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Technical **Report**



EAST HANTS



Title: Shubenacadie Leak Detection and Condition Assessment

Client: Municipality of East Hants

Report Classification: Final

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Executive Summary

Echologics, a Division of Mueller Technologies Company (Echologics), provided leak detection and condition assessment services for the Municipality of East Hants (East Hants) on approximately four kilometres of Asbestos Cement and PVC pipe. Echologics' field personnel completed the survey in Shubenacadie, NS between November 25th and 29th 2015. Echologics performed leak detection using the LeakFinder™ correlator and acoustic condition assessment using the ePulse™ method. This report presents the information gathered from these services including the location of suspected leaks and the results of ePulse™ testing.

East Hants's water delivery system consists of approximately 5 km of asbestos cement and PVC/HDPE pipe. The small demand placed on the system by customers causes non-revenue water losses in the system to have a large proportional impact.

Summary of key results

Echologics' field personnel did not uncover any leaks in the Shubenacadie area during the condition assessment survey. The asbestos cement mains were tested for both remaining structural wall thickness and leakage. Six asbestos cement mains tested are in moderate condition with structural wall thickness losses between 10% and 30%. Eleven segments tested are in poor condition with wall thickness losses greater than 30%. Four segments tested did not return a result due to inadequate correlation signals. No segments tested had wall thickness losses less than 10%. In the case of the East Hants' Shubenacadie system, inadequate correlation signals are likely caused by the noise attenuation from PVC pipes.

Echologics provides services that help water departments determine the current condition of their assets by providing them with information about leakage and pipe condition. This information is required to properly manage water delivery systems. All of this information is gained through non-invasive technology which is deployed non-intrusively so that the cost and risk associated with gaining the information is minimized.

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1. Project Background

The Municipality of East Hants (East Hants) issued a Request for Proposal to gain information on critical segments of its PVC and asbestos cement (AC) water mains in the community of Shubenacadie, N.S. Echologics, a Division of Mueller Technologies Company (Echologics), was awarded this proposal to address the following primary objectives:

- Assess the structural condition of the remaining AC pipe in the system
- Pinpoint leaks to identify non-revenue water sources
- Cause no disruptions to customers during testing

To achieve these objectives, Echologics utilized its patented EchoWave™ and ePulse™ technologies to locate leaks and determine the current condition of the pipe walls. This report provides detailed information on how these objectives have been met.

The Shubenacadie system has a relatively low base water demand of approximately 40 gallons per minute. This low rate causes any non-revenue losses such as leaks to place a large demand on the system relative to its normal capacity. As of December 2015, East Hants estimated there to be an unaccounted water loss of approximately 10 gallons per minute.

Once site testing commenced it was found that the items outlined as water points in Figure 1 did not provide access to the water mains as originally anticipated. As a result some segments were too long or complex to provide a successful correlation or the purposes of a condition assessment and this project.

