Condition Assessment Report

YXJ Subdivision Water Network and Sewer Network

Draft Report Prepared for:

Peace River Regional District

By:

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1. Executive Summary

In January August 2020, Pure Technologies, a Xylem Brand (Pure Technologies) was contracted to complete condition assessment of watermain network and sewer network in the YXJ subdivision, for the Peace River Regional District, British Columbia. Pure Technologies teamed up with Watermark Solutions for the watermain network external leak survey and AquaCoustic Remote Technologies to complete CCTV inspection of the sewer network.

The scope of work included:

- 2.3-Kilometre External leak survey on watermain network of Asbestos-Cement pipe and valve assessment
- 2.2-Kilometre CCTV survey on sewer network of Clay pipe and data analysis
- 30-days of Transient Pressure Monitoring
- AWWA design check of Asbestos-Cement pipe
- Condition Assessment Report summarizing the results and recommendations

Based on the external leak survey, CCTV survey, valve assessment, transient pressure monitoring, and the design check, Pure Technologies concludes and recommends the following:

1. One (1) leak was located during the survey. This was a leak on a hydrant lead on the hydrant located outside 10330 257 Rd. Good leak noise was audible on the hydrant and on the secondary isolation valve. The valve itself was the likely source of the leak and maintenance is required as soon as possible.

2. Seven (7) inline valves and eight (8) hydrants were located and assessed. Inline valves#1 and #2 could not be accessed, valves #3 and #7 were stuck and could not be turned and isolation valve for Hydrant G was stuck and could not be turned. Maintenance is required as soon as possible to ensure operability of these valves.

3. Without direct information on the physical condition of the watermain network's asbestos-cement pressure pipe, a prediction of the pipe's remaining life is not feasible. Pure has been informed that no failures have occurred in this pipe and there was nothing of concern found in the design check, which is an indicator that the pipe is still in relatively good condition. There are still thousands of kilometers of asbestos-cement pressure pipe in operation around the world, including Canada and the US. Most of this pipe has been in service well over 40 years with some now approaching 65 years in service. Strictly based on this information, the PRRD YXJ subdivision asbestos-cement pressure pipe might continue to operate under the current loading conditions for another 15 to 20 years.

4. Given the application, namely water distribution, it would be reasonable to expect the asbestos-cement pipe has not suffered any severe degradation unless its conveying "soft" water or is subjected to acidic sulfate bearing soils or groundwater. If PRRD wants some assurance that the pipe is still in good working condition then it would be advisable to check the Langelier Index (or Aggressiveness Index) of the water being conveyed through the pipes. It would also be advisable to retain a soils testing lab and have several tests run on soil samples extracted from the pipe zone. If the conveyed water is found to

be “soft” (Langlier Index less than -2.0) or the surrounding soils and groundwater contain soluble sulfate exceeding 20,000 mg/L or 10,000 mg/L respectively, then it would be recommended to extract a sample of the pipe from the line for laboratory testing. The laboratory testing would include microscopic examination of the wall cross-section, pH indicator testing of the pipe wall and a crush test. This would provide direct evidence on the physical condition of the pipe. A prediction of the remaining service life could be rendered at that point.

5. All defects observed during the CCTV survey of the sewer network, were graded from 1 to 5, with 5 being the most severe. Pipe defects with a grade of 5, especially a structural defect, should be repaired or replaced immediately as collapse of the pipe or fitting is imminent. Defects graded 4 should be addressed within the year, and defects graded 1 through 3 need to be periodically monitored to ensure they don’t continue to deteriorate rapidly. Based on a review of the CCTV video in conjunction with the PACP coding, some sewer lines need to be repaired (point repairs), replaced (CIPP) or cleaned (jet cleaning) for maintenance issues. To monitor deteriotion of the sewer network, it is recommended to do a routine inspection bi-annually. Refer to Appendix C for a detailed list of recommendations.

6. Pressure data collected using a pressure monitor installed on a hydrant, over a period of approximately 30 days indicated there is little difference between the minimum, average and maximum recorded values. Majority of the maximum pressure measurements (applies to minimum and average too) falls into a very narrow band and 70% of all maximum pressures fall between 53 and 55 psi. The two maximum recorded pressures above 60 psi, which occurred at 9:00AM and 9:04AM on September 3, 2020, were probably due to some minor transient event in the system.

7. The AWWA C401 design check found the pipe, assuming no significant degradation, to be operating well within the defined safety limits recommended by the AWWA standard. In fact, the factor of safety in pressure was 8.0 and for external load 4.19. This is versus a recommended minimum value of 4.0 and 2.5, respectively.

2. Introduction

The Peace River Regional District (PRRD) retained the services of Pure Technologies, a Xylem brand (Pure Technologies) to perform inspection of the 150mm watermain network & 200mm gravity sewer network for YXJ Subdivision in Fort St John, BC. The purpose of the inspection was to detect and locate leaks, perform valve assessment within the watermain network and assess the internal condition of sewer network. Given the complex nature of the network (multiple pipeline, short distances, smaller diameter, etc.) that would limit the use of inline inspection tools, Pure Technologies teamed up with Watermark Solutions for the watermain network external leak survey and AquaCoustic Remote Technologies to complete CCTV inspection of the sewer network.

In addition to the watermain network external leak detection survey and valve assessment; Pure Technologies performed transient pressure monitoring and conducted an AWWA design evaluation on the AC pipe (to determine if the pipe design is adequate for internal/external loading).

2.1 Background

The YXJ Subdivision watermain network is comprised of approximately 2.3 kilometres of 150-millimetre Asbestos Cement Pipe (ACP) and the sewer network is approximately 2.2 kilometres of 200-millimetre Vitrified Clay Pipe (VCP). The watermain and sewer network serves about 60 households in this neighbourhood.

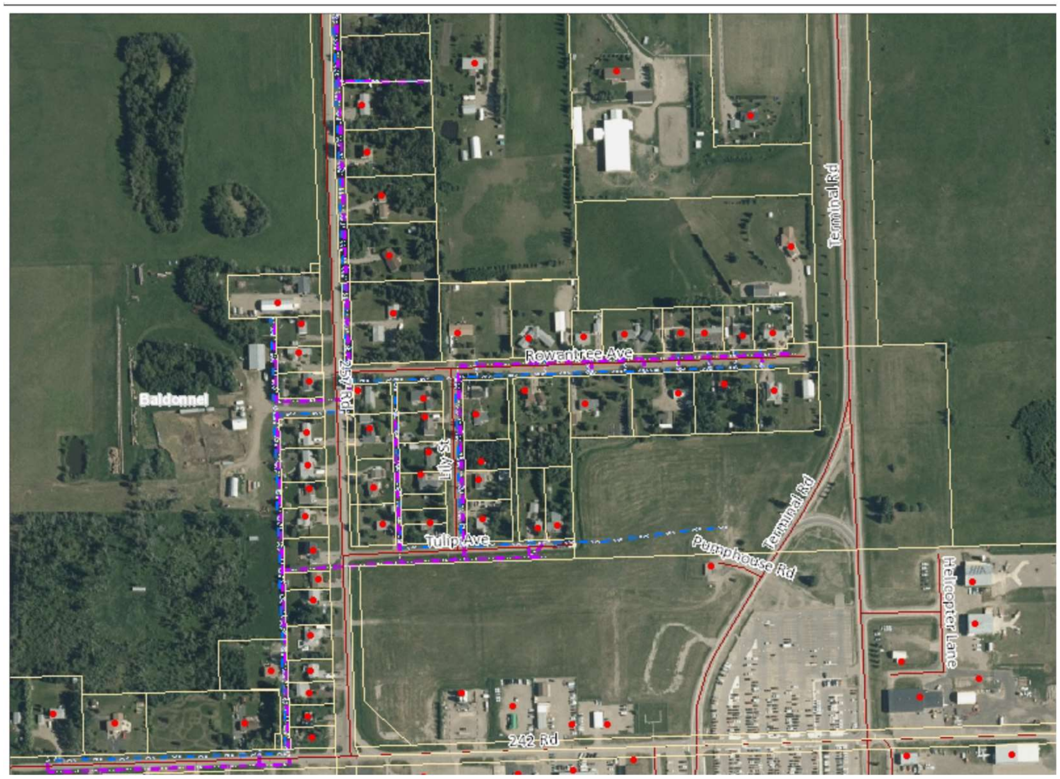

Figure 2.1: Inspection Scope of the 150mm watermain network and 200mm sewer network

3. Project Scope

This condition assessment report of the watermain and sewer network, provides findings from the network assessment. The following investigative techniques were deployed:

- External leak survey of watermain network
- CCTV inspection of sewer network
- Transient Pressure Monitoring
- Valve Assessment
- AWWA design evaluation

4. Inspection Overview

External leak survey for the watermain network and valve assessment was completed by Watermark Solutions the week of August 17th, 2020 and CCTV survey of the sewer network was completed by AquaCoustic Remote Technologies the week of August 24th, 2020. Pressure was monitored on the watermain network for a period of 30-days to collect transient pressure data.

4.1 Watermain Network

4.1.1 External Leak Survey

At the start of the external leak survey, a systematic "listening" procedure was used. The technician "listened" for sound on direct contact points such as main line gate valves, fire hydrants, meters/curb-valves, blow-offs, etc. On the mains, staff used a ground microphone to listen over the main approximately every two to three meters. With this method, comprehensive coverage of the system was attained, and all leak sounds were investigated and pinpointed immediately.

Any leak noises that were located by the field staff throughout the distribution system was graded by severity and this enabled the field technician to prioritize and identify the larger leaks first, then the technician systematically worked through the smaller leak noises. The Leak noises were then graded from 1 to 5, 5 being the typical sized mains break and 1 being a very small leak such as a weeping curb box or valve.

The noise produced by pressurized water forcing its way through a crack or joint makes a distinct sound when listened to on pipes, valves or services and as a proven method for leak detection, the Ground Microphone was used as acoustic listening device. Potential leak sites were identified by this method and further localized by Correlation Testing.

Figure 4.1: X-Mic Ground listening system

4.1.2 Valve Assessment

The valve assessment work was performed in accordance with the AWWA M44 standard. For the direct buried valves, Pure determined if the valve could be located, accessed and mechanically operated (if so, valves were exercised and turn count documented). The findings were documented, the as-is condition photographed, and GPS coordinates were taken.

4.1.3 Transient Pressure Monitor

Hydraulic pressure transients occur in pipelines when the steady-state conditions of the system change due to pressure and/or flow disturbances (e.g., the rapid closure of a valve, pump startup/ shutdown, air pockets). Transient pressure monitoring (TPM) captured these pressure transients, as well as captured the working pressures of a pipeline. Figure 4.2 shows an example of transient pressure data gathered on a pipeline.

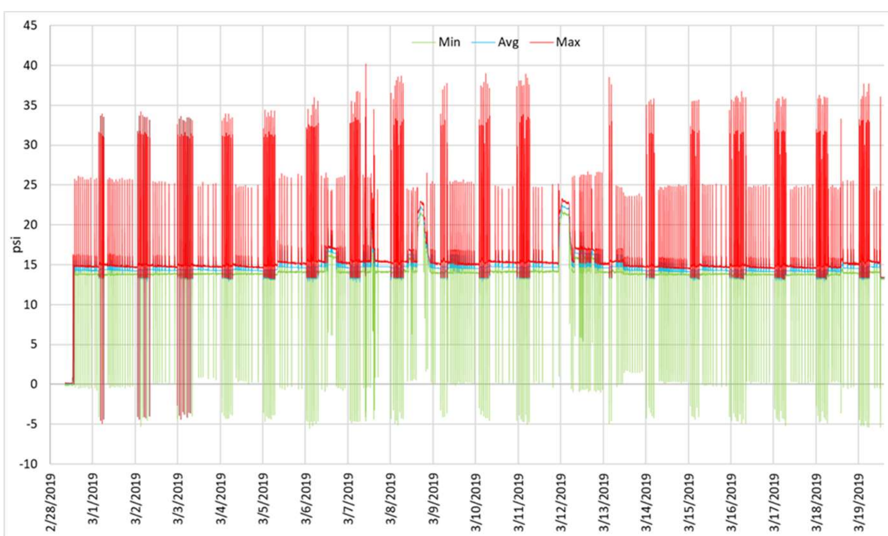

Figure 4.2: Example Transient Pressure Monitoring Data

A TPM was installed on a hydrant in the YXJ Subdivision for 30-days. Figures 4.3 and 4.4 below shows the Telog HPR installed on a hydrant.

