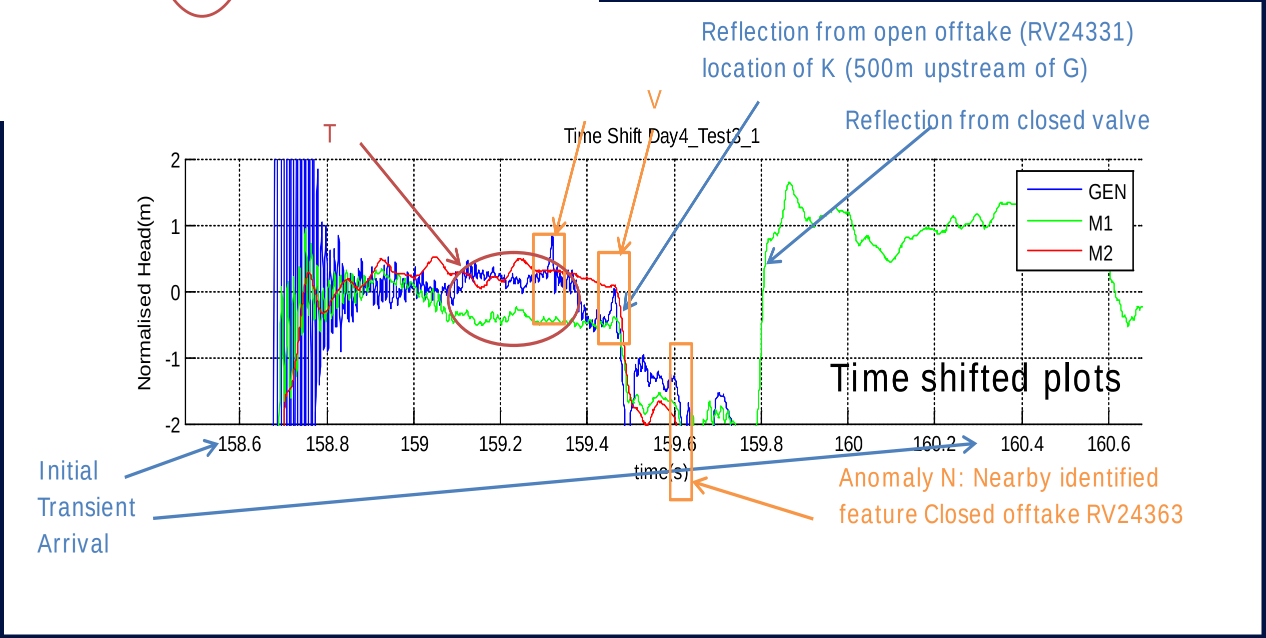
Example Field Signals

Major Boundary Reflection, Wall Thickness/Material Change and Localized Fault






Anomaly O
Anomaly L/M: Change in material and/or material properties
Reverse Time Shift Day4_Test1_2
Normalised Head(m)
4
2
0
-2
-4
-6
GEN
M1
M2
159
159.2
159.4
159.6
159.8
160
160.2
160.4
160.6
160.8
161
time(s)
Time shifted plots
Anomaly N: Nearby identified feature Closed offtake RV24363
Initial Transient Arrival


Reflection from open offtake (RV24331) location of K (500m upstream of G)
V
T
Time Shift Day4_Test3_1
Reflection from closed valve
Normalised Head(m)
2
1
0
-1
-2
GEN
M1
M2
158.6
158.8
159
159.2
159.4
159.6
159.8
160
160.2
160.4
160.6
time(s)
Time shifted plots
Initial Transient Arrival
Anomaly N: Nearby identified feature Closed offtake RV24363

Signal Analysis

P-CAT™ analysis uses two main techniques for interpreting the results from the transient pressure wave tests:

Sub-Section Partitioned Wave Speed Analysis™

Assessment of the level of deterioration in a sub-section

Localised Fault Detection

Significant anomalies such as air pockets and blockages

What Does It Deliver?

This theory has been developed into a non-invasive technique which can determine:

- Remaining Wall Thickness including corrosion and cement mortal lining spalling
- Locations of air/gas pockets and blockages
- The sealing status of valves
- Unknown connections and branches

Testing Equipment - Generation Point







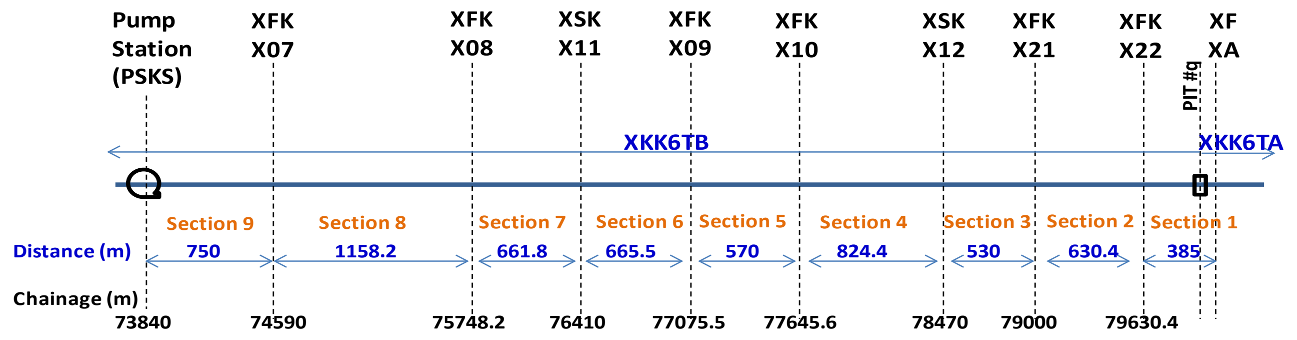

Testing Equipment - Measurement Point








Typical configuration for test series

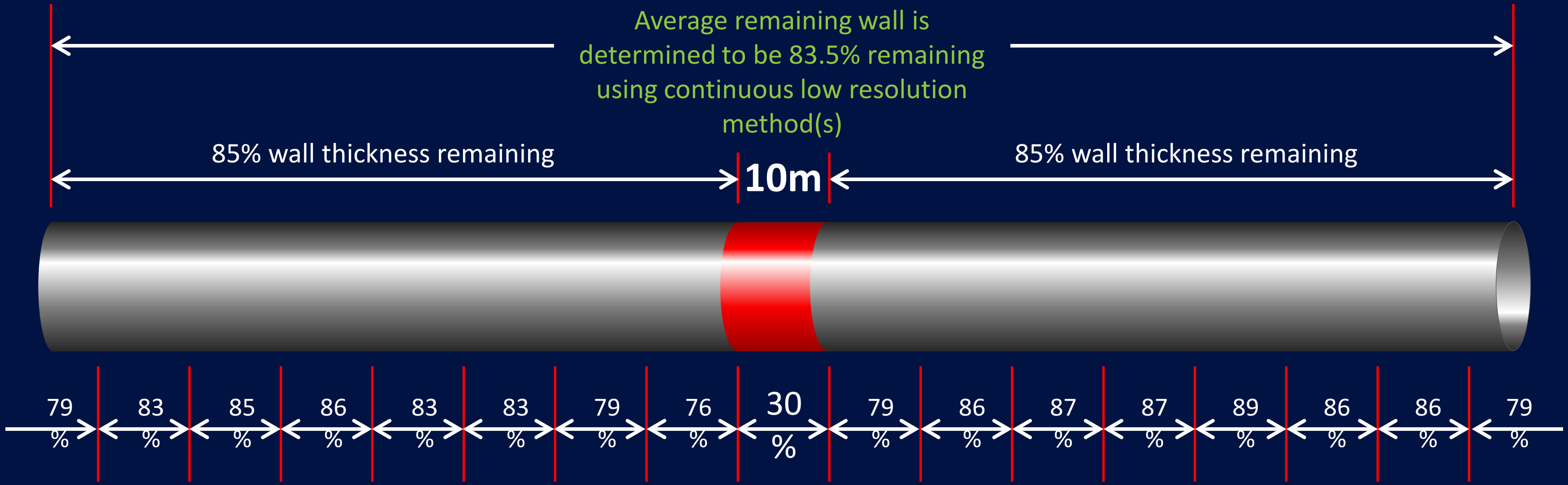


	X07	X08	X11	X09	X10	X12	X21	X22	XA
Day1-Test1					M1		G		M2
Day1-Test2					M2		M1		G
Day2-Test1						M1	G	M2	
Day2-Test2					M2	M1	G		
Day2-Test3				M1	G	M2			
Day2-Test4			M2	M1	G				
Day2-Test5		G	M1	M2					
Day2-Test6	M1	G	M2						

G: Transient Generator
M1 and M2: Measurement Stations

Average Condition vs. Sub-Sectional Condition

The *p*-CAT method could identify this corroded section from within the 500 metres, allowing for targeted repair or replacement and minimising risk while saving considerable cost.