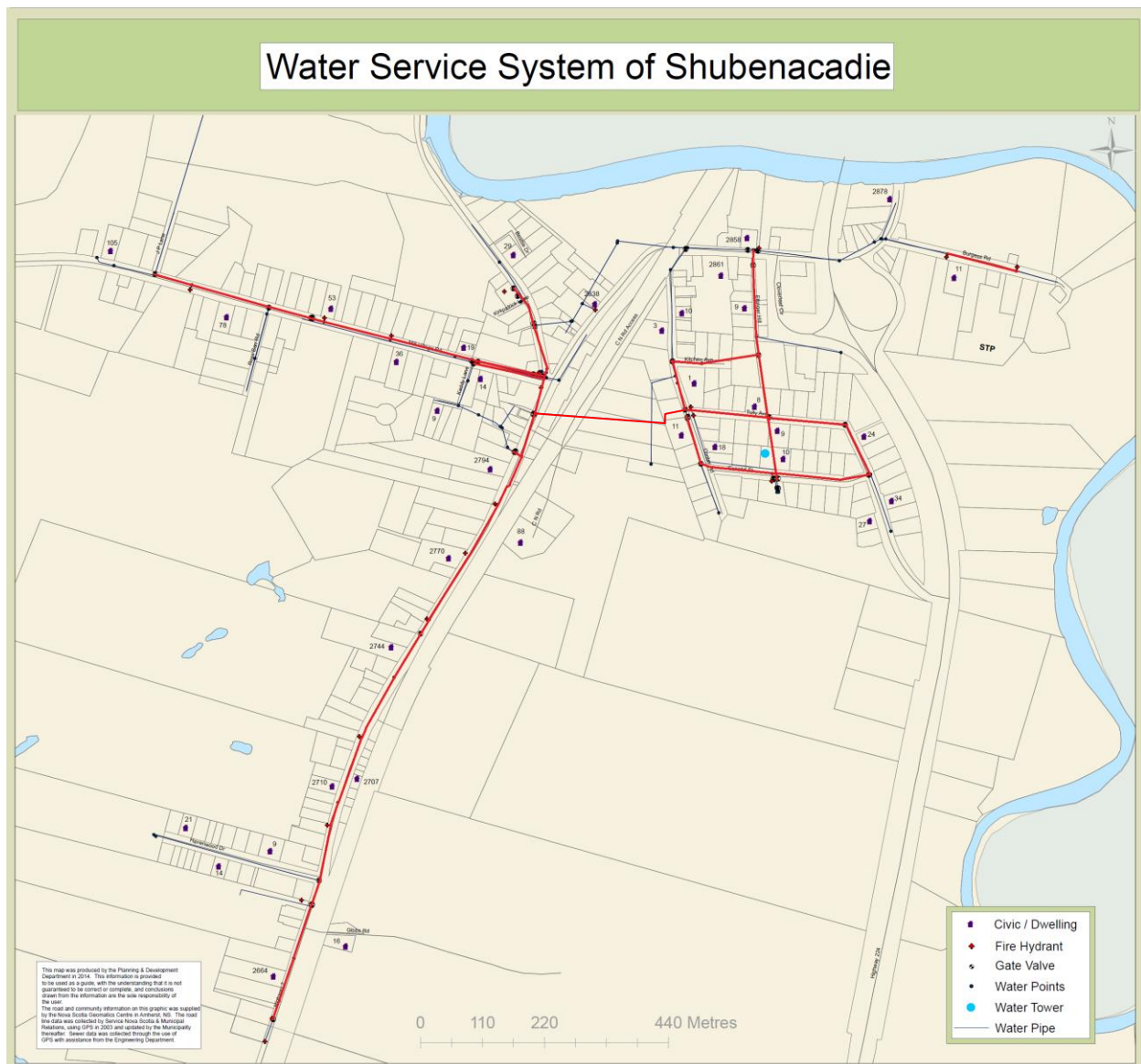


Figure 1: System Overview and Site Locations – Segments tested are coloured red

The project included four kilometres of mains spread over Shubenacadie, as detailed in Figure 1. Field tests began on November 25th, 2015 and required four days to complete. This system was selected for assessment due to the lack of information available on the integrity of the pipes as well as the apparent losses in the network.

ePulse™ condition assessment combines acoustic data measured in the field with information about a pipe's construction to calculate its current wall thickness. The pipe's material, internal diameter, and modulus of elasticity are critical variables in this calculation. ePulse™ condition assessment calculates the percentage of wall thickness loss by comparison of the measured wall

thickness to the design thickness of the pipe wall. Echologics used the pipe properties shown in Table 1: Pipe Properties. Further details on the pipe properties are available in Appendix A: Detailed Results.

Table 1: Pipe Properties for Condition Assessment

Site	Pipe Material	Pressure Class	Install Year	Internal Diameter (mm)	Nominal Thickness (mm)
Shubenacadie	AC	150	1967-68	150	12.7
Shubenacadie	AC	150	1967-68	200	19.3

Note: Asbestos pipes manufactured in the era have wall thickness tolerances of $\pm 1.5\text{mm}$

2. Results

2.1 EchoWave™ Leak Detection

No leaks were detected in Shubenacadie during the time of the survey.

Some segments were not able to be directly leak detected due to the unavailability of valves or due to the length of the segments.

Segment 10 was the only segment that was attempted that provided inconclusive results. Segment 10 involved testing an approximately 300 metre length of main that was 12 inches in diameter, made of HDPE and also crossed under a busy rail line. Plastic pipe has an increased difficulty associated with correlation testing due to the attenuation of noise in plastic pipes. Due to this, shorter segments are tested to help mitigate the dampening effect and ensure that leak noises are able to propagate all the way to the sensor. Segment 10 was attempted on a “best-efforts” basis after informing East Hants that sensitivity would likely be significantly reduced.

The maximum length recommended between Echologics surface mounted sensors in order to deliver reliable results on is 100 metres. It is recommended that future testing be performed with vacuum excavation holes dug at intermediate locations in order to increase the chances of finding a leak.

In the cases where no leaks are found, Echologics performs sensitivity tests to determine if noise, such as a hydrant flowing can indeed be correlated. Successful simulations further prove that no leaks are present on the tested segments.

Leak detection results are summarized below in Table 2: EchoWave™ Results.