Figure 4.3: Telog HPR on Hydrant

Figure 4.4: Telog HPR

4.2 Gravity Sewer Network

4.2.1 CCTV Inspection

A small crawler was deployed from a short-range system (~190 meters) to inspect the distances between manholes (~100 meters). The crawler was inserted into upstream manholes and surveyed downstream. In some locations, due to blockage, the sewer network was surveyed upstream from the downstream manhole. The video file was analyzed, and areas of concern recorded, including a NASSCO PACP coded observations table. PRRD flushed the gravity sewer pipes prior to inspection.

5. Inspection Results

5.1 Watermain Network External Leak Survey

Pure Technologies subcontracted Watermark Solutions to conduct an Acoustic Leak Survey at the subdivision adjacent to North Peace Regional Airport. The water system for the subdivision is fed from a main linked to the airport's domestic water supply. Between 50 and 55 properties are connected to the water mains which are made of asbestos cement material with a diameter of 150mm. There are eight hydrants with secondary isolation valves and seven main line valves throughout the system which is approximately 2 kms in total pipe length.

A shed to the south east of the subdivision contains the main system control valve (with bypass) and a Sensus water meter. Watermark Technician Lee Stansfield attended the location on August 17th and 18th, 2020. On August 17th, majority of valve assessment operations were carried out with Pure Technologies and Peace River Regional District assisting. On August 18th, a comprehensive acoustic leak detection survey was completed.

All hydrants, hydrant isolation valves, all main line valves and any located service valves (curb-boxes) in the subdivision were sounded using an X-Mic ®. This is an electronic device similar to a microphone or a stethoscope with which a trained operator can detect leaks on a water pipe.
One leak was located during the survey. This was a leak on a hydrant lead on the hydrant located outside 10330 257 Rd. (Figure 5.1). Good leak noise was audible on the hydrant and on the secondary isolation valve. When the isolation valve was operated, the leak noise increased and water began to surface in the valve box. This indicated that the valve itself was the likely source of the leak and maintenance is required as soon as possible.

Figure 5.1: Leak on hydrant located outside 10330 257 Road

Prior to this survey a similar leak on the southernmost hydrant on Rowantree Ave had been noted and stopped by Peace River Regional District. These two leaks were the likely cause of any ongoing substantial water loss within the community. Meter readings at the main subdivision supply were taken 48 hours apart after the leak detection survey with one of these leaks still needing attention.

These revealed an average of 16 l/h being fed into the system which is within the bounds of normal domestic usage. The repair of the remaining hydrant leak should reduce this further.

5.2 Watermain Network Valve Assessment

On August 17th, 2020, Watermark assisted Pure to perform a valve assessment on the system's main line and hydrant secondary valves. Pure Technologies also carried out a GPS location survey on all main and hydrant valves and hydrants within the system.

Figure 5.2: Location of Inline Valves and Hydrants

From the drawings provided, seven (7) inline valves were identified in the watermain network within the inspection limits. Inline Valves 1 and 2 could not be accessed as it is located in fence line in neighboring airport field.

5.2.1 Inline Valve#3

Type: 6-inch Gate Valve
Location: South of Lily-Rowantree

Notes: Buried 1 foot under gravel and raised back up while onsite. Value stuck and could not be turned.

Figure 5.3: Inline Valve#3

5.2.2 Inline Valve#4

Type: 6-inch Gate Valve
Location: Right of Way south of Rowantree and between 257 Road and Lily
Notes: Cap was stuck on and repaired onsite
Turn count: approximately 17.75 turns; fully closed and fully opened

Figure 5.4: Inline Valve#4

5.2.3 Inline Valve#5

Type: 6-inch Gate Valve
Location: Northeast corner od 257 Rd and Rowantree
Notes: Buried 1 foot in ditch; raised back up while onsite
Turn count: approximately 19.5 turns; fully closed and fully opened

Figure 5.5: Inline Valve#5

5.2.4 Inline Valve#6

Type: 6-inch Gate Valve
Location: Off of gravel right of way, southeast of 257 road and Rowentree
Turn count: 20.25 turns; fully closed and fully opened

Figure 5.6: Inline Valve#6

5.2.5 Inline Valve#7

Type: 6-inch Gate Valve
Location: On 242 road (242 road – 257 road intersection)
Notes: Valve was buried, and casing broken; cleaned up and raised. Valve could not be exercised.

Figure 5.7: Inline Valve#7

5.2.6 Hydrant A

Type: 6-inch isolation Gate Valve
Turn count: 19.5 turns; fully closed and fully opened

Figure 5.8: Hydrant A

5.2.7 Hydrant B

Type: 6-inch isolation Gate Valve
Turn count: 20.25 turns; fully closed and fully opened
Notes: Keys stuck on extension

Figure 5.9: Hydrant B

5.2.8 Hydrant C

Type: 6-inch isolation Gate Valve
Turn count: 20.5 turns; fully closed and fully opened
Notes: Leaks when valve operated

Figure 5.10: Hydrant C

5.2.9 Hydrant D

Type: 6-inch isolation Gate Valve
Turn count: 20.25 turns; fully closed and fully opened

Figure 5.11: Hydrant D

5.2.10 Hydrant E

Type: 6-inch isolation Gate Valve
Turn count: 20.5 turns; fully closed and fully opened
Notes: Leaks when valve operated

Figure 5.12: Hydrant E

5.2.11 Hydrant F

Type: 6-inch isolation Gate Valve
Turn count: 20.25 turns; fully closed and fully opened
Notes: Leaks when valve operated

Figure 5.13: Hydrant F

5.2.12 Hydrant G

Type: 6-inch isolation Gate Valve
Notes: Valve extension not on valve nut; could not be exercised

Figure 5.14: Hydrant G

5.2.13 Hydrant H

Type: 6-inch isolation Gate Valve
Turn count: 20.25 turns; fully closed and fully opened

Figure 5.15: Hydrant H

5.3 Sewer Network CCTV Survey

The PRRD YXJ subdivision's sanitary sewer system was CCTV surveyed by AquaCoustic Remote Technologies from August 24 to August 28, 2020. In total 26 lines between manholes were surveyed. The technician reviewing the video during the survey coded all defects observed in accordance to NASSCO's PACP grading system. This included both structural defects such as cracks, fractures, and breaks in either the barrel of the pipe or taps, as well as operational and maintenance defects such as root intrusion, debris, obstructions, encrustations in the barrel or at joints and infiltration stains at joints.

All defects observed were graded from 1 to 5, with 5 being the most severe. Typically a pipe defect receiving a grade of 5, especially a structural defect, should be repaired or replaced immediately as collapse of the pipe or fitting is imminent. Defects graded 4 should be addressed within the year, and defects graded 1 through 3 need to be periodically monitored to ensure they don't continue to deteriorate rapidly.

Table 5.1 summarizes the PACP coding data for the entire system, by line. The Structural Pipe Rating or O&M Pipe Rating is the sum of the product of each number of defect times it's grade. The larger this number the greater number of significant defects found. The Structural Pipe Rating Index is the Structural Pipe Rating divided by the total number of structural defects found in each line. Likewise for determining the O&M Pipe Rating Index. When these indices exceed 3.0 it means that a majority of the defects found in the line are of a very serious nature.

There was no active infiltration observed in any of the lines during the survey. All manhole interiors appeared to be in reasonable good shape and not requiring any maintenance or repair.

A review of the index data in Table 5.1 suggests that lines SMH 9 to SMH 10, SMH 9 to SMH 8, and SMH 7 to SMH 6 have some significant structural defects, while lines SMH 9 to SMH 8, SMH 11 to SMH 10 and SMH 3 to SMH 4 have a large number of serious defects. Line SMH 9 to SMH 8 falls into both categories. Line SMH 3 to SMH 4 also has a large number of structural defects. Details of each noted defect can be found in Appendix C.

Start Manhole	End Manhole	Structural Defects			Operational & Maintenance Defects			Pipe Material
		No. of Structural Defects	Structural Pipe Rating	Structural Pipe Rating Index	No. of O&M Defects	O&M Pipe Rating	O&M Pipe Rating Index	
SCO 2	SMH 11	7	17	2.4	21	34	1.6	VCP
SMH 11	SMH 10	12	35	2.9	63	120	1.9	VCP
SMH 9	SMH 10	8	26	3.3	70	138	2.0	VCP
SMH 9	SMH 8	9	39	3.3	78	152	1.9	VCP
SMH 8	SMH 7	9	16	1.8	23	46	2.0	VCP
SMH 7	SMH 8	3	5	1.7	22	44	2.0	VCP
SMH 7	SCO 1	9	21	2.3	60	118	2.0	VCP

SMH 7	SMH 6	1	3	3.0	52	102	2.0	VCP
SMH 6	SMH 5	5	13	2.6	65	131	2.0	VCP
SMH 102	SMH 101	1	3	3.0	4	10	2.5	PVC
SMH 101	SCO 3	0	0	0.0	3	6	2.0	PVC
SCO 3	SMH 17	4	9	2.3	25	50	2.0	VCP
SMH 16	SMH 17	3	7	2.3	83	163	2.0	VCP
SMH 16	SMH 15	8	21	2.6	55	107	1.9	VCP
SMH 15	SMH 14	5	15	3.0	19	38	2.0	VCP
SMH 13	SMH 14	8	20	2.5	18	32	1.8	VCP
SMH 13	SCO 5	8	18	2.3	47	95	2.0	VCP
SMH 12	SMH 13	11	29	2.6	9	16	1.8	VCP
SMH 18	SMH	10	23	2.3	38	78	2.1	VCP
SMH 12	SMH 18	11	32	2.9	34	63	1.9	VCP
SMH 12	SMH 5	7	19	2.7	48	92	1.9	VCP
SMH 4	SMH 5	12	29	2.4	20	39	2.0	VCP
SMH 3	SMH 4	18	47	2.6	74	140	1.9	VCP
SMH 3	SMH 2	9	24	2.7	74	144	1.9	VCP
SMH 2	SMH 1	3	5	1.7	52	101	1.9	VCP
SMH 1	SMH	0	0	0	6	12	2.0	PVC

Figure 5.1: Summary of CCTV survey results

Based on a review of the CCTV video in conjunction with the PACP coding, a number of pipe barrel locations as well as factory tee fittings and break-in taps will need to be repaired. Many of these can be point repairs. However, one line (SMH 3 to SMH 4) in particular would probably be best rehabilitated by a cured in place (CIPP) liner through the whole line. There are also a couple lines that should be cleaned given the large amount of debris that has accumulated at dips or inverted siphons in these lines.

Appendix C reviews each line in detail and identifies those structural items that need to be addressed, either with a repair or replacement, or jet cleaning for maintenance issues.

6. Transient Pressure Monitoring

6.1 Pressure Monitoring Details

The Telog high speed pressure transducer was installed on the fire hydrant (HYD B) located at the southeast corner of Rowantree Ave. (Road A) and Lily St. (Road D). This location (see Figure 6.1) was selected because it is approximately in the middle of the YXJ Subdivision serviced by the 6-inch AC water main.