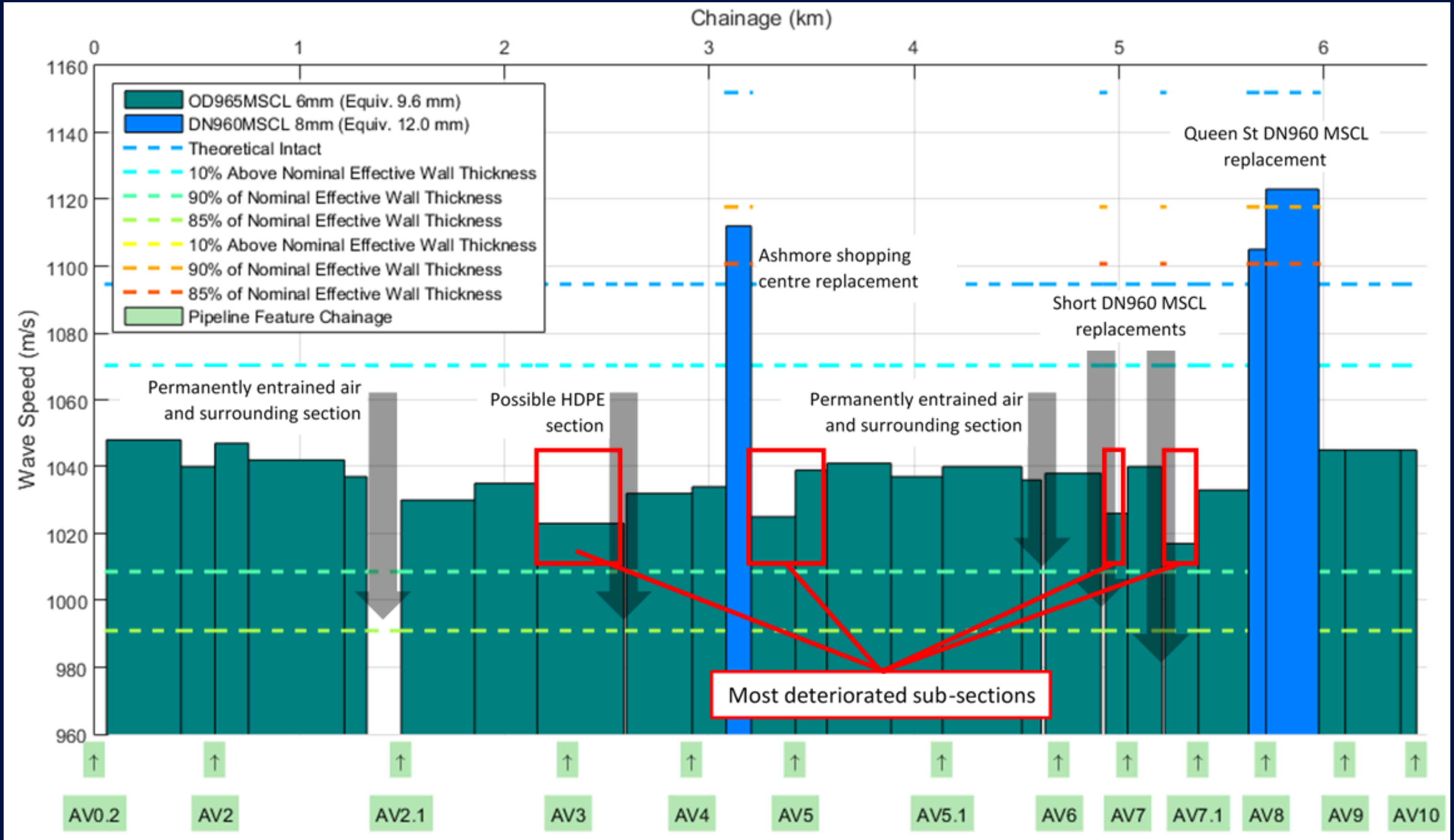


Sub-Sectional Pipeline Condition Assessment

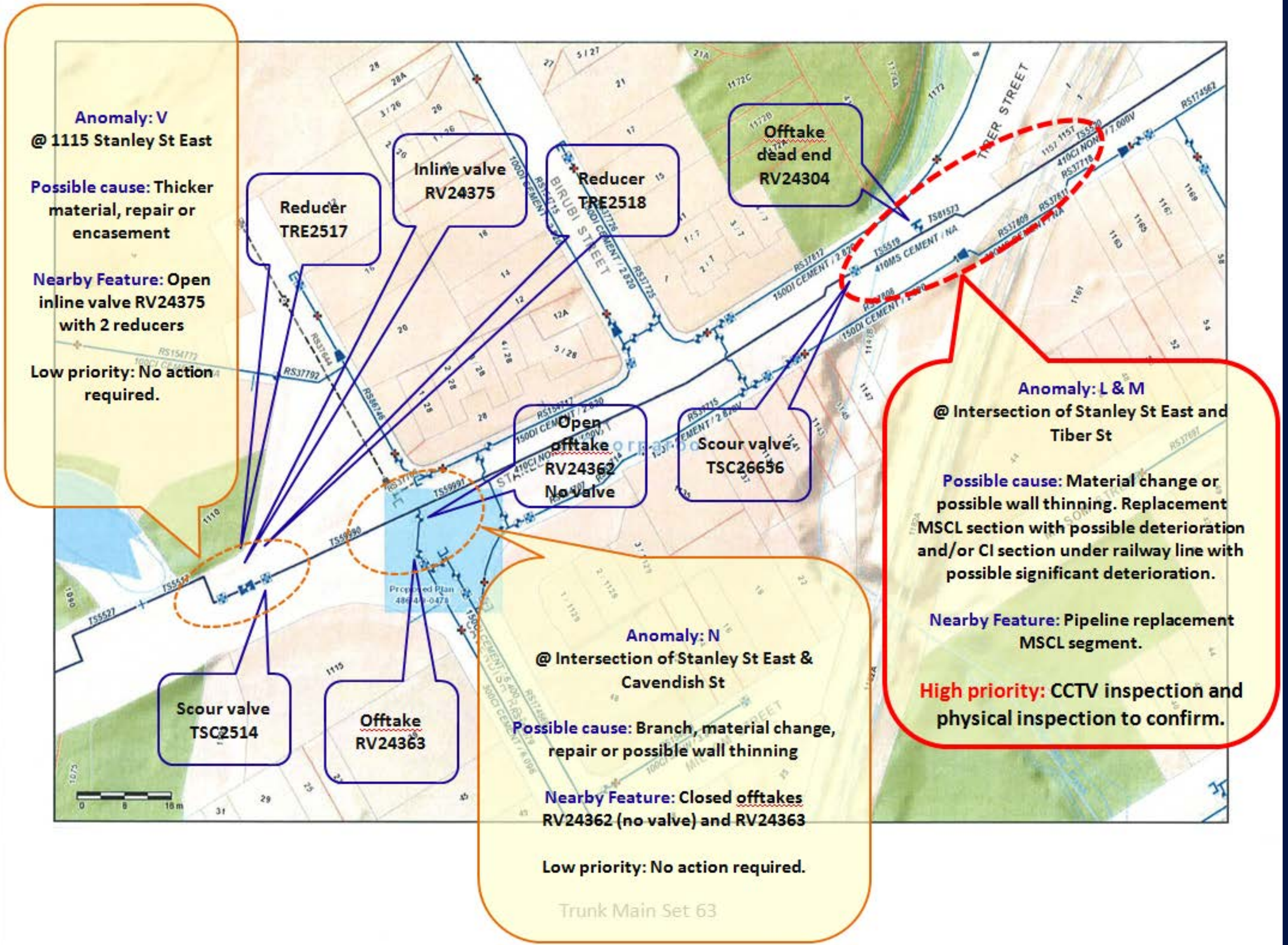
Section Identifier	Approx. Chainage (m)		Sub-section Location on Pipeline	Approx. Length (m)	Pipe	Theoretical Wall Thickness (mm)		Remaining Effective Wall Thickness[1] (Difference between metal wall or cement mortar lining from the nominal theoretical value) (mm)						Sub-Sectional Average Wave Speed (m/s)
								Assumed Internal Corrosion[2]			Assumed External Corrosion[3]			
	Start	End				Wall	Lining	Wall	Lining	% Remaining	Wall	Lining	% Remaining	
S1	0	57	AV0.2 to off-take 0	57	DN1125MSCL	8.8	20	Outside section of interest						
S2	57	421	Off-take 0 to AV1	365	OD965 MSCL	7.2	20	7.2 (0.0)	8 (-12)	85%	5.6 (-1.6)	20 (0)	83%	1048
S3	421	587	AV1 to AV2	166	OD965 MSCL	7.2	20	7.2 (0.0)	7 (-13)	83%	5.4 (-1.8)	20 (0)	81%	1040
S4	587	750	AV2 to off-take 1	162	OD965 MSCL	7.2	20	7.2 (0.0)	8 (-12)	85%	5.6 (-1.6)	20 (0)	83%	1047
S5	750	1218	Off-take 1 to off-take 2	468	OD965 MSCL	7.2	20	7.2 (0.0)	7 (-13)	84%	5.4 (-1.8)	20 (0)	81%	1042
S6	1218	1328	Off-take 2 to the horizontal section of Harper St.	110	OD965 MSCL	7.2	20	7.2 (0.0)	6 (-14)	82%	5.3 (-1.9)	20 (0)	80%	1037
S7	1328	1496	The horizontal section of Harper St to AV2.1	168	OD965 MSCL	7.2	20	Permanently entrained air and surrounding section						
S8	1496	1854	AV2.1 to SCV 3	357	OD965 MSCL	7.2	20	7.2 (0.0)	4 (-16)	80%	5.1 (-2.1)	20 (0)	78%	1030
S9	1854	2160	SCV3 to off-take 4	306	OD965 MSCL	7.2	20	7.2 (0.0)	6 (-14)	82%	5.2 (-2.0)	20 (0)	79%	1035
S10	2160	2583	Offtake 4 to possible 12 m HDPE section (444 Southport Nerang Rd)	423	OD965 MSCL	7.2	20	7.2 (0.0)	3 (-17)	79%	4.9 (-2.3)	20 (0)	76%	1023
S11	2595	2916	Possible HDPE section (442 Southport Nerang Rd) to AV4	321	OD965 MSCL	7.2	20	7.2 (0.0)	5 (-15)	81%	5.1 (-2.1)	20 (0)	78%	1032
S12	2916	3082	AV4 to Ashmore shopping centre replacement section	166	OD965 MSCL	7.2	20	7.2 (0.0)	5 (-15)	81%	5.2 (-2.0)	20 (0)	79%	1034
S13	3082	3204	Ashmore shopping centre replacement section	123	DN960 MSCL	9.6	20	9.6 (0.0)	7 (-13)	87%	7.8 (-1.8)	20 (0)	85%	1112
S14	3204	3420	Ashmore shopping centre replacement section to AV5	216	OD965 MSCL	7.2	20	7.2 (0.0)	3 (-17)	79%	4.9 (-2.3)	20 (0)	76%	1025
S15	3420	3574	AV5 to off-take 5.1	154	OD965 MSCL	7.2	20	7.2 (0.0)	6 (-14)	83%	5.3 (-1.9)	20 (0)	81%	1039
S16	3574	3887	Off-take 5.1 to SCV5	313	OD965 MSCL	7.2	20	7.2 (0.0)	7 (-13)	83%	5.4 (-1.8)	20 (0)	81%	1041
S17	3887	4138	SCV5 to AV5.1	251	OD965 MSCL	7.2	20	7.2 (0.0)	6 (-14)	82%	5.3 (-1.9)	20 (0)	80%	1037
S18	4138	4525	AV5.1 to SCV6.1	388	OD965 MSCL	7.2	20	7.2 (0.0)	7 (-13)	83%	5.4 (-1.8)	20 (0)	81%	1040