Table 2: EchoWave™ Results for Lengths of Main Where Only Leak Detection Was Conducted

Segment	Street Name	Distance (m)	Pipe Material	Internal Diameter	Leak Result
5	Second St	102.4	PVC	150	No Leak
6	Second St	182.0	PVC	150	No Leak
7	Conley Rd	121.0	PVC	150	No Leak
8	Conley Rd	106.7	PVC	150	No Leak
9	Tully Ave	148.7	PVC	150	No Leak
10	Rail Crossing	274.3	HDPE	300	No Result
11	Tully Ave	139.0	PVC	150	No Leak
12	Tully Ave	98.5	PVC	150	No Leak
29	Hwy 2	77.4	HDPE	300	No Leak
30	Hwy 2	68.6	HDPE	300	No Leak

2.2 ePulse™ Condition Assessment

The ePulse™ condition assessment results are presented in Table 3 below. Results are shown as remaining structural wall thickness. Where the original nominal thickness is available, results are also presented as a percentage loss in a colour-coded category indicating a qualitative description of the expected condition of the main.

Table 3: ePulse™ Pipe Wall Condition Assessment Results

Segment	Street Name	Distance (m)	Pipe Material	Internal Diameter (mm)	Nominal Thickness (mm)	Remaining Thickness (mm)	% Change from Nominal
1	Burgess Rd	134.7	AC	150	12.8	8.4	-35%
2	Ettinger Hl	184.7	AC	200	15.2	11.9	-21%
3	Ettinger Hl	125.3	AC	200	15.2	8.9	-42%
4	Second to Tully	114.9	AC	200	15.2	8.9	-42%
13	Hwy 215	53.3	AC	150	12.8	5.6	-56%
14	Hwy 215	78.0	AC	200	15.2	9.4	-38%
15	Mill Village Rd	117.3	AC	200	15.2	9.7	-37%
16	Mill Village Rd	154.2	AC	200	15.2	-	N/A
17	Mill Village Rd	143.0	AC	200	15.2	-	N/A
18	Mill Village Rd	74.4	AC	200	15.2	12.5	-18%
19	Kitchen Ave	146.9	AC	200	15.2	11.2	-26%

Segment	Street Name	Distance (m)	Pipe Material	Internal Diameter (mm)	Nominal Thickness (mm)	Remaining Thickness (mm)	% Change from Nominal
20	Mill Village Rd	146.3	AC	200	15.2	9.7	-37%
21	Mill Village Rd	79.6	AC	200	15.2	11.4	-25%
22	Hwy 2	154.2	AC	200	15.2	-	N/A
23	Hwy 2	142.6	AC	200	15.2	-	N/A
24	Hwy 2	99.1	AC	200	15.2	8.9	-42%
25	Hwy 2	167.9	AC	200	15.2	11.2	-26%
26	Hwy 2	241.4	AC	200	15.2	10.2	-33%
27	Hwy 2	236.8	AC	200	15.2	11.2	-26%
28	Hwy 2	99.1	AC	200	15.2	9.9	-35%

The majority of the pipes inspected showed high levels of degradation (greater than 30%) with some areas showing moderate levels of degradation (between 10 and 30% loss) Given that the mains are all asbestos cement pipe with similar installation age, it is not unusual for them to all exhibit a similar condition.

2.2.1 Burgess Road

Only one section of pipe on Burgess Road has sufficient access points in order to correlate successfully. The section that was tested proved to be in poor condition based on the pipe specifications used. Please note that a change of pipe class will not affect the remaining wall thickness and is just used as a base for a percentage loss calculation.

2.2.2 Mill Village Road

This section of pipe ran parallel to a PVC water main along the same street. Echologics attempted all available sections along this road however there were two segments that were not successful. This was due to the presence of new hydrants installed along the main, likely installed with PVC leads to the main from the shoe at the bottom. PVC material attenuates sound more than metallic mains. This attenuation can prevent Echologics from collecting the appropriate data required to present a structural thickness result.

2.2.3 Kitchen Avenue

Segment 19 on Kitchen Avenue was measured using a GPS device on site. Typically distances are physically measured with a measuring wheel on site. This measurement was not possible for segment 19 as the main runs underneath a wooded area. If a more reliable distance can be attained for this length of main the new value can be used to recalculate the result if needed.

2.2.4 Highway 2

Sound propagation issues were encountered at the farthest south reaches of the Shubenacadie water system. This issue was highly likely to be due to the presence of PVC leads similar to Mill Village Road or due to some dirt in the valve box that caused an improper sensor connection.

2.3 Limitations

The accuracy of the final results presented in this report can be impacted by a variety of factors, some of which are beyond our control. In addition, we accept no responsibility or liability for the results of decisions taken by our clients concerning their asset management.

2.3.1 Modulus of Elasticity

The modulus of elasticity of the pipe material is one of the factors in the calculation of the current pipe wall thickness. While Echologics has significant experience estimating the modulus of elasticity based on the material, age, and region of manufacture, we can improve the accuracy of the results by testing the actual modulus of elasticity of an exhumed sample of the pipe wall. If interested, please contact Echologics for more information.

2.3.2 Pipe Specifications

Detailed pipe specifications were not available for all pipes surveyed. Although Echologics has made reasonable assumptions for internal diameter, material and original wall thickness, the results can be improved if accurate pipe specifications can be provided. If original specifications cannot be located, East Hants may wish to exhume a pipe coupon to verify diameter, material and thickness assumptions.