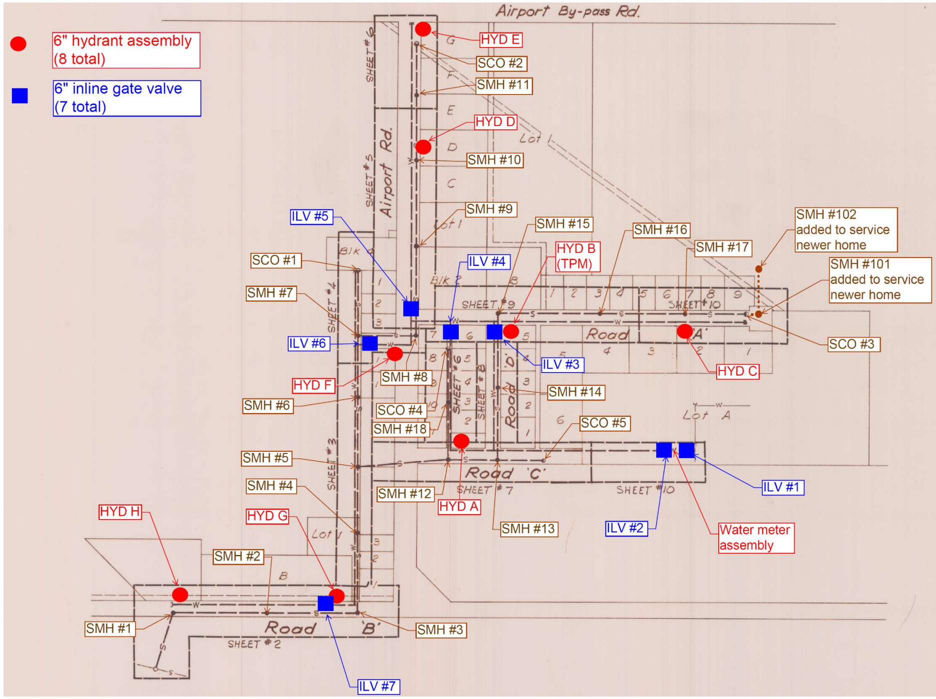

Figure 6.1: Location of Hydrants and Gate Valves in the 6-inch AC Water Mains

The transducer was activated on August 17, 2020 at 9:28 AM and was deactivated on September 15, 2020 at 11:32 AM. Pressure measurements are recorded every 4 minutes. If a transient (water hammer) event is detected, then the transducer records the pressure in micro-seconds. During the nearly one-month monitoring period 10,473 pressure measurements were recorded every 4 minutes. No significant surge pressure was detected.

Appendix A graphically shows the minimum, average and maximum pressure recorded during that month-long cycle. There is little difference in the minimum, average and maximum pressure over this time cycle due to the relatively short period (4 minutes) between pressure data recordings.

On September 3, 2020 at 10:08 AM a minimum pressure of magnitude -5.08 psi was recorded. This negative pressure lasted a duration of 3-1/2 hours, until 1:36 PM. An hour proceeding this registration of a negative pressure, the maximum pressure of 62.76 psi was recorded. This maximum pressure lasted approximately 8 minutes (2 recording cycles) before returning to a more normal level. It is suspected that the pressure to the subdivision was deactivated for that 3-1/2 hour period so maintenance or repair could be performed at some other location in the feeder system.

6.2 Analysis of Pressure Data

Table 6.1 below shows the statistical analysis of the three measurement values recorded every 4 minutes. As stated above, there is virtually little difference between the minimum, average and maximum recorded values. For the purposes of carrying out a design check on the 6-inch AC Class 150 pipe, the values for the maximum pressure were used. The median maximum pressure was 52.62 psi.

Statistical Value	Recorded Pressure, psi		
	Minimum	Average	Maximum
Minimum	-5.08	-4.34	-4.29
Average	49.99	51.14	51.94
Median	50.47	51.73	52.62
Maximum	58.35	59.03	62.76

Table 6.1: Statistical Analysis of Recorded Pressure Data

The frequency distribution of the 10,473 maximum pressure measurements can be seen in Figure 6.2 below. As expected from the graph in Appendix A, the majority of the maximum pressure measurements (applies to minimum and average too) falls into a very narrow band. In fact, 70% of all maximum pressures fall between 53 and 55 psi. This can also be observed in Figure 6.3 which shows the cumulative frequency distribution of this same data. More importantly, from a design perspective, 99.9% of all maximum pressures fall at 56 psi or below. The two maximum recorded pressures above 60 psi, which occurred at 9:00AM and 9:04AM on September 3, 2020, were probably due to some minor transient event in the system. The AWWA C401 design method incorporates a factor of safety of 4 on the working pressure to accommodate unexpected transients that may occur in a water distribution system. Consequently, for the AWWA C401 design check, a working pressure of 56 psi at the hydrant level was used. This represents the 99.9 percentile of all maximum pressure measurements in the YXJ subdivision.

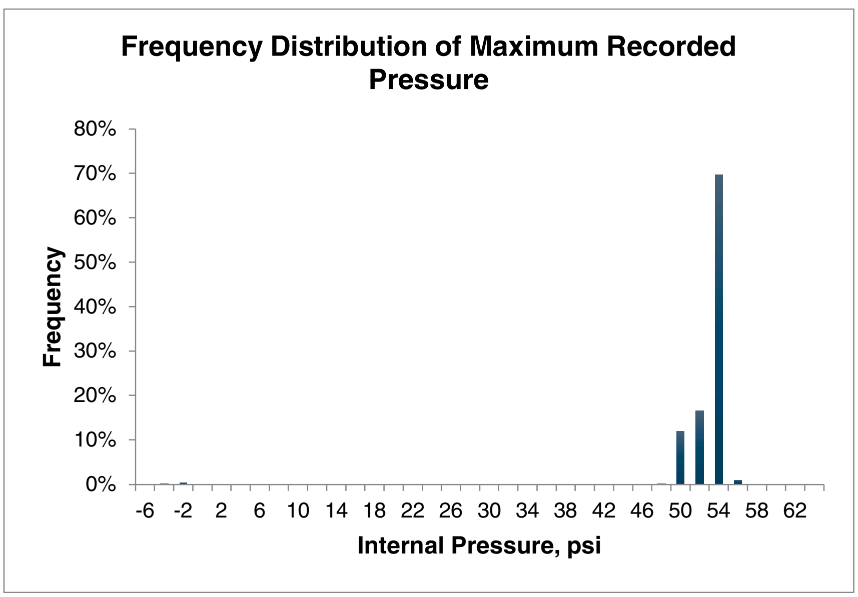

Figure 6.2: Frequency Distribution of Maximum Pressure

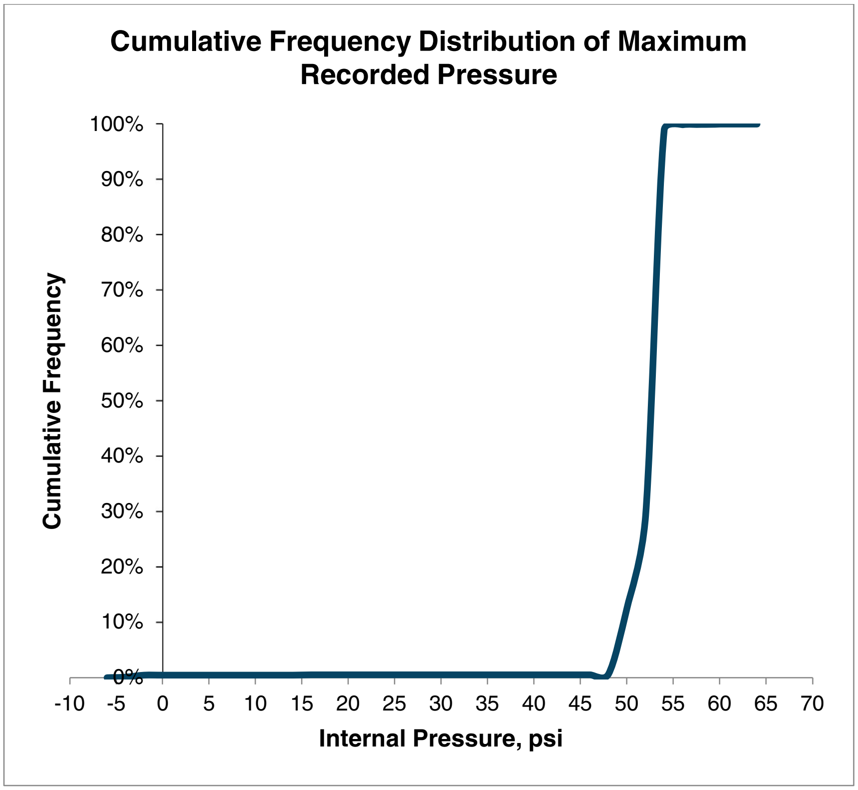

Figure 6.3: Cumulative Frequency Distribution of Maximum Pressure

7. Design Check

7.1 Design Methodology of AC Pressure Pipe

AWWA C401, *Selection of Asbestos-Cement Pressure Pipe*, incorporates the design method for AC pipe. AC pipe is designed on the basis of the interaction of both the internal pressure and external load on the pipe's strength. This is commonly called combined loading and was first introduced for cast iron pipe by Prof. Schlick, Iowa State University. The AC pipe industry adopted the same design methodology for AC pipe, after confirmation testing.

7.1.1 Design Equation

Tests of AC pipe with both internal pressure and external 3-edge bearing loads have shown that there is a relationship between the combined loads at the point of failure. This relationship at failure is expressed by the following Schlick formula, and is represented by a parabolic curve:

$$\left(\frac{w}{W}\right)^2 + \frac{p}{P} = 1 \qquad (1)$$

Where

w = external crush load on the pipe in conjunction with some internal pressure p at failure
W = 3-edge bearing (crush) load that will cause failure, with no internal pressure
p = internal pressure in conjunction with some external load w at failure

P = internal pressure that will cause failure, with no external load

For the purposes of design, factors of safety are applied to both the external load and internal pressure acting simultaneously on the pipe. In the case of AC pipe in a water distribution system, the AWWA standard recommends a safety factor of 4 be applied to the operating pressure when surge is not calculated. Likewise, for external load a safety factor of 2.5 is recommended.

With the incorporation of safety factors, the Schlick formula takes on the form:

$$\left(\frac{w}{W/_{fs_w}}\right)^2 + \left(\frac{p}{P/_{fs_p}}\right) = 1 \quad (2)$$

Where

fs_w = factor of safety for external load, 2.5 recommended
fs_p = factor of safety for pressure, 4 recommended

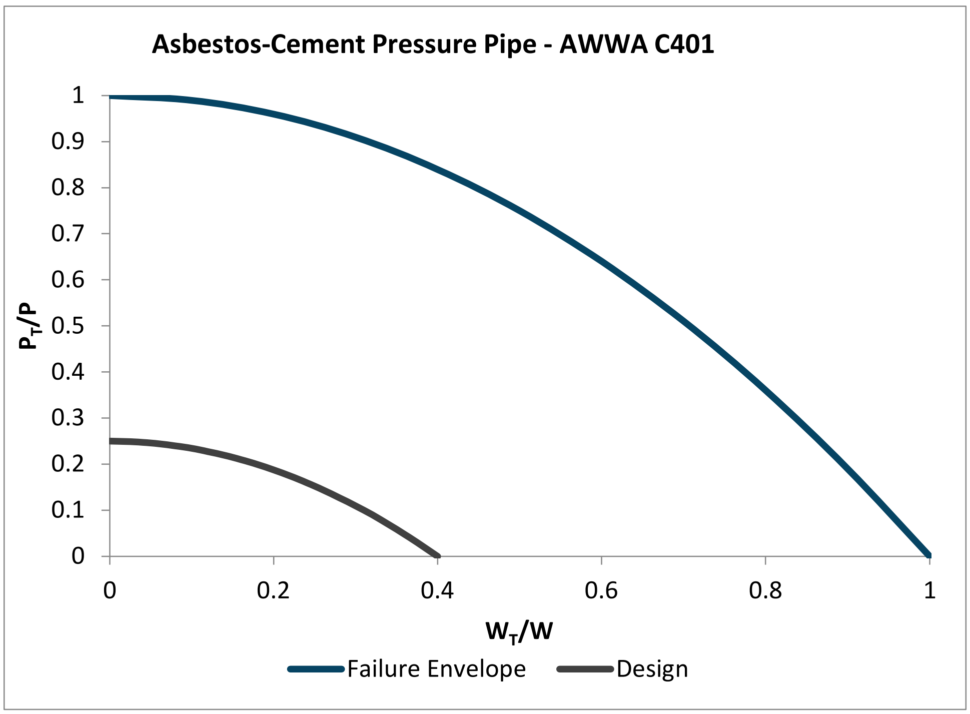

Figure 7.1: AWWA C401 Combined Loading

The above figure illustrates the application of the Schlick combined loading formula for AC pipe with the recommended AWWA factors of safety. Pipe safely meeting the design requirements will fall on or below the green design line in Figure 7.1.