Identification of Anomalies

Identifier	Approximate location	Interpretation	Priority	Recommended action
A	OT0	Large open offtake	Low	None, Known system feature.
B	The horizontal section of pipe beginning on Harper St, between the intersections of Ashmore Rd and Forrest Ave. *see Section 4.3.1	Large, permanently entrained, air pocket	**HIGH**	Remove entrained air as it may affect system performance. There is an increased likelihood of localised internal deterioration at this point.
C	OT4 at 490 Southport Nerang Rd. *see Section 4.2	Open off-take	**Medium**	Exercise the valve to determine valve sealing status.
D	444 to 442 Southport Nerang Rd.	Possible HDPE replacement section or air pocket.	**Medium**	Check records for replacement and investigate pipeline condition.
E	Main entrance of Ashmore Shopping Centre, Southport Nerang Rd to the intersection of Southport Nerang Rd and Currumburra Rd.	Replacement section to detour around underground carpark constructed after original pipeline construction	Low	Update GIS maps to show difference in material.
F	AV5.1 at the intersection of Keith Turnbull Dr and Dakara Dr *see Section 4.3.2	Air Pocket or low wave speed material of riser	**Medium**	Check functionality of air valve.
G	Spanning Binstead Dr *see Section 4.3.3	Large, permanently entrained, air pocket near joint of Stage 1 and Stage 2 of pipeline construction.	**HIGH**	Remove entrained air pocket as it may affect system performance. There is an increased likelihood of localised internal deterioration at this point.
H	Intersection of Bambarra St and Queen St	Replacement section under new tram and road reconstruction	Low	None, Known system feature.

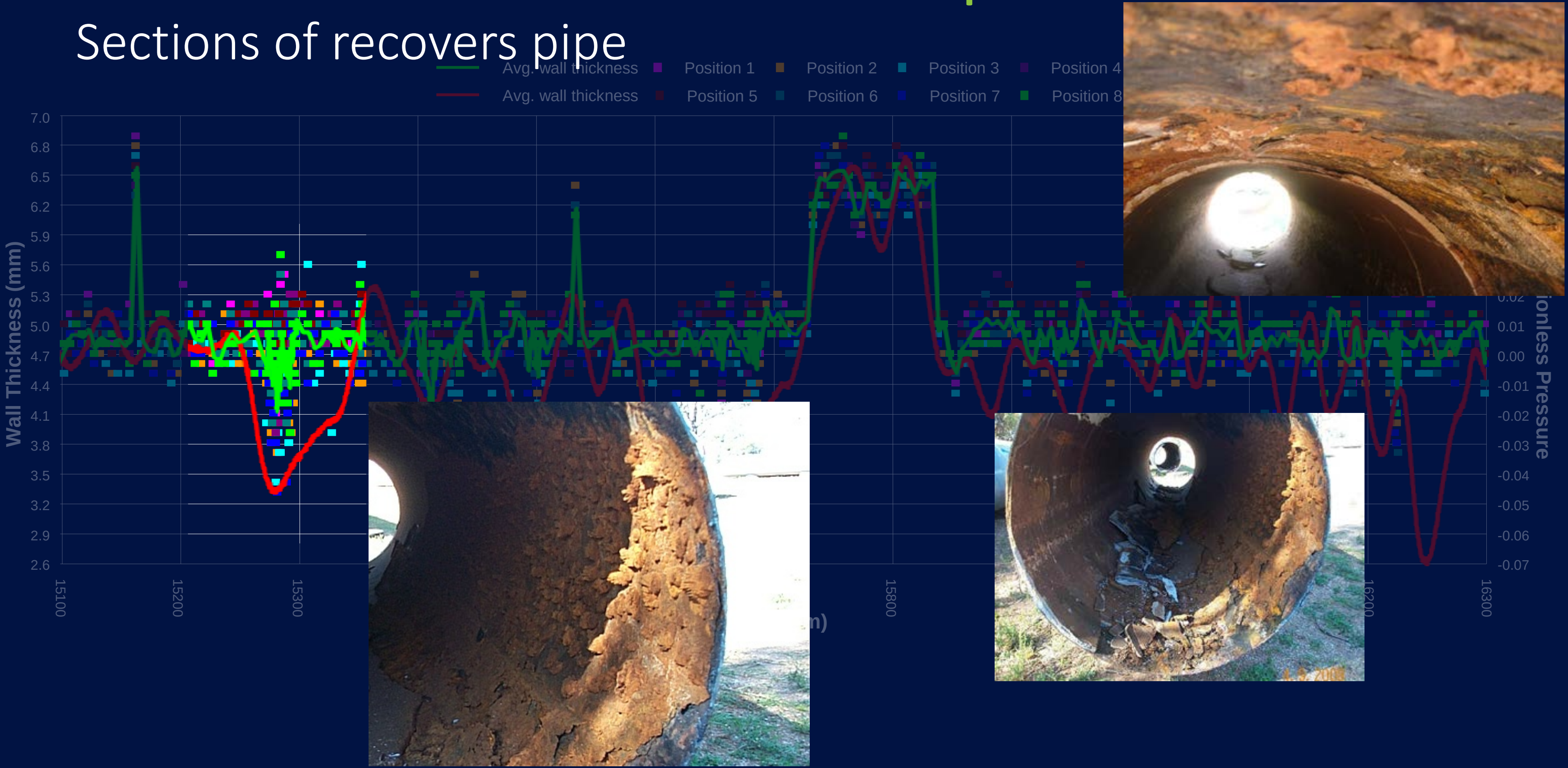


Chainage (km)
0
1
2
3
4
5
6
1160
1140
1120
1100
1080
1060
1040
1020
1000
980
960
Wave Speed (m/s)
OD965MSCL 6mm (Equiv. 9.6 mm)
DN960MSCL 8mm (Equiv. 12.0 mm)
Theoretical Intact
10% Above Nominal Effective Wall Thickness
90% of Nominal Effective Wall Thickness
85% of Nominal Effective Wall Thickness
10% Above Nominal Effective Wall Thickness
90% of Nominal Effective Wall Thickness
85% of Nominal Effective Wall Thickness
Pipeline Feature Chainage
Queen St DN960 MSCL replacement
Ashmore shopping centre replacement
Short DN960 MSCL replacements
Permanently entrained air and surrounding section
Possible HDPE section
Permanently entrained air and surrounding section
Most deteriorated sub-sections
AV0.2
AV2
AV2.1
AV3
AV4
AV5
AV5.1
AV6
AV7
AV7.1
AV8
AV9
AV10