2.3.3 Sound Attenuation

Segments that have many bends can cause sound waves to attenuate. This dampening effect can reduce the feasible testing length of longer segments to a point where correlation is not possible unless the length can be shortened.

2.3.4 Statistical Variation

The values generated by ePulse™ testing are averaged for a segment of pipe which ranges in length from 50 to 200 metres. This averaging allows for the possibility of having small lengths within the segment which are severely degraded. This degradation will not be shown in the final result. Therefore it is important to note that the value presented describes the general condition of the pipe and may not show future potential point failures.

2.4 Disclaimer

All forms of non-destructive testing involve an inherent and unavoidable level of uncertainty. The results provided by Echologics are not guaranteed. The methods used for leak detection and pipe condition assessment are highly dependent on input parameters; therefore, it is not possible to certify the results. Echologics is not responsible for any actions taken or recommendations made by its clients based on the results presented in this report.

Echologics uses a commercially reasonable and technology-based best effort methodology developed through experience and expertise in acoustic-based leak detection and pipe wall condition assessment. The findings summarized in this report represent survey level results. The accuracy of assessments is subject to, among other factors:

- interference from background noise, which, in specific cases, may make the data unsuitable for analysis; and
- the accuracy of certain information provided to Echologics by its clients, including, but not limited to, pipe infrastructure descriptions and layouts, water temperature and the distance and size of pipes.

3. Discussion and Next Steps

Echologics has provided information for East Hants on leak locations and pipe wall condition of four kilometres of asbestos cement and PVC. It appears that all segments of pipe tested are in poor to moderate condition with structural wall losses in the range of 18 to 56%. A further explanation of moderate to poor condition can be found in Echologics' qualitative interpretation of results located in Appendix B.2 ePulse™ Condition Assessment.

A measurement of the rail road crossing pipeline was attempted to determine the location of and confirm an apparent loss of water when the line was in service. Due to the length of the segment and the material, correlation was not successful. It is recommended that some intermediate vacuum truck excavation holes be dug in order to break up the distance into smaller sections for correlation with a higher chance of success.

If the remaining untested AC pipes wish to be tested for remaining structural wall thickness, pothole excavations should be installed using a hydro-vac excavation truck to reach the crown of the pipe. This allows for additional access points in order to create segments that have the proper specifications for testing.

Echologics' condition assessment results are an effective and valuable component of the asset management process for prioritization of pipeline repair and rehabilitation. Each water network will have its own dominant degradation mechanism, as well as unique local considerations. Comparing Echologics' results with some of the following datasets will allow East Hants to direct their rehabilitation efforts in a cost effective manner.

- **Soil Corrosivity.** This comparison will help determine if external corrosion due to aggressive soil is a significant degradation mechanism for these mains. For example, if corrosive soils are discovered and the main is in poor condition, the degradation is likely related to soil conditions.
- **Water Aggressiveness.** This comparison will reveal whether or not the water is a mechanism for uniform degradation. For example, aggressive water would suggest that some of the degradation is caused from the inside; this can be assumed to cause similar degradation rates for similar types of main.

- **Break History.** Collating condition assessment results and break history help identify sections of main that are at increased risk of failure. These factors are not necessarily related, as it is possible for pipes to have high break rates for reasons other than pipe wall degradation.
- **Consequence of Failure.** Combining condition assessment results with consequence of failure analysis is used to generate a risk assessment.

This report is intended to be used as a guide only. All forms of non-destructive testing involve an inherent level of uncertainty. Such testing is dependent on input parameters, and outputs can be significantly affected by variation from assumed parameters. This report includes certain suggestions and recommendations made by Echologics which are based on, among others, (i) the findings included in the report, (ii) its experience and (iii) an understanding of the client's particular requirements. Echologics acknowledges that the client may use this report to consider potential opportunities for pipeline replacement/rehabilitation; however, Echologics disclaims any liability that may arise in connection with decisions based on these suggestions or recommendations or their implementation.

Please do not hesitate to contact us should you have any questions or comments regarding the study or this report.

Appendix A Detailed Results

This section provides a detailed presentation of the project scope, as well as the data collected and results obtained during the project.

A.1 Site Details

This project was divided into two distinct parts:

- The condition assessment and leak detection of the asbestos cement pipes
- The leak detection of the PVC pipes

An overview map of the sites is shown in Figures A.1-1 and A.1-2 below, followed by detailed information on each of the sites. The segments are numbered according to their results displayed in the condition assessment table. Segments that are associated with condition assessment data have been colour coded to correspond to their condition with yellow representing moderate (10-30% loss) and red representing poor (greater than 30% loss).