7.1.2 External Soil Load and Relationship to 3-Edge Bearing

External soil load is calculated using the Marston's formula for a rigid pipe (AC is actually semi-rigid) and any live load determined using the integration of the Boussinesq formula or a simplification of same. The general form of Marston's equation:

$$W_E = C\gamma B_d^2 \quad (3)$$

Where:

C = coefficient dependent on ratio of height of fill to width of trench or pipe diameter, shearing forces between earth prisms and direction of relative settlement between interior and adjacent earth prisms

γ = unit weight of fill material (120 lbs/ft^3)

B_d = width of trench at top of pipe

For trench conditions,

$$C_d = \frac{1-e^{-2Ku'\left(H/B_d\right)}}{2Ku'}$$

Where:

K = Rankine's ratio of active lateral unit pressure to vertical unit pressure

$$= tan\left(45^o - \frac{\varphi'}{2}\right)$$

u' = coefficient of friction between fill material and sides of trench

$$= tan\varphi'$$

Generally, when the character of the soil is uncertain a value of *Ku'* of 0.150 maybe typically selected, corresponding to saturated top-soil. The external field load is then converted to an "equivalent" 3-edge bearing load by the application of a bedding factor, BF. The external load applied to a buried pipe is actually distributed over a broader arc of the pipe's circumference than a 3-edge bearing load, dependent on the type of installation. So, the calculated external load (soil plus live load) is divided by the bedding factor to arrive at an equivalent 3-edge bearing load. Mathematically,

$$w = \frac{W_E+W_t}{BF} \tag{4}$$

Where

W_E = external soil load

W_t = live load

BF = bedding factor (ranges from 1.1 to 2.2 dependent on the class of bedding as defined in AWWA 401)

AWWA C401 and AWWA C603, *Standard for the Installation of Asbestos-Cement Pressure Pipe*, identify four classes of bedding for pipes buried in trench installations. Class A involves either a concrete cradle or arch and Class D is placement of the pipe on a flat bottom with loose sidefill soil. Neither of these classes of installation were common for AC pipe. The most common installation types would be represented by Class B and Class C beddings. Class B, which has a bedding factor of 1.9, can be achieved by placing the pipe in a trench with a shaped bottom and granular bedding and carefully compacted backfill to each side, or the use of carefully compacted granular material under the pipe (1/4 B_c min) and up to the springline with compacted backfill from there to over the pipe a minimum of 12 inches (300 mm). Class C, which has a bedding factor of 1.5, is similar to Class B except in the case of the shaped trench bottom there is no granular fill and the soil sidefill is only lightly compacted, or a bedding of carefully compacted granular material is placed under the pipe to a depth of 1/8 B_c or 4 inches minimum, then extended up the sides a further 1/6 B_c minimum, with the balance of the backfill to 6 inches over the pipe composed of lightly compacted backfill. The use of shaped bottom trenches was a very uncommon practice, so realistically the following figures illustrate the Class B and Class C beddings in AWWA C401 most commonly used.

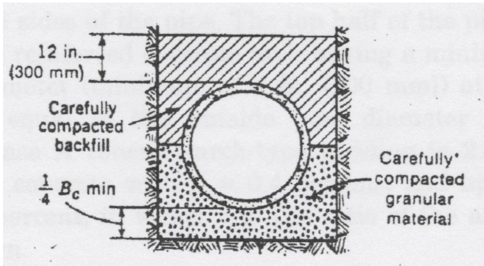

Figure 7.2: Class B

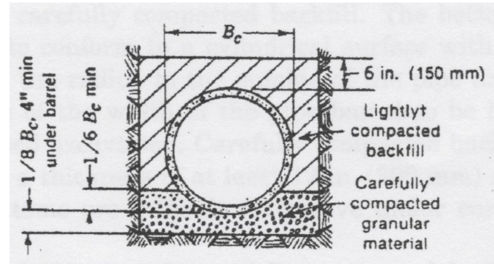

Figure 7.3: Class C

There was no information provided regarding the type of installation for the 6-inch AC pressure pipe so the Class C detail as described in AWWA C401 and illustrated in Figure 7.3 is assumed. The bedding or load factor for Class B is 1.5.

7.1.3 Burst Pressure and Crush Strength from Stress

The internal pressure that will cause failure, P, can be expressed in terms of the burst or hoop tensile strength of the pipe, namely:

$$P = \frac{2ts_h}{D} \tag{5}$$

Where

t = wall thickness
D = mean diameter
s_h = hoop tensile strength

For the 6-inch AC pressure main, the minimum internal design pressure per AWWA C400-77 for Class 150 is 632 psi. Obviously as the pipe degrades these values decline too.

Likewise, the 3-edge bearing load, W, can be expressed in terms of the modulus of rupture or circumferential flexural strength, s_f, of the pipe wall:

$$W = \frac{1.048\, t^2 s_f}{D} \tag{6}$$

Where

s_f = circumferential flexural strength

For the 6-inch AC water main, the AWWA C400 standard specifies that the minimum design external load, namely the 3-edge bearing load that will cause failure without internal pressure, W, for Class 150 it is 5400 lb/ft (79 kN/m). Similarly, these values will decline as the pipe degrades. It should be noted that that this design approach does not cover longitudinal (beam) and transverse shear stresses caused by ground movement and/or uneven bedding. These result in circumferential rather than longitudinal fractures. Such transverse fractures have been the most common type of structural failure observed in asbestos cement pipes in some North American communities, especially in smaller diameters.

7.1.4 Internal Pressure

As covered in Section 6.2, the 99.9 percentile maximum internal pressure for the 6-inch AC distribution main was determined to be 56 psi after the statistical analysis of the Telog hi-speed transducer data. This is the pressure that was measured by the transducer mounted on a fire hydrant (HYD B) at a ground elevation of approximately 2299 ft. The buried pipe is 9 ft. lower. Plus, the lowest ground elevation in the YXJ subdivision is at 2265 ft. Therefore, the pipe at the lowest elevation in the system would be 44 ft. below the transducer's level, which would impose an additional 19 psi of head on the buried pipe resulting in a maximum working pressure of 75 psi.

The AWWA C401 standard for a water distribution pipe recommends a minimum factor of safety of 4 on working pressure, especially when transients are unknown. The AWWA C403 design standard that covers transmission pipes has a reduced factor of safety, but this factor of safety is applied to the maximum pressure the pipeline could experience which would include both working pressure and water hammer. Theoretically, transmission mains are "engineered" pipelines where transient pressures are either quantifiable or are limited by water hammer mitigation equipment (eg. surge vessels). For this distribution system, the factor of safety of 4 on the 99.9 percentile maximum pressure is reasonable.

7.1.5 External Load

There are no profile drawings available for the 6-inch AC water main. According to sheet 2 of the "as constructed" drawings (FJ 6169-1), the minimum depth of soil cover is to be 9 feet.
The dead soil load on the pipe was calculated using the Marston trench formula and the embankment or wide trench formula. The smaller of the two is then used for the dead load on the pipe, as recommended in AWWA C401. A trench width of the pipe outside diameter plus 2 feet (.6m) was used with a soil unit weight of 120 lb/ft^3 (18.9 kN/m^3). The results are shown in Table 7.1 below.

The pipe was also installed inside a casing where it passes under 257 Road. This was no doubt to protect the pipe from large vehicular loading. However, it does appear from the drawings that some portions of the pipeline could be subjected to light vehicular loading, especially from automobiles. For the design check, the live load on the 6-inch AC pipe was calculated using an HS20 truck load (individual wheel load 71 kN), with the appropriate impact factor based on cover depth. The results of this calculation are also shown in Table 7.5 below. Using the bedding factor of 1.5, the above soil and live loads are converted to an equivalent 3-edge bearing load. This is the load in a 3-edge bearing test that would produce the same flexural stress level as that due to the higher burial load. The 6-inch Class 150 pipe's minimum 3-edge bearing strength is 5,400 lb/ft, (79 kN/m) and with a factor of safety of 2.5, the maximum permitted load becomes 2,160 lb/ft (31.5 kN/m) with no internal pressure. As the pressure increases, this maximum allowable external load drops in accordance to the Schlick formula (Eqn. 1 in Section 7.1.1)

Property	**External Load, lb/ft (kN/m)**
	9 ft. (3.24 m) Burial
Trench Load, Wd	1,738 (25.4)
Embankment Load, Wc	13,339(195)
Dead Load, We	1,738 (25.4)
Live Load, Wl	77 (1.1)
Total External Load, Wt	1,815 (26.5)

Table 7.1: External Soil and Live Load

With the bedding factor of 1.5, this total external soil and live load transforms to an equivalent 3-edge bearing load of 1,210 lb/ft (17.7 kN/m).

7.2 Results of the Design Check

To aid in the design check, Pure installed a high speed recording pressure transducer on the hydrant located at the SE corner of Lily St. (Road D) and Rowantree Ave. (Road A) for 30 days. This TPM recorded the minimum, average and maximum pressure at the monitoring site every four minutes. If a transient is detected the pressure is recorded every micro-second thus capturing any surge (water hammer) pressures that are often overlooked by standard SCADA gauges that only sample every few minutes. The analysis of the pressure data collected may be in found in Section 6.

All total there is approximately 7,351 linear feet (2,241 m) of AC pipe in this subdivision. The closed piping system is plugged at Airport Road, 242 Ave., and Rowantree Ave. and has it's only feed from the east by an extension of the line from Tulip Ave to a metering chamber and connection at another 6-inch line. The metering chamber and connection is approximately 25 meters north of a pump house.

The "as constructed" drawings are dated August 1977. The name of the roads on the 1977 drawings have all changed. Road A is now Rowantree Ave., Road B is 242 Ave., Road C is Tulip Ave., Road D is Lily Street and Airport Road is 257 Road. The Airport By-pass Road to the north is now Airport Road. The site plan shows the airport just to the south as Fort St. John Airport, but it is now known as North Peace Regional Airport (YXJ).

7.2.1 Pipe Information from Drawings

The drawings (FJ 6169-1, sheets 1 to 10) identify the water pipe as 6-inch Class 150 asbestos-cement (AC). The drawings show a plan view of the water pipeline but no profile. A plan and profile for the sewer pipeline that lies adjacent to the water main is shown. The general notes on sheet 2 states that all watermains shall have a minimum of 9 ft. cover and that all watermains shall be designated in accordance to the latest AWWA specifications.

The gound elevation along the sewer pipeline ranges from a low of 2263 (ft.) at the end of the line on 242 Ave. to a high of 2303 (ft.) at the end of the line on Rowantree Ave. It would be reasonable to assume the ground elevations for the watermain follow these same patterns, as these lines are parallel, and are generally only separated by 10 feet (3 m). This 40 foot (12.2 m) of elevation change would translate into a difference of 17.2 psi of pressure between the pipeline's low and high points. The pressure transducer was placed on a hydrant with a ground elevation of approximately 2299 ft., or near a high point in the system.

The pipeline where it crosses under 257 Road (old Airport Road) is installed in a 24-inch corrugate casing filled with sand. This is undoubtably designed to protect the pipe from any large traffic loads. Aside from this location there is no information on the drawings to indicate how the pipe was installed, or specifically the type of trench construction (bedding, side-support, trench width) used. Assumptions will have to be made about these conditions in order to calculate the dead load (soil cover) on the 6-inch AC pipe.

7.2.2 Pipe Information from AWWA Standard

The AWWA C400 pipe standard that would have been in effect at the time of this project was published in 1977. This standard, AWWA C400-77, covered asbestos-cement pressure pipe in diameters 4-inch through 16-inch. The three main strength requirements in the AWWA C400 standard are a flexural load test, an internal design pressure (burst) and an external design load (crush) requirement. The specified design internal pressure (minimum burst pressure) is 632 psi (4400 kPa) and the design external load (3-edge bearing crush strength) is 5400 lb/ft (79 kN/m). The AWWA C400 standard is a performance based specification and does not include any minimum wall thickness requirements for AC pipe. Using nominal hoop and flexural strength values for AC pipe, as outlined in Section 3.2, an approximation of what the wall thickness should be for the 6-inch Class 150 pipe. Interestingly, the burst pressure requirement generally controls the minimum wall thickness for pipe diameters 8-inch and above, while 4-inch and 6-inch pipe wall thickness are typically controlled by the crush strength requirement. Specifically in the case of 6-inch Class 150, the nominal wall needed to meet the burst pressure requirement of 632 psi is 0.545 inches (13.4 mm), and the nominal wall to meet the crush strength requirement of 5400 lb/ft is 0.596 inches (15.1 mm).