Anomaly: V
@ 1115 Stanley St East
Possible cause: Thicker material, repair or encasement
Nearby Feature: Open inline valve RV24375 with 2 reducers
Low priority: No action required.
Reducer TRE2517
Inline valve RV24375
Reducer TRE2518
Offtake dead end RV24304
Open offtake RV24362 No valve
Scour valve TSC26656
Scour valve TSC2514
Offtake RV24363
Anomaly: N
@ Intersection of Stanley St East & Cavendish St
Possible cause: Branch, material change, repair or possible wall thinning
Nearby Feature: Closed offtakes RV24362 (no valve) and RV24363
Low priority: No action required.
Anomaly: L & M
@ Intersection of Stanley St East and Tiber St
Possible cause: Material change or possible wall thinning. Replacement MSCL section with possible deterioration and/or CI section under railway line with possible significant deterioration.
Nearby Feature: Pipeline replacement MSCL segment.
High priority: CCTV inspection and physical inspection to confirm.
TIBER STREET
BIRUBI STREET
Trunk Main Set 63

Verification of Technique

Sections of recovers pipe



Case Study #1_Water Main

Location	Approx. Length	Size	Material	Year
Between FPAV174 and FPAV181 (from 43M 4777/5 to 45M 3461/- as per as-constructed drawings)	2.8 km	30-inch	MSCL	1943 - 1944

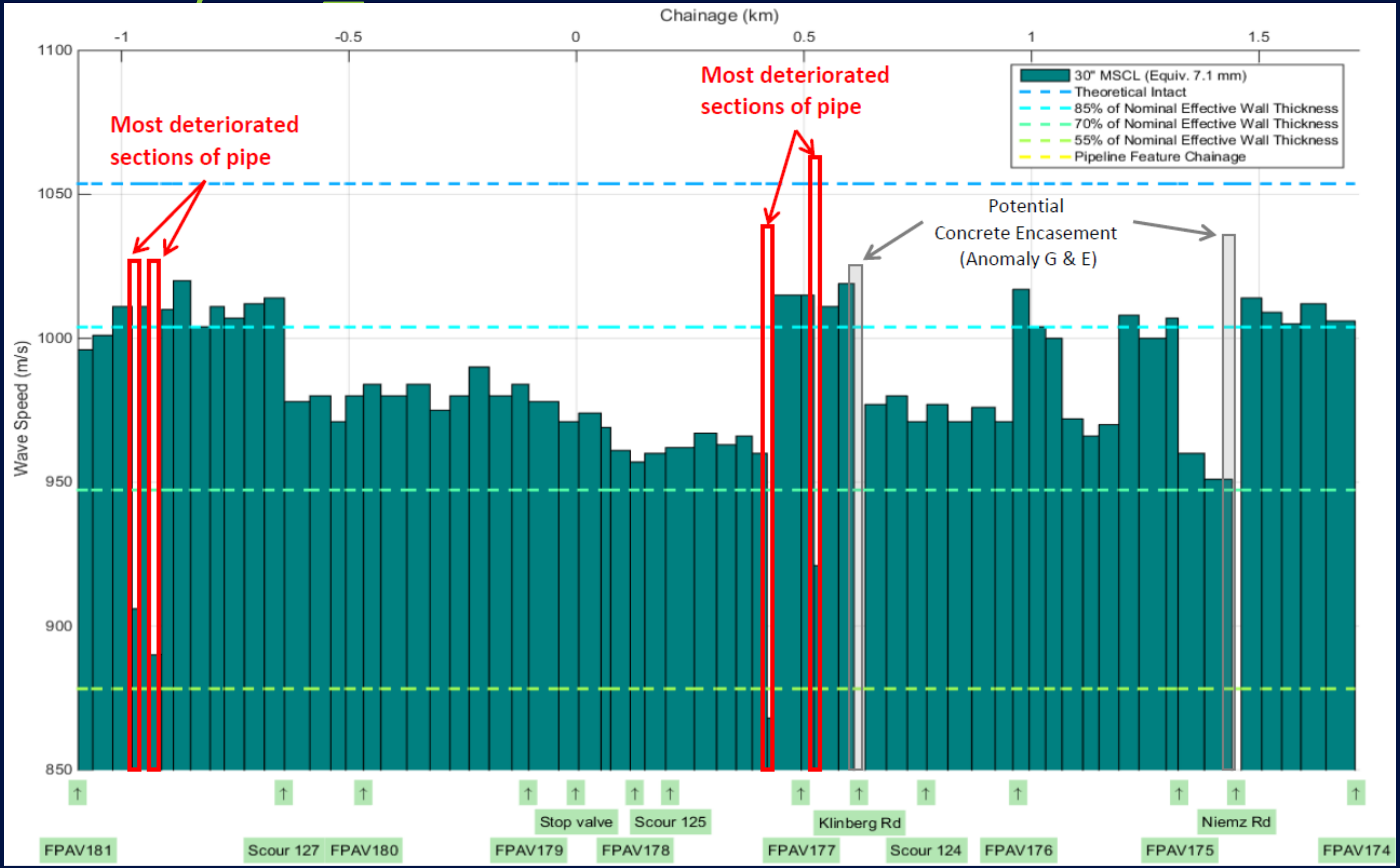
Localised Fault Detection Results

Identifier	Approximate location	Interpretation	Priority	Recommended action
A	127 m south from FPAV181	Potential deterioration	**Medium**	Further investigation recommended
B	169 m south from FPAV181	Potential deterioration	**Medium**	Further investigation recommended
C	220 m south from FPAV181	Section of replacement	Low	None, known system component
D	106 m north from FPAV179	Section of replacement	Low	None, known system component
E	69 m north from FPAV177	Potential air pocket or deterioration	**Medium**	Further investigation recommended
F	34 m south from FPAV177	Potential deterioration	**Medium**	Further investigation recommended
G	116 m south from FPAV177	Potential concrete encasement for pipe section under Klinberg Road crossing	Low	Check for record of concrete encasement
H	91 m south from FPAV176	Potential presence of blockage	**Medium**	Further investigation recommended
I	115 m south from FPAV175	Potential concrete encasement for pipe section under Niemz Road crossing	Low	Check for record of concrete encasement

Sub-sectional Pipe Wall Condition Results

Section Identifier	Approx. Chainage (m)		Sub-section Location on Pipeline	Assumed Pipe	Approx. Length (m)	Theoretical Thickness (mm)		Remaining Total Equivalent Wall Thickness [1] (Difference between metal wall or cement mortar lining from the nominal theoretical value)			Sub-Sectional Average Wave Speed (m/s)
	Start	End				Wall	Lining	Wall (mm)	Lining (mm)	% remaining	
S38	419	432	Anomaly E - potential air pocket or deterioration	30"MSCL	13	5.7	12	3.8 (-1.9)	0 (-12)	53%	868[3]
S39	432	494	as per chainage	30"MSCL	62	5.7	12	5.7 (0.0)	5 (-7)	88%	1015
S40	494	522	From FPAV177 to 29 m south	30"MSCL	29	5.7	12	5.7 (0.0)	5 (-7)	88%	1015
S41	522	533	Anomaly F	30"MSCL	11	5.7	12	4.6 (-1.1)	0 (-12)	64%	921
S42	533	576	as per chainage	30"MSCL	42	5.7	12	5.7 (0.0)	4 (-8)	87%	1011
S43	576	610	as per chainage	30"MSCL	34	5.7	12	5.7 (0.0)	6 (-6)	89%	1019
S44	610	634	Anomaly G – concrete encasement under Klinberg Rd Crossing	30"MSCL	25						N/A [4]
S45	634	681	as per chainage	30"MSCL	47	5.7	12	5.6 (-0.1)	0 (-12)	77%	977
S46	681	727	as per chainage	30"MSCL	45	5.7	12	5.6 (-0.1)	0 (-12)	78%	980
S47	727	770	as per chainage	30"MSCL	43	5.7	12	5.4 (-0.3)	0 (-12)	76%	971
S48	770	816	Scour 124 to 46 m south	30"MSCL	46	5.7	12	5.6 (-0.2)	0 (-12)	78%	977
S49	816	869	as per chainage	30"MSCL	53	5.7	12	5.4 (-0.3)	0 (-12)	76%	971