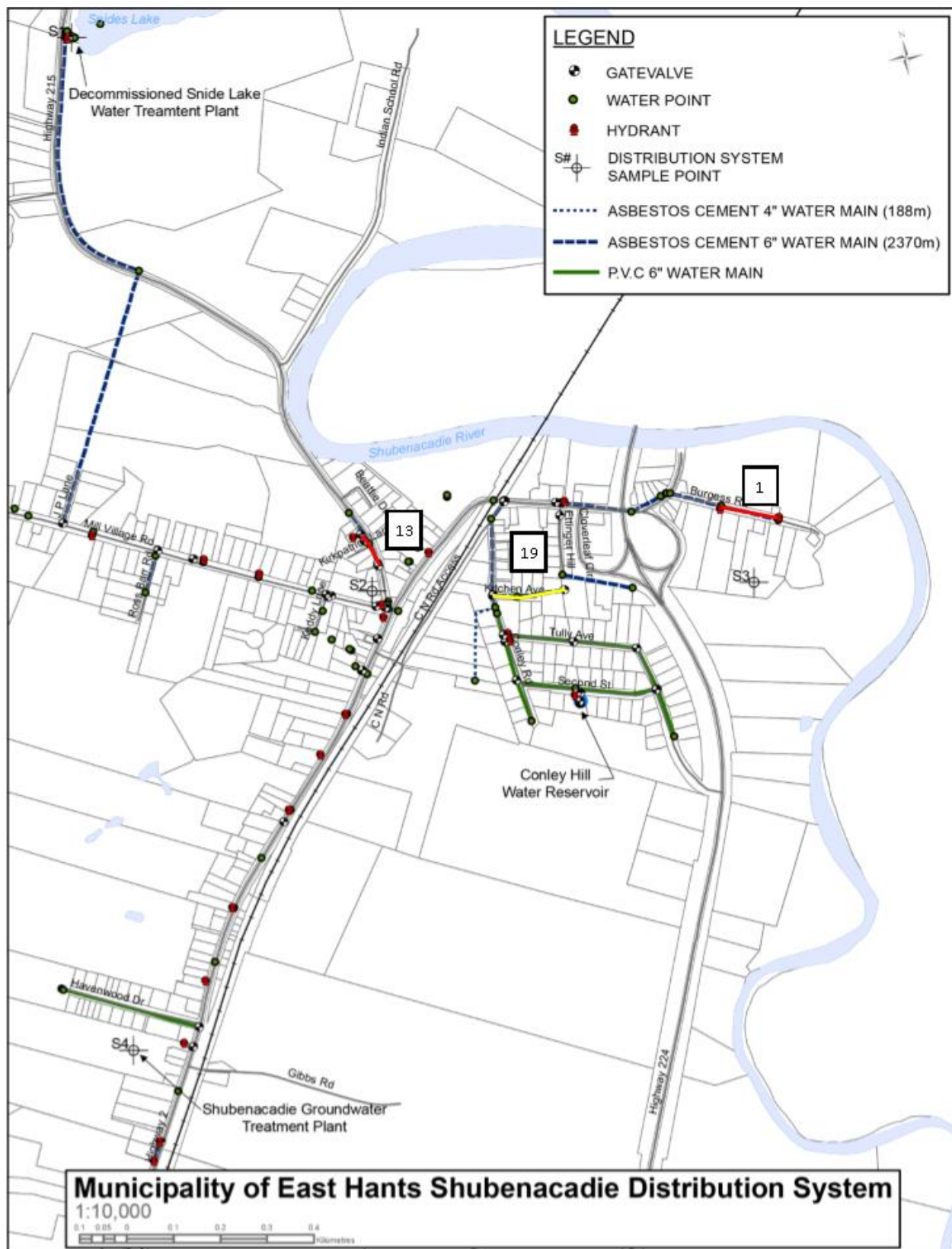


Figure A.1-1: 150mm Diameter Asbestos Cement Pipe

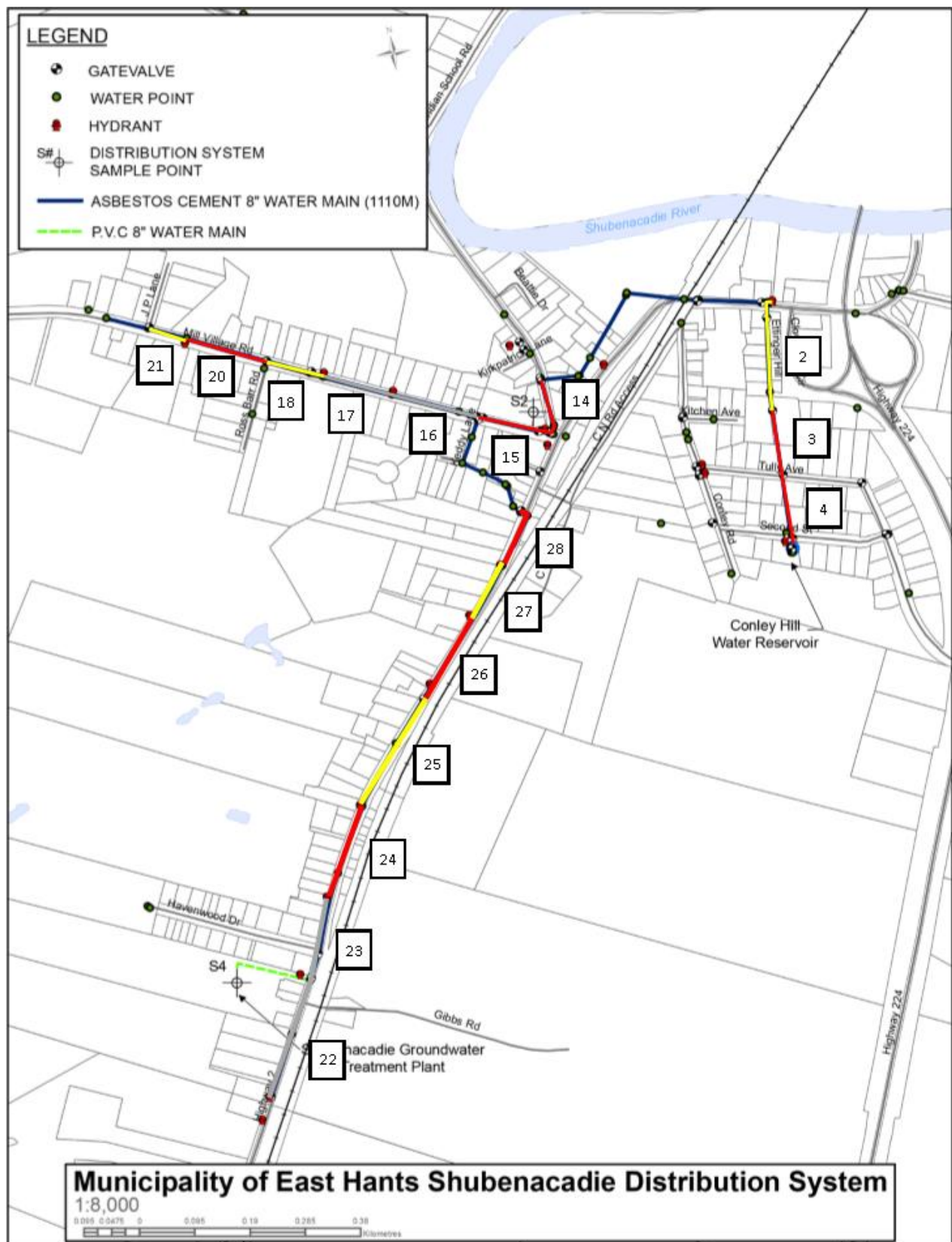


Figure A.1-1: 200mm Diameter Asbestos Cement Pipe

A.2 Leak Detection Site Details

Table A1-1: EchoWave™ Results for lengths of Main Assessed for Leakage

Segment	Street Name	Distance [m]	Pipe Material	Internal Diameter	Leak Result
5	Second St	102.4	PVC	150	No Leak
6	Second St	182.0	PVC	150	No Leak
7	Conley Rd	121.0	PVC	150	No Leak
8	Conley Rd	106.7	PVC	150	No Leak
9	Tully Ave	148.7	PVC	150	No Leak
10	Rail Crossing	274.3	HDPE	300	No Result
11	Tully Ave	139.0	PVC	150	No Leak
12	Tully Ave	98.5	PVC	150	No Leak
29	Hwy 2	77.4	HDPE	300	No Leak
30	Hwy 2	68.6	HDPE	300	No Leak