7.2.3 Results

Using the AWWA C400 design (i.e., burst) internal pressure of 632 psi and a design external (crush) load of 5400 lb/ft, the failure envelop for the 6-inch Class 150 AC pipe can be calculated and plotted (blue line in Figure 7.4). Then applying the AWWA C401 recommended factors of safety of 4 for internal pressure and 2.5 for external (crush) load, the allowable or design envelope can be established (red line in Figure 7.4). Figure 7.4 shows the two curves, failure and design, for a 6-inch Class 150 AC pipe meeting the performance requirements of AWWA C400.

Superimposed on this design and failure graph in Figure 7.4 is the intersection of the maximum working pressure of 75 psi and the external load of 1,210 lb/ft. This point falls well below the design line, meaning the pipe exceeds the recommended minimum safety requirements in AWWA C401. Table 7.2 below shows the factors of safety in pressure and external crush load for the 75 psi maximum working pressure and 9 ft. of soil burial with live load.

Loading Condition	Factor of Safety
Working Pressure	8.0
External Load	4.2

Table 7.2: Factors of Safety

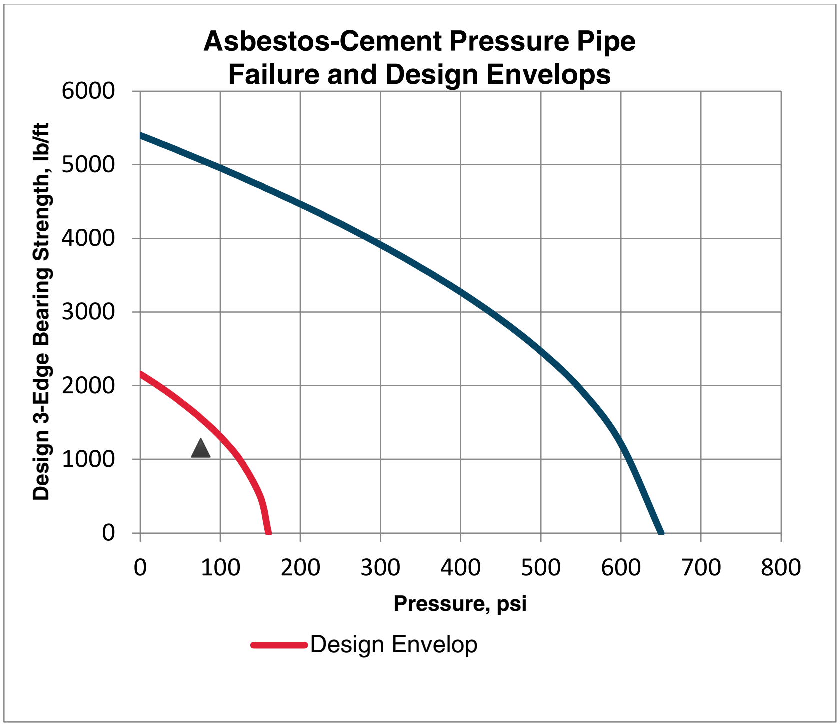

Figure 7.4: Design and Failure Envelop for 6-in Class 150 AC Water Pipe

The 6-in Class 150 AC water pipe in the YXJ subdivision has been in service since 1977, a total of 43 years. There have been no reported failures in this piping system. Pure Technologies has assessed the condition of asbestos-cement pipes used for water pipes and sewer force mains on other projects. Although we have seen significant degrees of deterioration in some AC pipes used for sewer force mains, the condition of water main pipes has been relatively good. Unless AC water pipes are conveying "soft water" or buried in acidic sulfate bearing soils there would be little to no expectation to see significant degradation of these pipes.

Profile drawings of the 6-inch water main was not included in the "as constructed" drawings provided Pure Technology. A note in the drawings states that pipes were to be buried with a minimum of 9 ft. of soil cover. This depth of soil cover was used to determine the external soil load on the buried main. A HS-20 wheel live load was also included, although at this depth it's contribution to the total external load was minimal.

Pure monitored the pressure in the YXJ subdivision's system with a Telog hi-speed pressure transducer from August 17, 2020 to September 15, 2020. The measured pressures fell into a very narrow band. Based on the maximum pressure values measured, the 99.9 percentile value was determined to be 56 psi. The pressure transducer was installed on a fire hydrant at approximately ground elevation of 2299 ft. Based on the elevation of the buried pipe at the lowest ground elevation location (2265 ft), an additional pressure head of 44 ft. (19 psi) was added for a total working pressure of 75 psi.

The AWWA C401 design check found the pipe, assuming no significant degradation, to be operating well within the defined safety limits recommended by the AWWA standard. In fact, the factor of safety in pressure was 8.0 and for external load 4.19. This is versus a recommended minimum value of 4.0 and 2.5, respectively.

While the structural evaluation based on AWWA standards indicate that the pipe section has been designed within the defined safety limits, with no direct information on the physical condition of the existing pipe, a prediction of the pipe's remaining life is not feasible. No pipe samples were available for physical property testing and no failures have be recorded. This would be a good indicator that the pipe is still in relatively good shape. Given the application, namely water distribution, it would be reasonable to expect the asbestos-cement pipe has not suffered any severe degradation unless its conveying "soft" water or is subjected to acidic sulfate bearing soils or groundwater.

If the pipe owner wants some assurance that the pipe is still in good working condition then it would be advisable to check the Langelier Index (or Aggressiveness Index) of the water being conveyed through the pipes. If the Langelier Index is equal to or greater than zero, then the water is not aggressive to AC pipe. For a Langelier Index less than -2.0, some degradation would be expected. The following table (extracted from AWWA C401) illustrates this point and compares the Aggressiveness Index and Langelier Index.

Table 9.

Effect on AC Pipe	pH + log (AH)	Langelier Index
Highly Aggressive	<10.0	<-2.0
Moderately Aggressive	10.0 to 11.9	-2.0 to -0.1
Non-aggressive	>= 12.0	>=0

External corrosion can occur when AC pipe is buried in acidic sulfate soils. The pH and water soluble sulfate in the surrounding soils and groundwater can be assessed to determine if these substances might pose a problem for the pipe. It would be advisable to retain a soils testing lab and have several tests run on soil samples extracted from the pipe zone. Table 10 (extracted from AWWA C401) shows the possible effect of sulfates on the pipe.

Table 10.

Sulfate Aggressiveness Classification	Water	Soil
	Water-Soluble Sulfates - mg/L SO4	Water-Soluble Nuetral Sulfates-mg/L SO4
Non-aggressive	150 and less	1000 and less
Mildy Aggressive	150-1500	1000-2000
Moderately Aggressive	1500-10,000	2000-20,000
Highly Aggressive	10,000 and greater	20,000 and greater

If the conveyed water is found to be "soft" (Langlier Index less than -2.0) or the surrounding soils and groundwater contain soluble sulfate exceeding 20,000 mg/L or 10,000 mg/L respectively, then it would be recommended to extract a sample of the pipe from the line for laboratory testing. The laboratory testing would include microscopic examination of the wall cross-section, pH indicator testing of the pipe wall and a crush test. This would provide direct evidence on the physical condition of the pipe. A prediction of the remaining service life could be rendered at that point.

If the conveyed water or surrounding soil and groundwater are found to be not aggressive, then there is a good chance the pipe is still in reasonable working condition. However, it would be recommended that if any future modification are made to the line, for example the line is extended, or if a failure does occur, that a section of pipe be removed from the line at those opportunities and subjected to the laboratory testing mentioned in the previous paragraph.

APPENDIX A

Transient Pressure Data

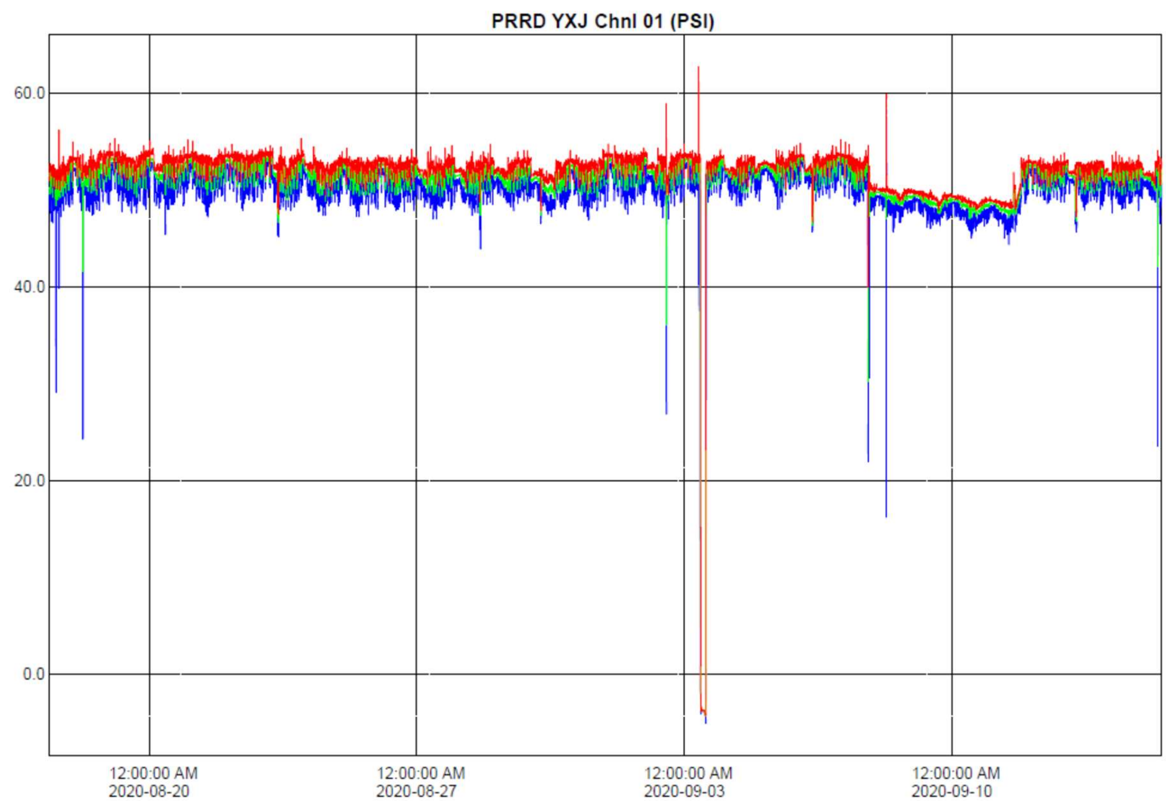

Figure A: Pressure Data over a 30-day monitoring period

APPENDIX B

Asbestos – Cement Pipe

Asbestos – Cement Pipe

B.1 Composition

AC pipe is composed of a mixture of asbestos fibers, Portland cement, and inorganic hydrated silicates. Typically, the asbestos fibers comprise less than 20% of the AC pipe. The AWWA product specifications for AC pipe (AWWA C400 and C402) also include physical and chemical requirements for the pipe itself. For the pipe composition, it requires that AC pipe shall be composed of an intimate mixture of either:

- Portland cement or Portland blast furnace slag cement and asbestos fiber with or without silica; (or)
- Portland pozzolana cement in asbestos fibers.

The same specifications limit the amount of uncombined calcium hydroxide, presumably to curtail pipe dissolution: for Type I, there is no limit, and for Type II, 1.0% or less uncombined calcium hydroxide is permitted. Manufacture of Type I, which is not autoclaved, was discontinued in North America in the 1960s. Type II Portland cement is moderately sulfate resistant. The asbestos portion of AC pipe is composed of naturally occurring hydrated mineral silicates that possess a crystalline structure. There are four main types of asbestos. The principal type of asbestos found in AC pipe is chrysotile (white asbestos). Another type of asbestos, crocidolite (or blue asbestos) is also used for reinforcement of the pipe and improves the manufacturing process. Most high-pressure AC pipes had some crocidolite in addition to chrysotile fibers used in the manufacture.