Case Study #1_ Water Main



Case Study #1_Water Main

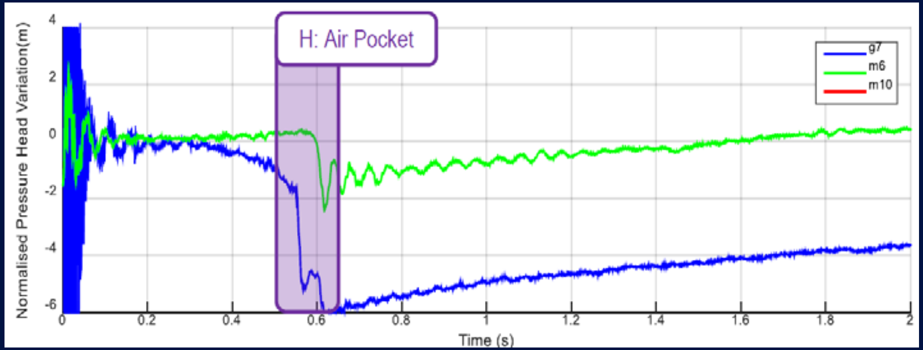
- 2% of the pipeline was found to be in the most deteriorated condition with a remaining wall thickness of between 50% and 64%.
- 68% of the pipeline showed to have some deterioration with a remaining wall thickness of between 70% and 84%.
- The rest of the pipeline (29% of the total length) has remaining wall thicknesses of between 85% and 90%.

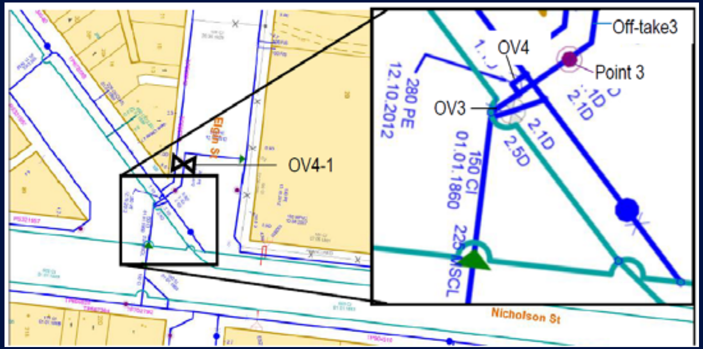
Case Study #2_Water Main

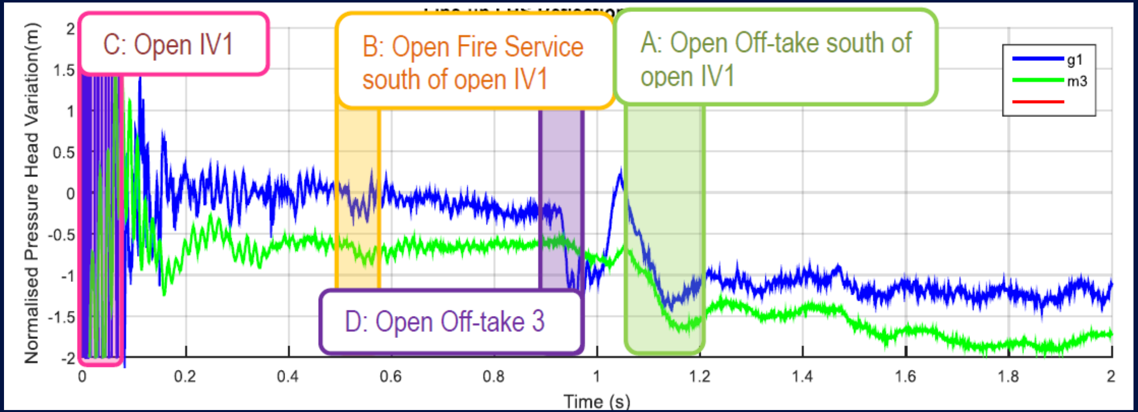
- The tests undertaken on this pipeline were conducted as part of a condition assessment project for a system in a busy CBD area. This particular section was one of two parallel pipelines following a busy main road into the city.

- The 450 CI(CL) water main was constructed from 450 CI in 1886 and later concrete lined in-situ in 1982. The pipe section of interest was 2.8 km and contains two replacement sections of 450 MSCL.

Case Study #2_Water Main







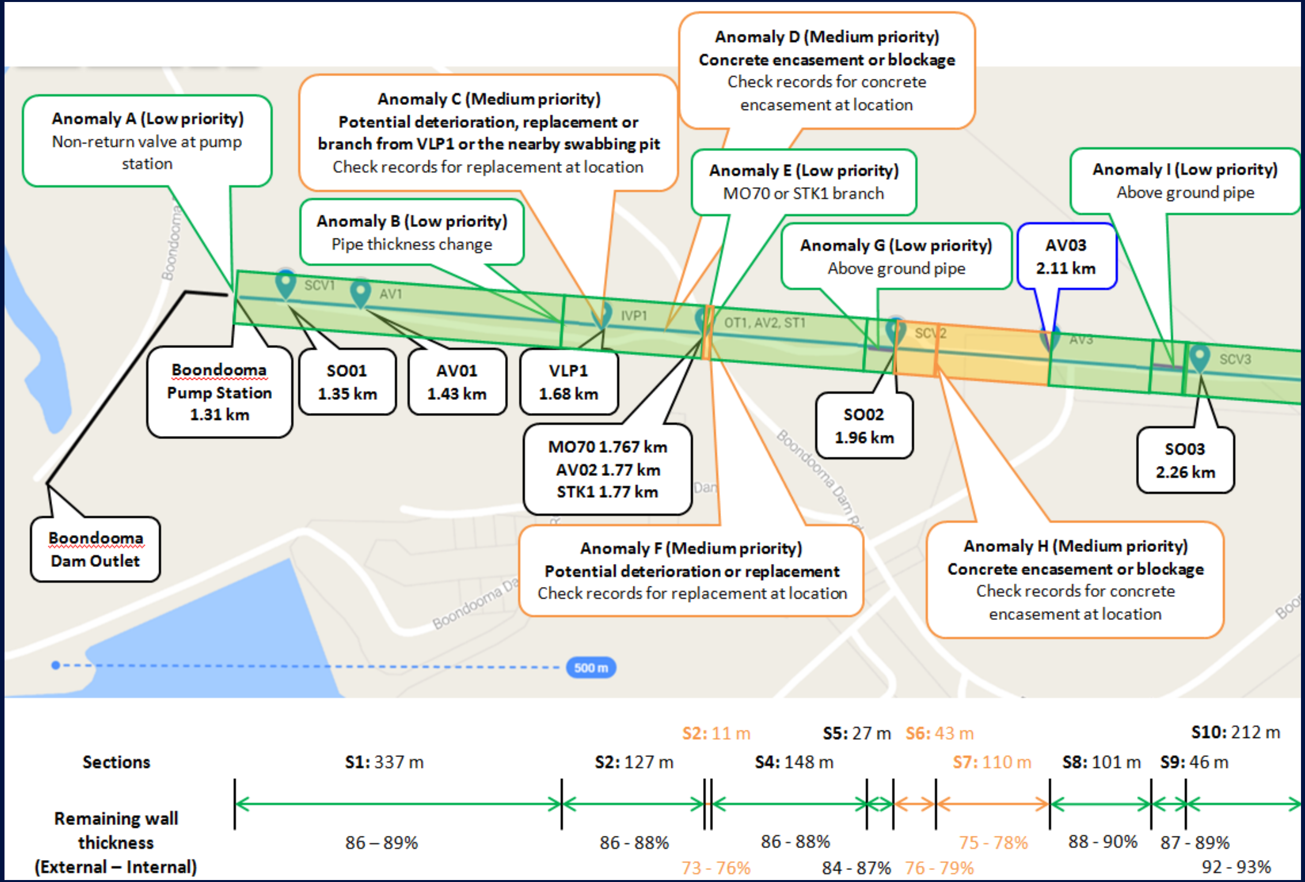
Case Study #3_Water Main

- The pipeline of interest is the first 10 km of the 23.5 km long rising main beginning at a dam pump station. The water rising main was constructed of MSCL, with a 1085 mm outside diameter.