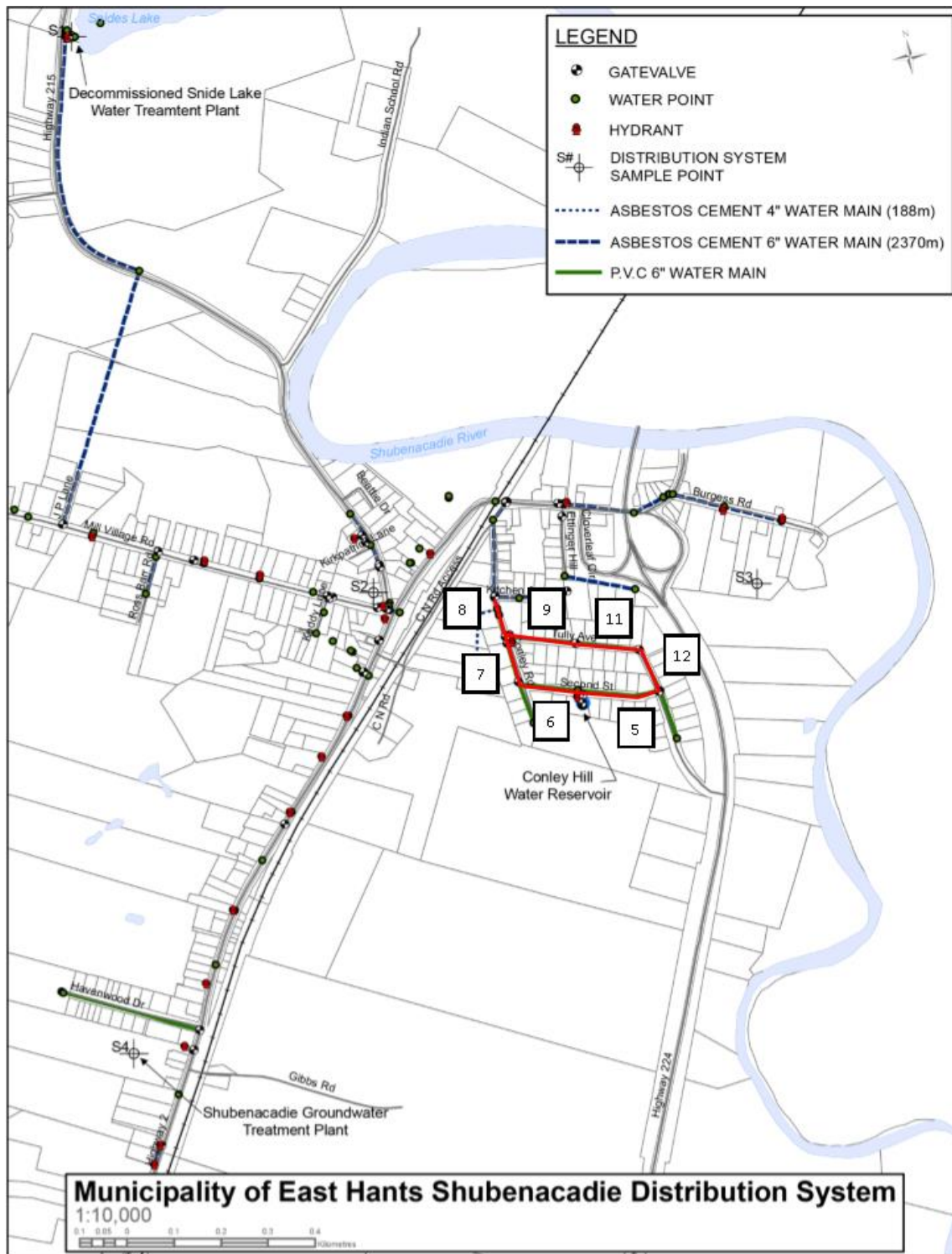


Figure A.2-1: 150mm Diameter PVC Pipe

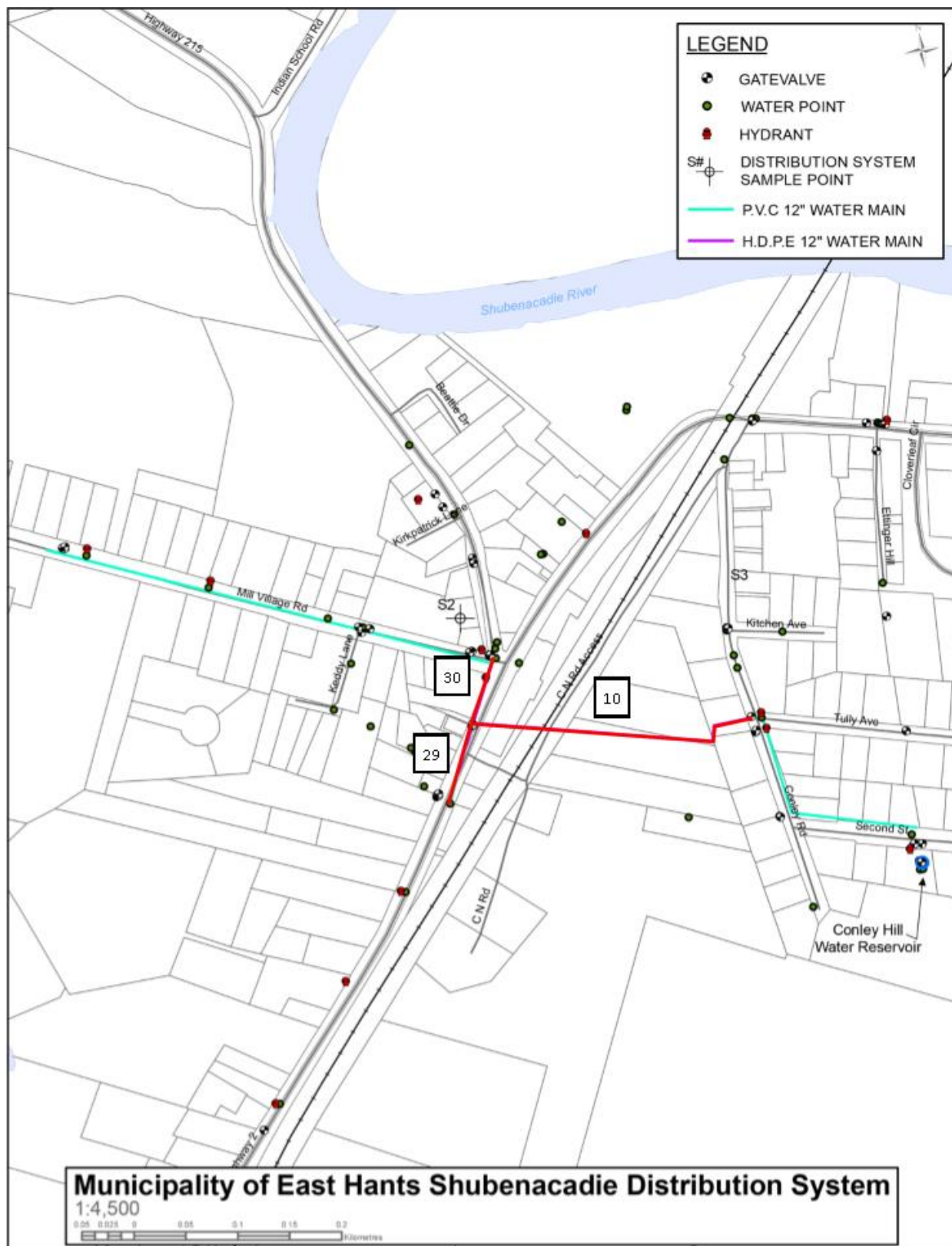


Figure A.2-1: 300mm Diameter PVC and HDPE Pipe

A.3 Pipe Property Details

The pipe properties used in this project are presented in Table A.3-1, which were obtained from AWWA C400.80 Standards

Table A.3-1: Pipe Properties

Site	Material	Pressure Class	Year of Installation	Internal Diameter (mm)	Nominal Thickness (mm)
Shubenacadie	AC	100	1967-68	150	12.7
Shubenacadie	AC	100	1967-68	200	19.3

Manufacturing tolerances for AC pipe during this period were ± 1.5 mm

A.4 ePulse™ Condition Assessment Result Details

Table A.4-1 below presents the full results of the ePulse™ testing.

Table A.4-1: ePulse™ Pipe Wall Condition Assessment Result Details For Shubenacadie

Segment	Site	Distance (m)	Pipe Material	Internal Diameter (mm)	Pressure Class	Install Year	Temp (°C)	Pressure (psi)	Nominal Thickness (mm)	Remaining Thickness (mm)	% Change from Nominal
1	Burgess Rd	134.7	AC	150	100	1967	9.3	90	12.8	8.4	-35%