During the formation of asbestos cement, the constituent oxides contained in Portland cement react with water to form calcium hydroxide (lime) and calcium silicate/aluminate hydrates. The physical binding of these hydration products cures the cement mortar and together with the formation of lime determines the structural integrity of the final product.

B.2 Manufacture

AC pipes produced in North America mainly used the ‘Mazza’ method whose origins are in the paper making industry. In this method a felt sheet was fed through a cement, silica and asbestos slurry bath where cement, silica and asbestos was picked up by the felt and then later transferred to a rotating mandrel under compactive force until the required thickness was achieved. The finished pipe is then removed from the mandrel by subjecting the mandrel to a strong electrostatic charge that produces steam around the pipe and thereby breaking the bond with the mandrel. The pipe is then steam cured under 2 atmospheres of pressure in an autoclave for 24 hours.

B.3 Degradation

Degradation can occur at both the internal and external surfaces of a pipe. Internal corrosion of a water pipe is mostly due to leaching of calcium hydroxide from the cement matrix. External attack can be from low pH (acidic) soils and/or groundwater as well as high sulfate bearing soils.

B.3.1 Internal Corrosion

In contrast to the original expectations that AC pipe would not be attacked by corrosive water, it became evident that under certain circumstances AC pipe can be attacked by aggressive (soft) water. If the pipe is exposed to aggressive water, the cement matrix constituents dissolve, thereby exposing asbestos fibers and releasing some into the water.

The AC pipe industry developed the concept of an Aggressiveness Index for use as a guide in determining whether AC pipe would be appropriate in a given situation. The original purpose of the index was to ensure the structural integrity of the pipe. More recently, it has been used to predict whether water quality degradation would occur from pipe dissolution. The Aggressiveness Index is a simplified form of the Langelier Index and has some shortcomings, which are noted below.

The Aggressiveness Index (AI) is defined as follows:

$$AI = pH + \log(AH)$$

where:
A = total alkalinity, mg/liter as calcium carbonate
H = calcium hardness, mg/liter as calcium carbonate.

The Aggressiveness Index does not incorporate corrections for temperature and ionic strength.

Application of the Aggressiveness Index (AI) to determine when AC pipe could be used was incorporated into standards published by ASTM (1976) and AWWA (1975, 1980). The standards applied the Aggressiveness and Langelier Indices to relate water quality and the use of AC pipe.

AI < 10	Aggressive water
AI 10 - 12	Moderately aggressive water
AI > 12	Non-aggressive water

Table B.1: AI levels

These standards recommended that Type I (non-autoclaved) or Type II (autoclaved) AC pipe could be used with non-aggressive water. Type II pipe is permitted for moderately aggressive water. For highly aggressive water, ''the serviceability of pipe for such applications should be established by the purchaser in conjunction with the manufacturer'' (AWWA, 1980). Recognizing the relationship between water quality and the use of AC pipe, the U.S. EPA proposed that the Aggressiveness Index should be > 12 for water transported through AC pipe in order to prevent adverse effects.

The Aggressiveness Index is based on calcium carbonate saturation, therefore it should yield a fairly accurate prediction of "non-aggressiveness" provided by a protective calcium carbonate coating if water is oversaturated. However, if the water is undersaturated with calcium carbonate, there is no reason to expect the Aggressiveness Index to predict with accuracy the dissolution of AC pipe since calcium carbonate is only a minor constituent of the cement and calcium silicate is the predominant pipe component. Furthermore, the Aggressiveness Index does not account for temperature and ionic

strength as does the Langelier Index. Finally, the Aggressiveness Index fails to account for protective chemical reactions in drinking water.
The Aggressiveness Index was used for several years by pipe manufacturers and the water supply industry. Therefore, the majority of the data on water quality and AC pipe deterioration contains information on the Aggressiveness Index, calcium, and alkalinity of the water. In the absence of a better predictor of pipe performance, this index has been used extensively and is still a simple first approximation for predicting water pipe performance.

B.3.2 External Corrosion

Attack of asbestos cement pipe from the exterior can come from soft groundwater (low in calcium carbonate) or acidic sulfate soils. The mechanism of attack from soft groundwater is the same as internal attack, i.e., leaching of calcium hydroxide. For acidic sulfate soils, the sulfate in the soil reacts with calcium hydroxide and silica compounds in the pipe to form weaker and larger compounds that result in swelling of the cement matrix. Three different corrosion products can be formed by the reaction with the sulfate solution, namely gypsum, ettringite and thaumasite. Gypsum and ettringite formed by these reactions can swell to 123% to 224% (Matti, 1985) of the original solids they replace leading to expansion and destruction of the cementitious portion of the pipe.

B.4 AWWA and ASTM Standards

There were several important standards governing the supply, design and installation of AC pressure pipe. Those standards are:

AWWA C400 *Asbestos-Cement Pressure Pipe, For Water Distribution Systems and Other Liquids* - this is the product standard which includes minimum performance requirements

AWWA C401 *The Selection of Asbestos-Cement Pressure Pipe, For Water Distribution Systems and Other Liquids* - this standard essentially covers the interactive design approach for AC pressure pipe

AWWA Manual M16 (1978) *Work Practices for Asbestos-Cement Pipe* - replaced by another AWWA handbook of the same title in 1995

AWWA C603 *Standard for Installation of Asbestos-Cement Pressure Pipe* - covers recommended installation practices and laying of the pipe

ASTM C500 *Standard Test Method for Asbestos-Cement Pipe*

In 1975, AWWA revised AWWA C400 to only cover pipe diameters 4-inch through 16-inch which were considered distribution sized pipes and introduced AWWA C402 for transmission pipe in diameters 18-inch through 42-inch. ASTM C500 not only contains three important test protocols for AC pipe, namely hydrostatic pressure (burst), 3-edge bearing (crush) and uncombined calcium hydroxide tests, but also guidelines for establishing the degree of aggressiveness of transported water to the internal surface of the pipe, and acidic and sulfate laden soils and waters to the external surface.

B.4.1 Pipe Classes

Pressure classes covered by AWWA C400 include class 100, 150 and 200 psi rated products. It was very common to specify Class 200 for 4-in and 6-in diameter pipe, not because of pressure requirements but in order to increase the available beam strength. Diameters 8-in and above were normally specified Class 150.

B.4.2 Physical Requirements

The AWWA product standards are performance based. They do not specify minimum unit strength properties or physical dimensions (eg. thickness) for the AC pipe. Rather, they specify the minimum “design” internal pressure (or burst pressure) and the minimum “design” external load (or 3-edge bearing crush load) that the pipe’s are required to have in order to meet the standard. The following table (Table B.2. from AWWA C400) lists those minimum “design” pressures and loads. It should be noted that the 1964T version of AWWA C400 did not list any internal design pressures. The design pressures shown in Table 2 first appeared in the 1975 version of AWWA C400. The 1964T version did state that each length of pipe should have sufficient strength to withstand an internal hydrostatic pressure of four times the rated operating pressure for it’s class.

Nominal Diameter in	Class 100		Class 150		Class 200	
	Internal Pressure psi	External Load lb/ft	Internal Pressure psi	External Load lb/ft	Internal Pressure psi	External Load lb/ft
4	417	4100	616	5400	809	8700
6	441	4000	632	5400	815	9000
8	472	4000	653	5500	824	9300
10	490	4400	650	7000	826	11000
12	490	5200	658	7600	830	11800
14	500	5200	650	8600	826	13500
16	500	5800	654	9200	825	15400
18		6500		10100		17400
20		7100		10900		19400
24		8100		12700		22600
30		9700		15900		28400
36		11200		19600		33800

Table B.2: Design Internal Pressure and Design External Load

The “design” internal pressure requirement is at least 4 times the pressure class. In reality, it has to be slightly higher as the pressure class supposedly applies to a buried pipe with approximately 5 feet of soil cover. As shown in Section B.4.1, there is an interaction between the pipe’s internal pressure and external load capacity.

B.4.3 Standard Pipe Diameters and Lengths

The pipe average internal diameter is not less than the nominal diameter by more than 5%. Standard lengths are either 10 ft. (3m) or 13 ft. (4m) for 4-in, 6-in and 8-in diameters, and 13 ft. (4m) for 10-in and larger. The shorter length for the smaller diameters was to limit the bending moment (beam action) in those sizes as their relatively thin walls did not provide adequate beam strength in some soil conditions. Beam breaks in 4-inch AC pipe were not uncommon especially in clayey soils.

B.4.4 Wall Thickness

The wall thickness is not specified in the standards. It was up to each manufacturer to determine the minimum thickness their product needed to meet the design pressure and external design load requirements. However, there was a tolerance on the manufacturer's stated standard thickness.

Nominal Pipe Size		Wall Thickness Tolerance	
4-12 in	100-300 mm	-0.06 in	-1.5 mm
14-16 in	350-400 mm	-0.12 in	-3.0 mm

Table B.3: Wall Thickness Tolerance

B.4.5 Joints

The standard joint for AC pipe was a coupling machined with two inner grooves from thicker AC stock. Rubber gaskets meeting the requirements of ASTM D1869 were used. Similarly, each end of a standard length of AC pipe was machined to fit inside the coupling and seal against the compressed rubber gasket. Approximately 15% compression of the gasket was achieved when the spigot end entered each side of the coupling. The spigot end actually had two machined surfaces, D_2 and D_3, as shown in Figure B.1.

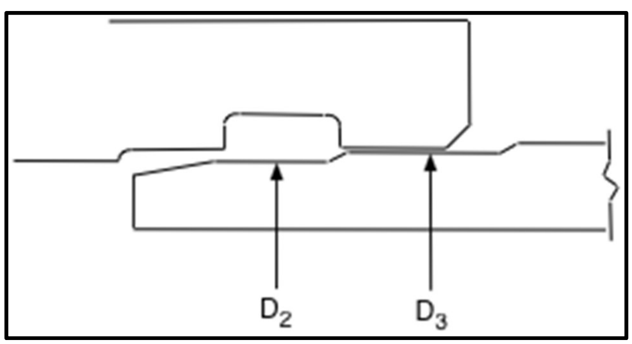

Figure B.1: Coupling and Spigot End of AC Pipe

All fittings used with AC pressure pipe were cast iron, ductile iron or steel. No AC pressure fittings were made, except heavy tapped couplings, which were couplings with threaded bushings factory installed that would accept ¾" and 1" corporation stops. In order to facilitate the manufacture of fittings for AC pipe standardized D_2 and D_3 dimensions were adopted by the industry. The following table (Table A.1 in AWWA C400) identifies those pertinent dimensions.

Pipe Size		Class 100				Class 150/200			
		D_2		D_3		D_2		D_3	
in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
4	100	4.64	118	4.80	122	4.81	122	4.97	126
6	150	6.91	176	7.07	180	6.91	176	7.07	180
8	200	9.11	231	9.27	236	9.11	231	9.27	235
10	250	11.24	286	11.40	290	11.66	296	11.82	300
12	300	13.44	341	13.60	345	13.92	354	14.08	358
14	350	15.07	383	15.23	387	16.22	412	16.38	416
16	400	17.15	436	17.31	440	18.46	469	18.62	473

Table B.4: Dimensions of Spigot End of AC Small Diameter Pressure Pipe

B.5 Physical Strength Parameters

B.5.1 Unit Strengths

As stated previously, the AWWA standards are performance oriented and do not include any minimum strength properties aside from the design (burst) internal pressure and the design (crush) external load. However, there are other worldwide standards for AC pipe that do include minimum properties. These can be helpful in an investigation of AC pipe's current and future performance expectations, especially when little is known about the pipe itself.