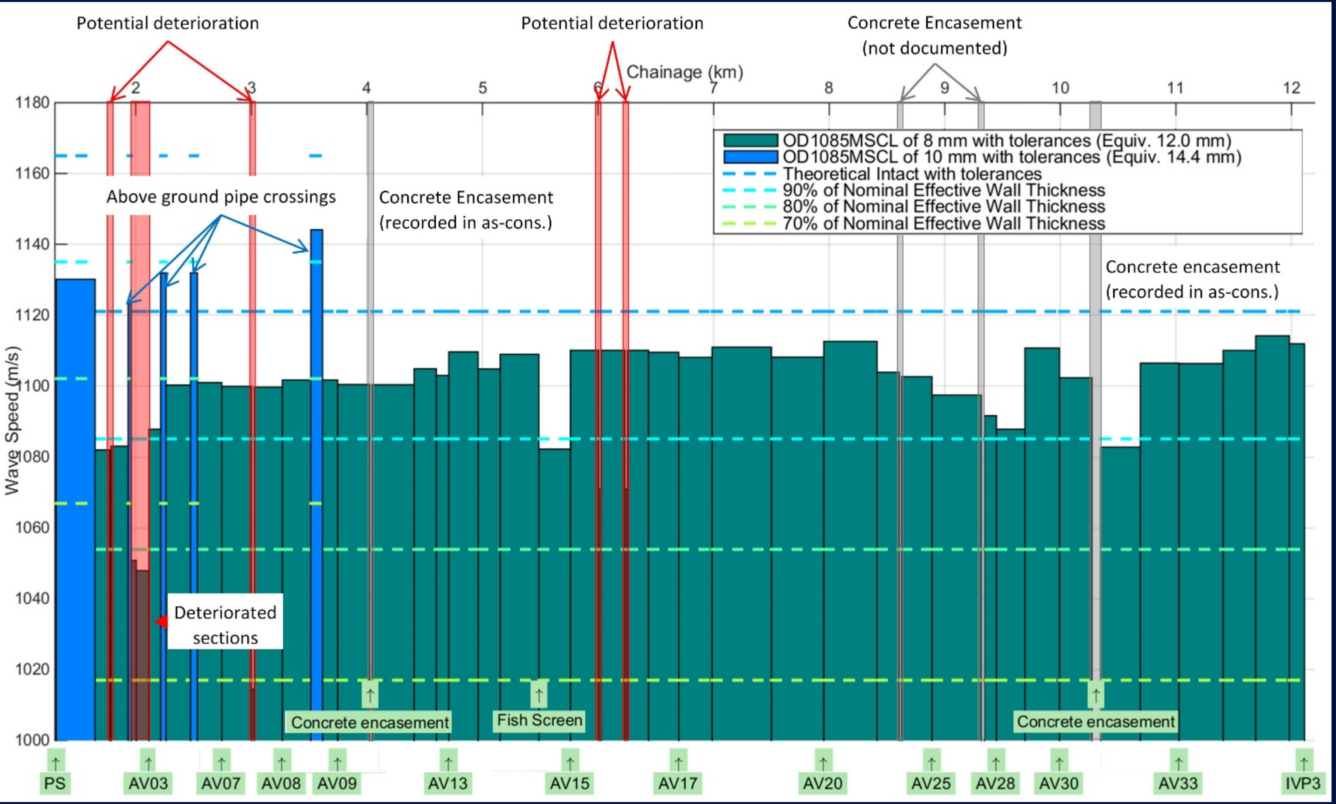
- For the sections with an original wall thickness of 8 mm:
  - 1.7% of the length of the pipeline was found to have the highest deterioration with remaining wall thickness of between 67% and 80%.
  - 9% of the pipeline showed to have remaining wall thickness of between 80% and 90%.

- Fourteen anomalies representing:
  - The presence of a blockage or partially closed isolation valve at an isolating valve pit at 12.11 km.
  - Four short lengths of deterioration or replacement of lower wave speed pipe material.
  - Four short lengths of deterioration, replacement of lower wave speed pipe material, or branch of a known pipe feature
  - Five potential concrete encasement sections or the presence of a blockage.

Case Study #3_Water Main



Case Study #3_Water Main

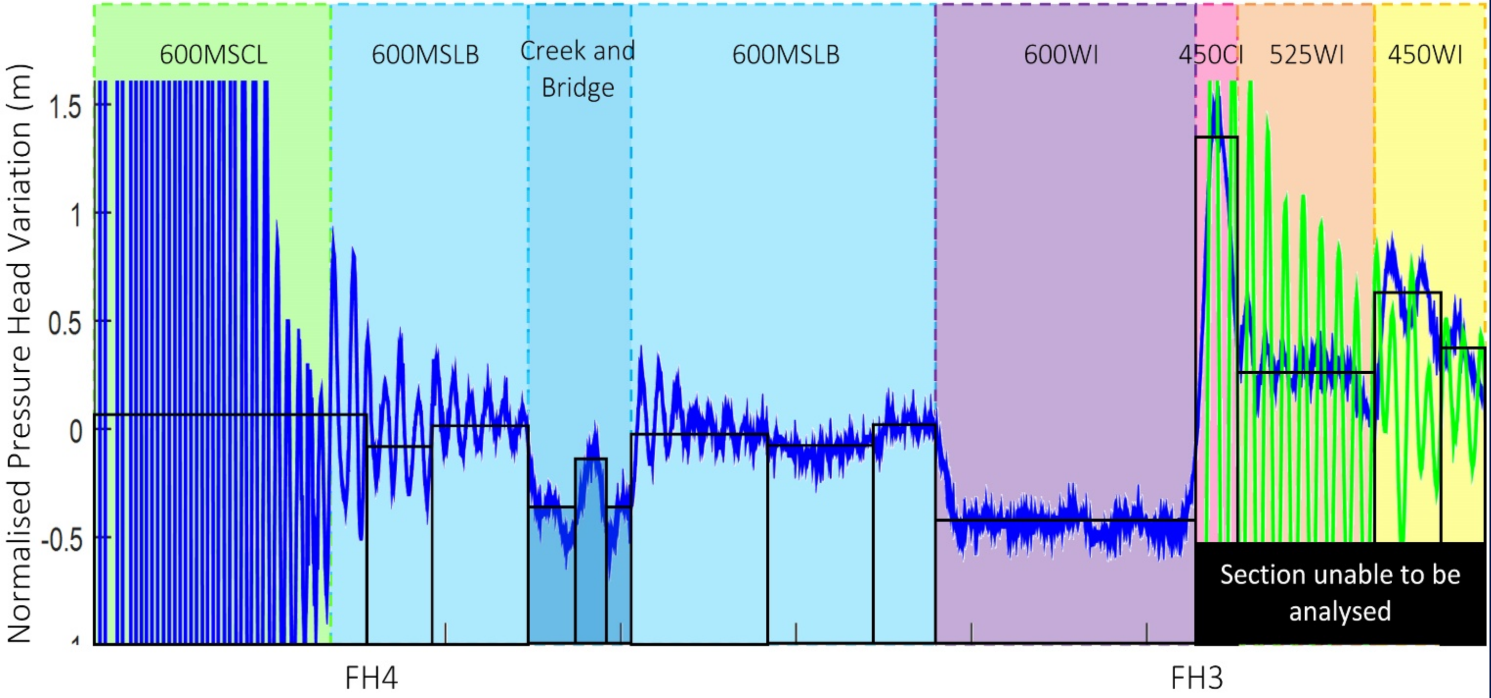


Case Study #4_Water Main

The trunk water main consists of the following various pipe materials and sizes, including some sections with in-situ cement lining:

- 450 and 525 Wrought Iron (WI) constructed in 1893
- with in-situ cement lining added in 1953.
- 600, 700 and 825 Mild Steel Cement Lined (MSCL) constructed in 1979.
- 450 Cast Iron (CI), 600 WI and 600 Mild Steel Locking Bar (MSLB) constructed in 1916 with in-situ cement lining added in 1983.

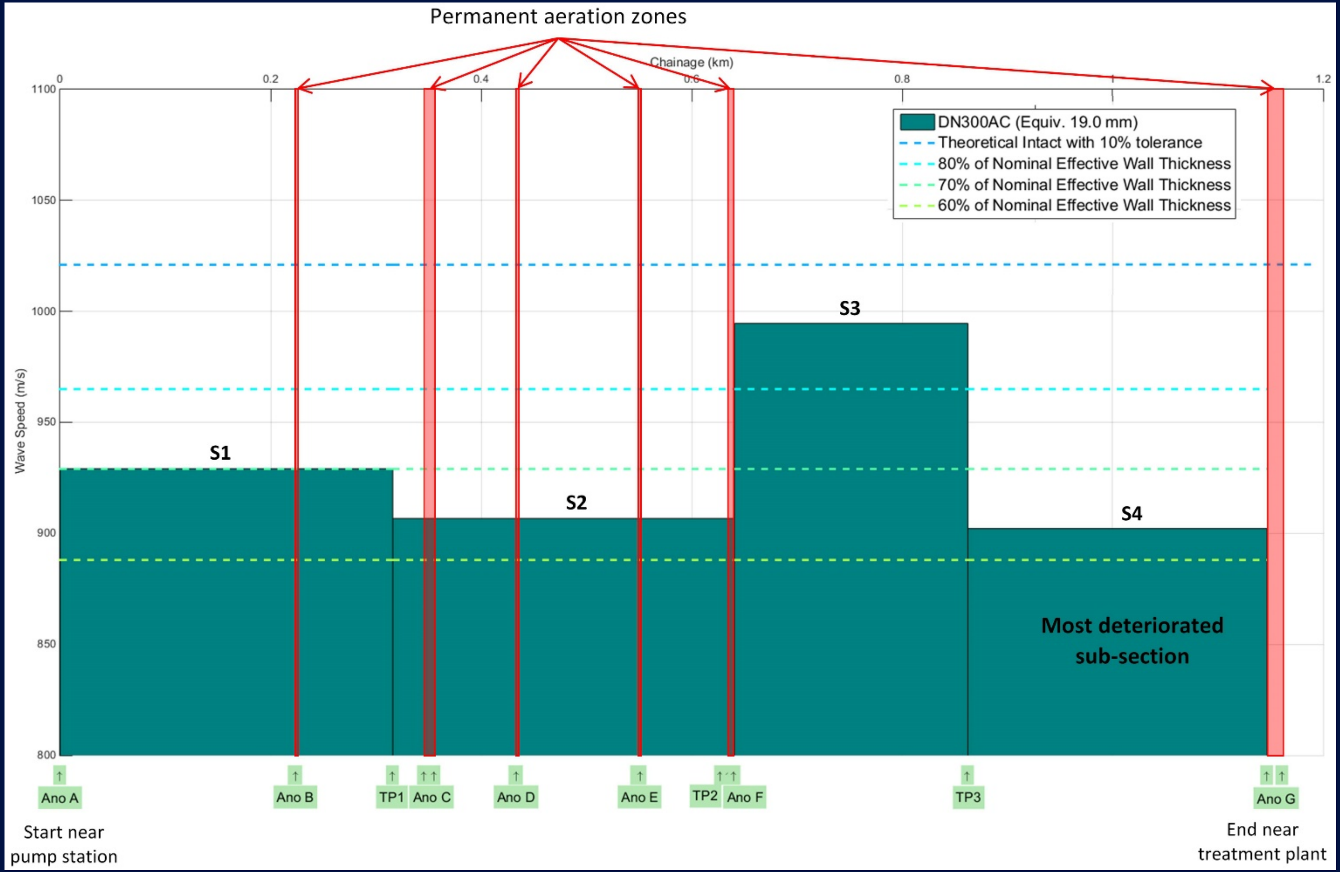
Case Study #4_Water Main



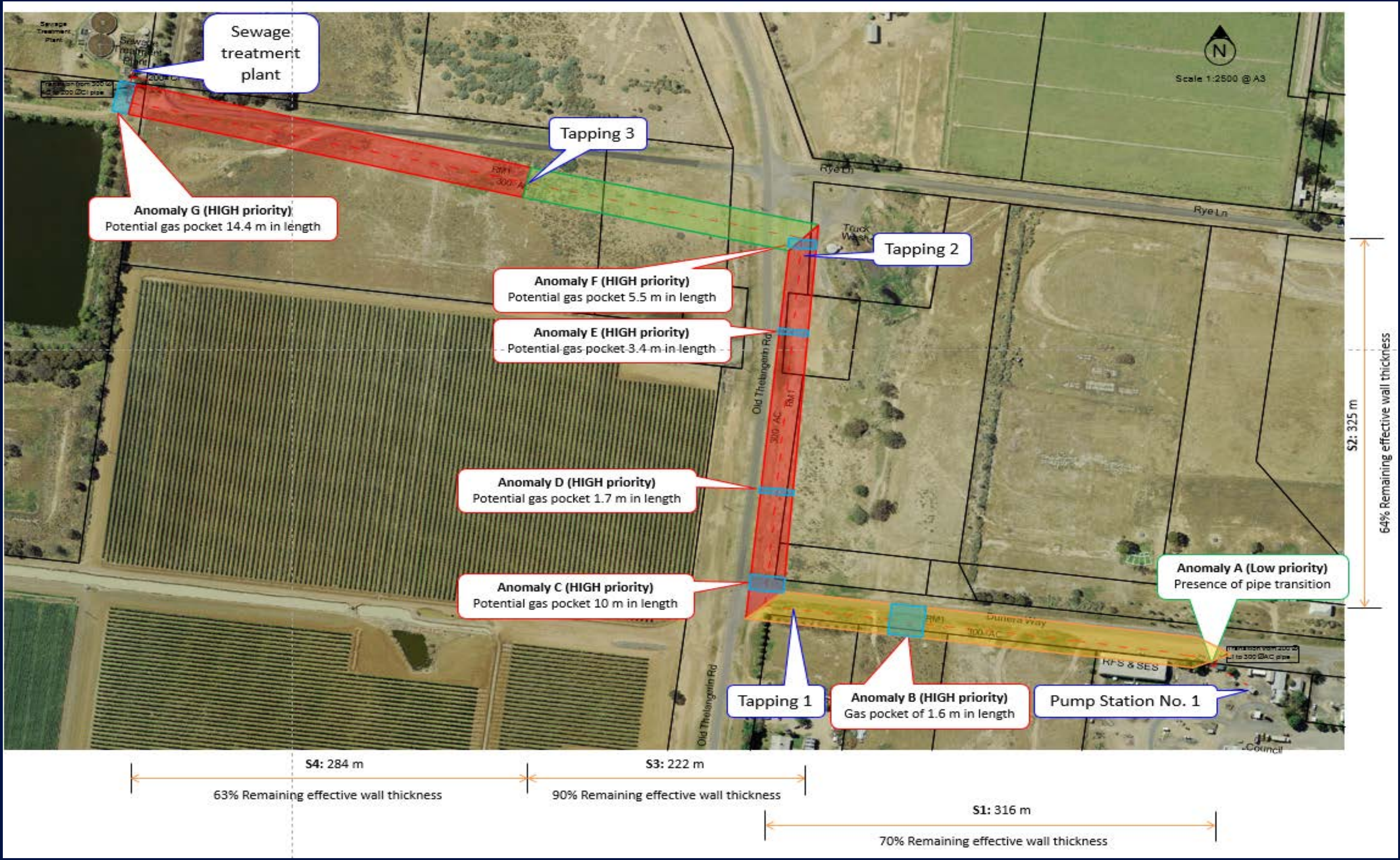
Case Study #5_Sewer Rising Main

The sewer rising main was approximately 1.2 km consisting of predominantly D.N.300 AC. The pipeline section of interest lies between a pump station and an inlet of a sewerage treatment plant.