The Australian Standard AS 1711 (1975) offers a minimum tensile strength of 3,915 psi (27 MPa). The British Standard for AC pipe includes a crush strength (modulus of rupture) of 6,380 psi (44 MPa). There were several AC pipe manufacturing plants in the Middle East (Saudi Arabia, Dubai, Oman, Jordan, Lebanon). The Saudi Arabian Standards Organization (SASO) did include 28 day strength requirements (pipe produced in the Middle East was normal cured, not autoclaved, hence the need for a 28 day requirement). The SASO requirements, according to one of the manufacturers, was as follows:

- Longitudinal bending strength of small diameter pipes, Rf - 3,988 psi (27.5 MPa)
- Circumferential bending strength (crushing strength), Re - 7,250 psi (50.0 MPa)
- Bursting strength, Rb - 3,480 psi (24 MPa)

The SASO standard did not have a requirement for longitudinal compressive strength, Rc, or longitudinal tensile strength, Rt, but the Saudi manufacturer included this information in their literature:

- Longitudinal compressive strength, Rc - 7,250-9,425 psi (50-65 MPa)
- Longitudinal tensile strength, Rt - 1,450 psi (10 MPa)

The elastic modulus properties of AC pipe depends on the direction in which the stresses are applied to the pipe, given the preferential orientation of the reinforcement fibers (asbestos) in the circumferential plane. The following table, extracted from the Saudi Arabian Amiantit Company's brochure, gives design values for the elastic modulus.

Stress	10 MPa	18 MPa	8 MPa	10-35 MPa
Loading	Beam	3-Edge Bearing	Internal Pressure	Longitudinal Compression
Emin, GPa	22.5	25.5 (3.7 x 10^6 psi)	31.0 (5.5 x 10^6 psi)	22.0
Emax, GPa	24.0	27.8	33.0	24.0

Table B.5: Elastic Modulus of AC pipe (Saudi Arabian Amiantit Company)

For calculation of water hammer, it is recommended that an elastic modulus of 25.0 GPa (3.62 x 10^6 psi) be used.

APPENDIX C

AquaCoustic Video Analysis

Line by Line Detailed Review

C.1 SCO 2 to SMH 11

There are 4 joints in this line that show infiltration staining or encrustation around the joint, both signs of possible infiltration. None viewed during the survey. Four joints showed some signs of root intrusion but not significant enough to warrant action. There were five locations, at or near joints, with cracks or fractures.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.0	4	Multiple fractures and cracks, ~1m long	Point repair
11.8	2	Longitudinal crack - minor	None
13.2	1	Circumferential crack - minor	None
28.8	3	Multiple cracks at joint	Monitor
30.0	2	Longitudinal/spiral crack, ~1m long	None
65.6	3	Longitudinal fracture, ~.3m long	Monitor

Table C.1: Sewer Data Analysis – SCO 2 to SMH 11

C.2 SMH 11 to SMH 10

There are 2 joints with infiltration staining. No active infiltration. There is a 1.4m length of PVC pipe in this line, beginning at 20.0m from SMH 11, with the joint offset from the clay pipe. This line had a lot of floating and underwater debris. There were 8 locations with cracks or fractures, one requiring immediate repair.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.3	1	Circumferential crack - minor	None
11.8	1	Longitudinal crack - minor	None
20.0	3	PVC section - joint offset	None
40.7	2	Longitudinal crack - minor	None
63.1	2	Longitudinal crack - minor	None
73.8	4 (2)	Entire length of pipe has 2 to 3 longitudinal cracks	Point repair
75.0	5	Multiple longitudinal and circumferential fractures	Point repair
81.2	3 (4)	Broken joint - minor	None
83.2	3	Several (2) longitudinal cracks along entire pipe	Monitor

Table C.2: Sewer Data Analysis – SMH 11 to SMH 10

C.3 SMH 9 to SMH 10

There are 3 joints with infiltration stains, but no active infiltration. There was a lot of encrustation on the interior of this pipe over its whole length. There are 4 taps in this line, three are factory tees and one a break-in tap. Eight (8) locations with cracks or fractures, six are relatively minor but two are significant and need to be addressed.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.0	2	Circumferential fracture at joint - minor	None
2.9	3 (4)	Multiple fractures at joint - minor	Monitor
11.3	1	Tap break-in at 3 o'clock - good	None
17.1	3	Tap tee at 3 o'clock, plugged with deposits	Clear
34.8	2	Longitudinal crack - minor	None
52.6	3	Multiple longitudinal cracks at joint - minor	None
62.4		Tap tee	None
66.6	3	Longitudinal fracture at joint - ~.2m long - minor	None
93.7	3 (4)	Multiple fractures at joint - minor	Monitor
110.3		Tap tee - 2 o'clock - good	None
111.8	4	Several longitudinal & spiral fractures - 0.6 to 1m long	Point repair
112.4	4	Multiple fractures entire last pipe at MH	Point repair

Table C.3: Sewer Data Analysis – SMH 9 to SMH 10

C.4 SMH 9 to SMH 8

More than seven (7) joints with signs of infiltration staining. There are two factory taps (tees) in this line with one showing 60% blockage and requiring clearing. Eight (8) locations with varying cracks and fractures, two (2) very significant and requiring repair

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.0	4	Multiple longitudinal and spiral cracks about 0.6m long.	Point repair
1.5	4	Break at joint	Monitor
18.8	1	Very minor crack from 10 to 11 o'clock	None
26.3	3 (4)	Spiral crack - minor	Monitor
34.7	1	Insignificant crack	None
44.2	3	Tap (tee) 60% plugged	Clear
63.6	2	Longitudinal crack - 0.6m long - minor	None
68.1		Tap (tee)	
95.5	4	Multiple fracturs at joint - not too significant	Monitor
104.8	2	Cracks at joint - very minor	None
107.7	4	Multiple fractures - ~-.6m long	Monitor
120.2	4	Broken pipe with significant fractures - last pipe at MH	Point repair

Table C.4: Sewer Data Analysis – SMH 9 to SMH 8

C.5 SMH 16 to SMH 17

Six (6) joints with signs of infiltration staining or encrustation. There are six (6) taps on this line, some showing signs of infiltration or encrustation but not active. One tap has 30% blockage. Three (3) locations with cracks at joints but none major enough to require repair.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
9.3		Tap (tee) at 2 o'clock - good	None
10.0		Tap (tee) at 10 o'clock - good	None
46.4	1	Tap break-in - some minor restriction	None
53.3	3	Multiple small cracks at joint - minor	None
68.9	1	Tap (tee) at 2 o'clock - good	None
87.1	2	Longitudinal crack - minor	None
91.2	2	Spiral crack - 0.6m long - minor	None
99.7		Tap (tee) 10 o'clock - good	
100.3	2	Tap (tee) 2 o'clock - 30% blockage	Clear

Table C.5: Sewer Data Analysis – SMH 16 to SMH 17

C.6 SMH 16 to SMH 15

Three (3) joints with infiltration stains. No active infiltration. Three (3) taps in this line, two tees and one break-in tap. The break-in tap had some potential infiltration during the survey. Seven (7) locations had cracks or fractures, two significant enough to require repair.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
7.4	3	Longitudinal crack - 0.5m long - minor	None
8.6	1	Minor crack	None
33.8		Tap (tee) at 2 o'clock - good	None
37.5	2	Tap break-in - some sign of infiltration	Monitor
42.5	2	Two longitudinal cracks at springline - 0.6m long	None
44.0	2	Two longitudinal cracks at springline - 0.6m long	None
50.7	3	Multiple cracks	Monitor
77.0	4	Fracture at joint - significant	Point repair
103.1		Tap (tee) at 1 o/clock - good	None
120.9	4	Multiple fractures in last pipe next to MH 15	Point repair

Table C.6: Sewer Data Analysis – SMH 16 to SMH 15

C.7 SMH 15 to SMH 14

Six (6) joints had infiltration staining or encrustation indicative of past infiltration. There are two taps in this line, with one being a break-in tap and requiring repair. Three(3) locations in this line had fractures and cracks, with one in bad shape and requiring repair. This line also had a lot of underwater debris and would be a good candidate for jet cleaning with a vacuum truck.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
17.6 to 23.2		PVC pipe (previous repair) with large dip. Lots of debris.	Clean the entire line
27.5	2 (3)	Longitudinal fracture - 0.3m long - minor	None
43.8	2	Circumferential fracture at joint - minor	None

67.5		Tap (tee) at 10 o'clock	None
93.3	3	Tap break-in at 11 o'clock - not good	Top hat repair
97.0	5	Multiple fractures, including spiral fracture in last pipe section and cracks at joint - collapse possible	Immediate point repair

Table C.7: Sewer Data Analysis – SMH 15 to SMH 14

C.8 SMH 14 to SMH 13

Seven (7) joints show infiltration staining or encrustation, signs of past infiltration. There are two taps in this line, both break-in taps. One tap protrudes 25mm into the clay pipe. This line has five (50 locations with cracks or fractures with four (4) being minor, and one a missing triangular section of the pipe wall at joint. This line also had a lot of debris, especially the last 12m near SMH 13. It would be a good candidate for jet cleaning with a vacuum truck.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.0	2	Circumferential fracture - minor	None
24.3	2	Longitudinal crack at joint - .2m long - minor	None
24.4		Tap break-in at 10 o'clock - okay	None
60.9		Tap break-in at 11 o'clock - lateral protrudes 25mm into sewer	Top hat
62.8 to 74.1		PVC (previous repair)	
81.7	4	Triangular section of pipe missing at joint - 75mm on side at 8 o'clock	Monitor
89.0	2	Circumferential fracture from 9 to 12 o'clock at joint - minor	None

Table C.8: Sewer Data Analysis – SMH 14 to SMH 13

C.9 SMH 13 to SCO 5

There are four (4) joints in this line with infiltration stains. This line has three (3) taps, one is a factory tee with a 150mm inlet in good shape, one is a factory tee that is 90% plugged, possibly and one break-in tap that is possibly defective. Four (4) locations all at joints with fractures and cracks were noted.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
8.0	2(3)	Multiple small cracks at joint - minor	None
20.3	4	Multiple fractures at joint with lots of encrustation	Point repair
36.0	2	Circumferential fracture - minor	None
51.0 to 56.0		Steep upslope - 6% to 9% grade	None
60.7		Tap factory 150mm tee - 9 o'clock -good	None
75.2	3	Tap break-in - 10 o'clock - possible defective	None

80.2	3	Tap factory tee at 9 o'clock with 90% blockage	Clear
81.9	2	Circumferential fracture - minor line 70% full - line goes up	None

Table C.9: Sewer Data Analysis – SMH 13 to SCO 5

C.10 SMH 12 to SMH 13

There are four (4) joints with infiltration staining and/or encrustation suggestive of past infiltration. No taps on this line. Six (6) locations with cracks or fractures, three (3) especially bad and in need of repair.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.4	4	Broken joint - roots intruding	Point repair
28.0	2	Longitudinal crack ~ .6m long - minor	None
44.8	3	Two cracks about .6m long, at 8 and 11 o'clock	None
55.6	3	Two cracks about .5m long at 11 and 1 o'clock	None
58.9	4 (3)	Multiple cracks at 12 and 1 o'clock	Monitor

Table C.10: Sewer Data Analysis – SMH 12 to SMH 13

C.11 SCO 3 to SMH 17

This line has seven (7) joints with infiltration staining and/or encrustation. One joint also has possible root intrusion. There are six (6) taps in this line, five (5) are factory tees and one is a break-in with PVC lateral protruding 50mm into the sewer. Three (3) locations with cracks and fractures.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.0	1	Circumferential crack - minor	None
8.2		Tap factory tee at 10 o'clock - good	None
8.8		Tap factory tee at 2 o'clock - good	None
31.0	2	Joint with possible root intrusion	None
34.0		Tap factory tee at 2 o'clock - good	None
60.6	3	Longitudinal fracture	
60.6	4	Tap break-in - PVC protrudes into sewer ~50mm	Trim
62.0	3 (0)	Tap factory tee with 90% blockage	Clear
62.4		Tap factory tee at 2 o'clock - good	None
77.8	4	Break (fracture) at joint from 3 to 8 o'clock	Point repair

Table C.11: Sewer Data Analysis – SCO3 to SMH 17

C.12 SMH 101 to SCO 3

This is the eastern extension to the Rowantree line and is all PVC. No defects observed in this line.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.0 to 27.1		All new PVC line. No defects.	None