Case Study #5_Sewer Rising Main



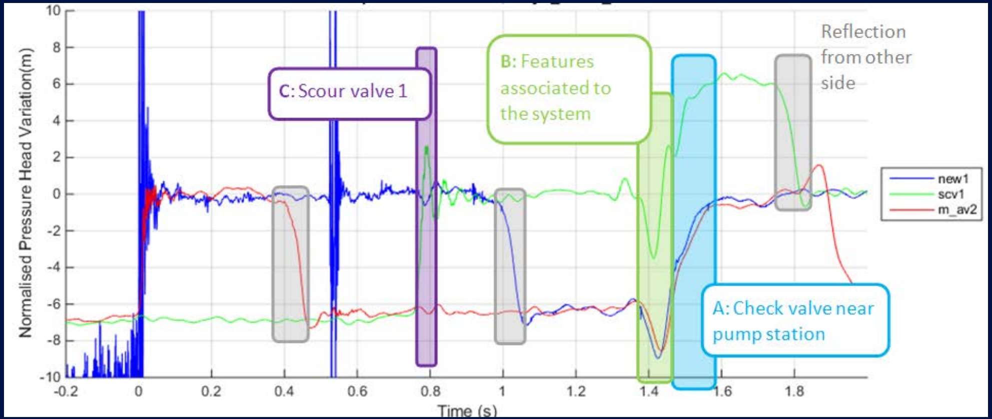
Case Study #5_Sewer Rising Main

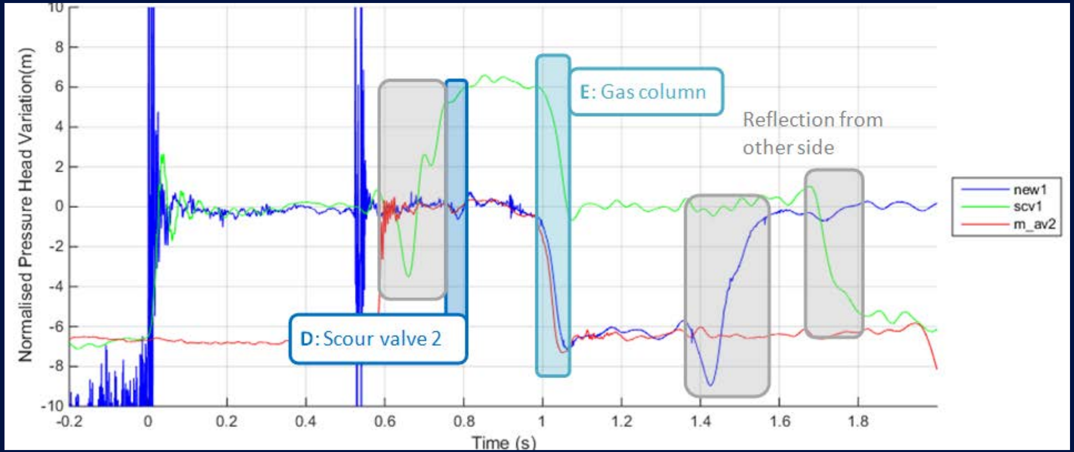


Case Study #6_ Sewer Rising Main

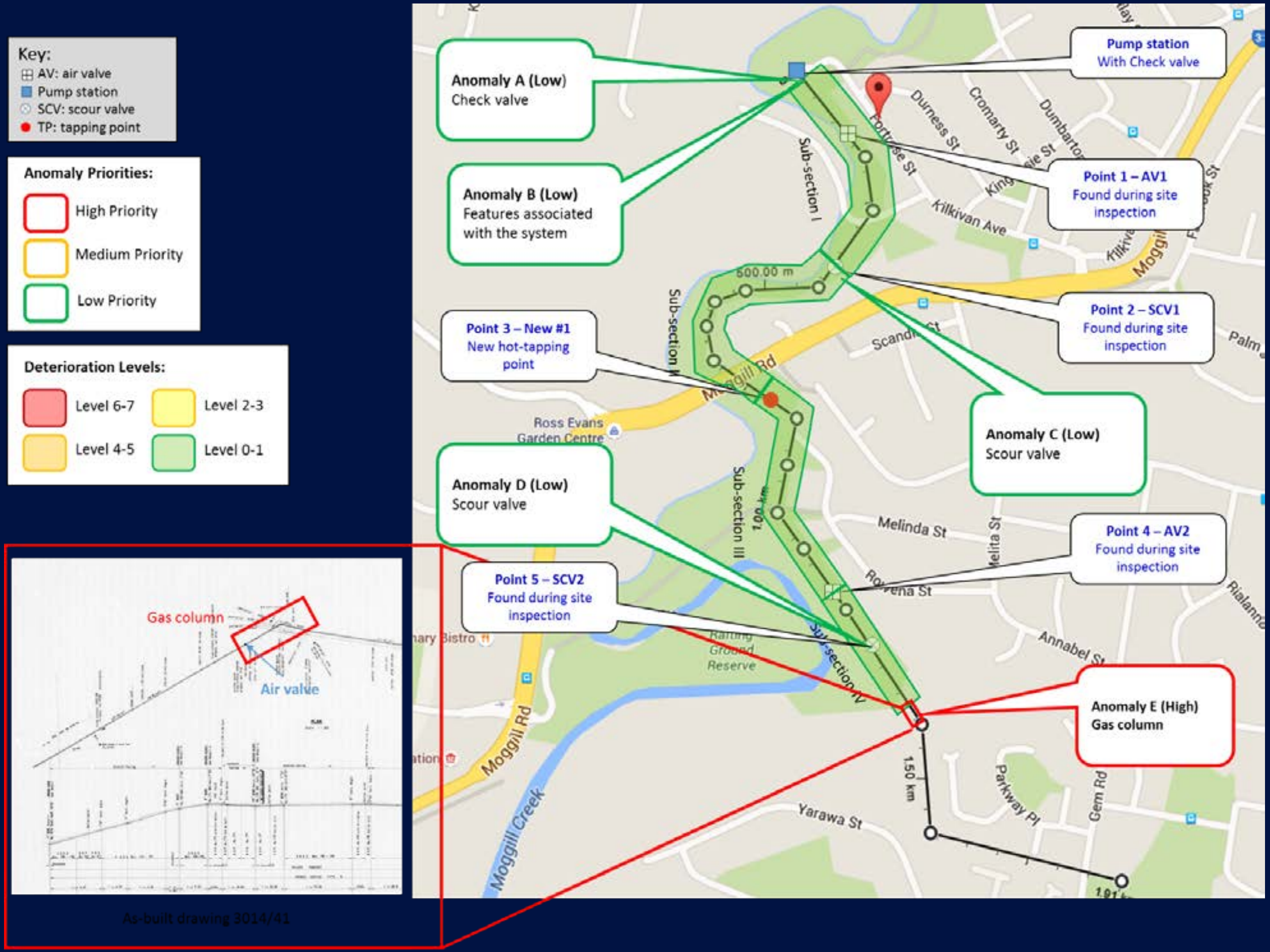
Location	Approx. Length (km)	Size (mm)	Material	Year
Pump station on Fortrose street to SCV2 located near the southern corner between number 18 and 20 Rowena st.	1.25	410 mm (as-built maps)	MS/MSCL	1976 from GIS

Case Study #6_ Sewer Rising Main





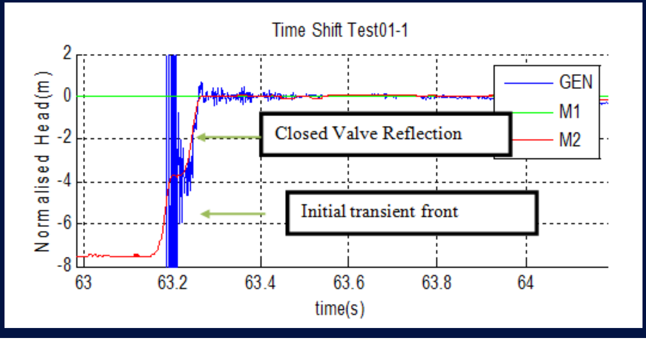
Case Study #6_ Sewer Rising Main

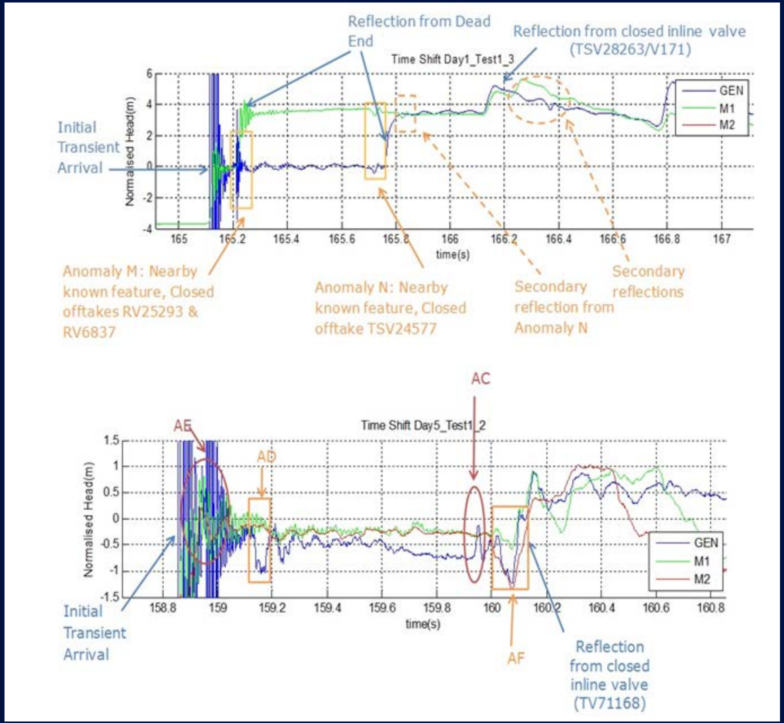


Case Study
Valve Sealing

Corroded valve

Evaluation of transient techniques undertaken at Iron Knob





2006 – 2017 Field Program

For 62 different clients

Such as water utilities, councils, contractors and mining companies

For over 176 different pipeline systems

For over 1500km of pipeline

Thank You

Finding the weak link...

DETECTION SERVICES

PIPELINE INSPECTION AND ANALYSIS