Table C.12: Sewer Data Analysis – SMH 101 to SCO 3

C.13 SMH 101 to SMH 102

This is also an extension to the Rowantree line and is PVC. Several joints were found to have noticeable elliptical deflection (up to 5%). There is also a big dip in this line between 36.4m and 41.8m where the water level reached 50% of the pipe diameter.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
23.9	3	5% elliptical deflection at joint - could allow some infiltration	None
35.9		2% to 3% elliptical deflection at joint	None
47.8	2	Infiltration at joint	None

Table C.13: Sewer Data Analysis – SMH 101 to SMH 102

C.14 SMH 7 to SCO 1

There are five (5) joints with infiltration staining and/or encrustation. There are five (5) taps in this line, four (4) are factory tees and one is a break-in. The break-in tap has cracks all around and one factory tee is 50% plugged.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
9.3	4	Multiple fractures at joint, ~0.3m long, also infiltration staining	Point repair
12.5		Tap factory tee at 2 o'clock - good	None
37.6	4	Multiple fractures and cracks that extend to tap	Point repair
38.0	3	Tap break-in at 10 o'clock with cracks all around	Monitor
40.9		Tap factory tee at 2 o'clock - good	None
51.0	2	Two longitudinal cracks at 9 and 3 o'clock - 0.6m long	None
54.2		Tap factory tee at 3 o'clock - good	None
55.1	2	Complete circumferential fracture 0.3m from joint - no staining	None
58.0	2	Longitudinal crack at 3 o'clock - extends 0.6m from joint	None
69.5	3	Tap factory tee at 2 o'clock - 50% plugged with deposits	Clear

Table C.14: Sewer Data Analysis – SMH 7 to SCO 1

C.15 SMH 6 to SMH 5

Five (5) joints have encrustation associated with infiltration. There are three (3) taps in this line, two (2) are factory tees in good shape and one is a break-in tap of PVC with cracks surrounding the tap. Three (3) locations were observed with cracks with one with spiral fractures that initiate at a joint and proceeds to the break-in tap.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
9.9		Tap factory tee at 10 o'clock - good	None
35.1		Tap factory tee at 10 o'clock - good	None
45.2	1	Minor crack at 8 o'clock	None
72.9	3	Spiral fracture -minor	None
72.9	3	Tap break-in PVC with fractures around tap	None

Table C.15: Sewer Data Analysis – SMH 6 to SMH 5

C.16 SMH 7 to SMH 6

Two (2) joints with infiltration staining and/or encrustation. There are two (2) factory tee taps that are in good shape. Two (2) locations observed with cracks but not major and not needing repair.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.1	2	Minor cracks at 3 o'clock	None
37.1		Tap factory tee at 10 o'clock - good	None
61.1		Tap factory tee at 10 o'clock - good	None
65.7	3	Multiple circumferential cracks at joint - minor	None

Table C.16: Sewer Data Analysis – SMH 7 to SMH 6

C.17 SMH 7 to SMH 8

Three (3) joints with encrustation, two particularly bad. No taps. There was surface spalling in a large number of pipes. Only one location with small cracks, but minor.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.3	3	Longitudinal fracture at joint - small	None
21.6	2	Joint has large amount of encrustation	None
25.9	2	Joint has large amount of encrustation over 60% of circumference	None

Table C.17: Sewer Data Analysis – SMH 7 to SMH 8

C.18 SMH 8 to SMH 7

Three (3) joints with encrustation. No taps. There are four (4) locations with cracks and fractures, the one adjacent to MH 8 needing repair.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.0	4	Multiple longitudinal fractures at manhole, at 3 and 9 o'clock - ~0.6m long	Point repair
0.2	3	Multiple circumferential cracks from 8 to 12 o'clock	Point repair (with above)
40.2	2	Spiral crack - minor	None
41.6	2	Spiral crack - minor	None

Table C.18: Sewer Data Analysis – SMH 8 to SMH 7

C.19 SMH 3 to SMH 2

There are six (6) joints showing signs of infiltration staining and/or encrustation. No active infiltration. One tap factory tee in good shape. Five (5) locations with cracks or fractures, but only one needing repair at the moment.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.0	4(3)	Multiple cracks at first joint at MH	Point repair
0.8	2	Circumferential fracture - minor	None
2.0	3	Multiple circumferential cracks with staining - minor	None
3.8	2	Longitudinal crack at 11 o'clock - less than 0.3m long	None
27.4	4	Large joint separation - no signs of infiltration	None
29.7	4	Large joint separation - encrustation	None
30.0		Tap factory tee at 2 o'clock - good	None
30.1		Dip in line - 35% water level	None

Table C.19: Sewer Data Analysis – SMH 3 to SMH 2

C.20 SMH 12 to SMH 5

This line had considerable amounts of debris (including rocks) and should be jet cleaned with a vacuum truck. In addition there were twelve (12) joints in this line with infiltration staining and/or encrustation. Three (3) joints in particular had some root intrusion, but not clogging the line yet. No taps. Four (4) locations were observed with cracks or fractures, one being a clean 360° break around the entire circumference.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.3	4	Clean 360o break around the entire circumference	Point repair
14.2		Roots intruding into joint	None

15.5		Roots intruding into joint	None
23.8		Roots intruding into joint	None
47.0		Dip in line - 50% water level	Clean whole line
76.8	2	Longitudinal crack at 10 o'clock - 0.5m long	None

Table C.20: Sewer Data Analysis – SMH 12 to SMH 5

C.21 SMH 3 to SMH 4

This is the worst line in the system and the entire line should be lined with a CIPP liner. There are 13 joints showing signs of infiltration staining and/or encrustation. There are six (6) taps in this line, four (4) are factory tees and two (2) break-ins. The greatest concern are the fifteen (15) locations with pipe breakage, cracks and fractures, many requiring repair.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.3	5(4)	Break in pipe from 12 to 12 o'clock. Pipe ready to collapse	Repair immediately
16.1		Tap break-in - fair condition	None
19.4	4	Multiple fractures	Point repair
25.4	3	Tap factory tee at 2 o'clock - 70% plugged	Clear
26.9	3	Longitudinal crack - 0.3m long - minor	None
31.3	2	Longitudinal crack at 3 o'clock at joint - minor	None
35.4	2	Longitudinal crack at 10 o'clock - minor	None
46.4	3	Multiple cracks - fair	Monitor
53.4	4	Multiple fractures near joint	Point repair
53.7	3	Longitudinal fracture in crown - 1m long	Monitor
54.3		Tap break in at 2 o'clock - okay	None
57.6	2	Circumferential fracture - minor	None
65.0		Tap factory tee at 2 o'clock - partial blockage	None
83.3	2	Small longitudinal crack at 3 o'clock - 0.15m long	None
84.0	3	Three longitudinal cracks - 0.6m long	Point repair
85.8	4	Two longitudinal fractures - 1m long	Point repair
88.8	2(3)	Two longitudinal cracks -minor	None
89.2		Tap factory tee at 10 o'clock - good	None
89.7		Tap factory tee at 2 o'clock - good	None
109.2	3	Multiple cracks - not too bad	None
116.6		Tap factory tee - 30% blockage	Clean
116.9	2	Two longitudinal cracks at springline - 0.15m long	None

Table C.21: Sewer Data Analysis – SMH 3 to SMH 4

C.22 SMH 4 to SMH 5

This line has six (6) joints with infiltration staining and/or encrustation. There are four (4) taps, all factory tees, with only one having some blockage. Six (6) locations have broken, fractured or cracked pipe with three (3) needing repair.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.4	4	Multiple fractures in the pipe - 0.5m to 0.6m long	Point repair
2.7	2	Minor cracks at 2 o'clock	None
10.2		Tap factory tee at 2 o'clock - good	None
28.8	4	Fitting has break through the crown	Point repair
28.8		Tap factory tee - 30% blockage	Clear
37.2	2	Crack at joint crown - small	None
38.6	2	Longitudinal crack at joint - ~0.3m long - minor	None
45.9		Tap factory tee at 3 o'clock - good	None
46.8	4	Break 360^{o} around circumference	Point repair
64.3		Tap factory tee at 2 o'clock - good	None
75.0	3	Multiple cracks at joint - not too bad	None

Table C.22: Sewer Data Analysis – SMH 4 to SMH 5

C.23 SMH 12 to SMH 18

There are eight (8) joints in this line with infiltration staining and/or encrustation. There are six (6) taps with two (2) factory tees and four (4) break-in taps. One of the break-in taps is a 150mm lateral and protrudes into the sewer main. Another break-in tap is poorly constructed and is nearly 100% plugged with roots. One of the factory tees also has 25% blockage by roots. Ten (10) locations were found with breaks, fractures or cracks in the pipe. The pipe break near SMH 18 needs immediate repair as it could collapse.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
11.5	3	Spiral fracture at joint - 0.3m long	None
12.5	3(4)	Multiple longitudinal fractures at joint - 0.5m long	Monitor
15.0		Tap break-in at 2 o'clock - fair	None
19.2		Tap (150mm) break-in at 10 o'clock - intrudes into the main sewer, poorly constructed	
26.5	3	Two longitudinal cracks at joint along springline - 0.3m long	None
30.6	2	Spiral crack	None
31.1	3	Tap break-in - 100% plugged with roots	Clear and treat roots
33.4	2(3)	Multiple cracks at joint - minor	None
34.8	3	Two longitudinal cracks at 11 and 3 o'clock, one spiral crack at joint	None
55.6	3	Multiple cracks at joint, less than 0.3m long	None
67.2		Tap factory tee at 2 o'clock - 20% plugged with roots	None
69.4	3	Tap break-in with PVC - roots	None
69.4	2	Spiral crack at tap - minor	None

72.0		Tap factory tee - okay	None
74.6	4	Circumferential break at joint, with multiple fractures	Point repair immediately

Table C.23: Sewer Data Analysis – SMH 12 to SMH 18

C.24 SMH 18 to SMH

One joint with encrustation was found. There are six (6) taps in this line, with four (4) being factory tees and two (2) break-in taps. One of the taps has cracks surrounding it. Nine (9) locations were observed with breaks, fractures and cracks with two requiring a repair.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
0.0	4	Multiple breaks in first pipe joint	Point repair
11.7	2	Longitudinal crack - 0.3m long - minor	None
22.8		Tap break-in at 10 o'clock - fair	None
23.3		Tap break-in at 2 o'clock - fair	None
23.7	4	Multiple fractures near joint	Point repair
28.0	2	Longitudinal crack - minor	None
40.6	2	Spiral crack from 1 to 3 o'clock - minor	None
46.2	2	Longitudinal crack at 9 o'clock - 0.3m long	None
52.2	3	Tap factory tee at 9 o'clock - fracture inside tap	None
54.1	3	Tap factory tee at 2 o'clock - fracture inside tap	None
61.0	2	Spiral crack at joint - minor	None
62.5	3	Multiple cracks at joint	Monitor
72.4		Tap factory tee - okay	None
72.9	3	Tap factory tee - fracture around tap	None
72.9	2	Circumferential fracture in tee fitting	None

Table C.24: Sewer Data Analysis – SMH 18 to SMH

C.25 SMH 2 to SMH 1

There are seven (7) joints in this line with infiltration staining and/or encrustation. One break-in tap in this line with PVC lateral protruding into sewer main 25mm. The line has three (3) locations with cracks, and one short section of PVC.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
50.1	2	Joint with large amount of encrustation	None
62.3	2	Tap break-in at 2 o'clock - PVC protrudes into main 25mm. Crack around the tap	Repair
62.3	2	Spiral crack at tap - minor	None
77.0	1	Short longitudinal crack at 9 o'clock - less than 0.15m	None
116.8	1	Circumferential crack at joint - from 9 to 10 o'clock - minor	None
119.5 to 124.5		PVC - previous repair by replacement	None

Table C.25: Sewer Data Analysis – SMH 2 to SMH 1

C.26 SMH 1 to SMH

This line is all PVC. The CCTV survey was stopped at 18.5m due to high water. No taps or structural defects in the portion of the line surveyed. There is debris and grease in the line probably due to dip. The line should be jet cleaned with a vacuum truck.

Distance From SMH to Defect	Defect Grade	Description of Defect(s)	Rehabilitation Recommendation
10.5		Dip in pipe. Water level at 50% of diameter	Clean
18.5		Siphon. Water level at 100% of diameter. End of survey.	Clean

Table C.26: Sewer Data Analysis – SMH 1 to SMH