2	Ettinger Hl	184.7	AC	200	100	1967	9.3	90	15.2	11.9	-21%
3	Ettinger Hl	125.3	AC	200	100	1967	9.3	90	15.2	8.9	-42%
4	Second to Tully	114.9	AC	200	100	1967	9.3	90	15.2	8.9	-42%
13	Hwy 215	53.3	AC	150	100	1967	9.3	90	12.8	5.6	-56%
14	Hwy 215	78.0	AC	200	100	1967	9.3	90	15.2	9.4	-38%
15	Mill Village Rd	117.3	AC	200	100	1967	9.3	90	15.2	9.7	-37%
16	Mill Village Rd	154.2	AC	200	100	1967	9.3	90	15.2	N/A	N/A
17	Mill Village Rd	143.0	AC	200	100	1967	9.3	90	15.2	N/A	N/A
18	Mill Village Rd	74.4	AC	200	100	1967	9.3	90	15.2	12.5	-18%
19	Kitchen Ave	146.9	AC	200	100	1967	10.2	90	15.2	11.2	-26%
20	Mill Village Rd	146.3	AC	200	100	1967	10.2	90	15.2	9.7	-37%
21	Mill Village Rd	79.6	AC	200	100	1967	10.2	90	15.2	11.4	-25%
22	Hwy 2	154.2	AC	200	100	1967	10.2	90	15.2	N/A	N/A
23	Hwy 2	142.6	AC	200	100	1967	9	78	15.2	N/A	N/A
24	Hwy 2	99.1	AC	200	100	1967	9	78	15.2	8.9	-42%
25	Hwy 2	167.9	AC	200	100	1967	9	78	15.2	11.2	-26%
26	Hwy 2	241.4	AC	200	100	1967	9	78	15.2	10.2	-33%
27	Hwy 2	236.8	AC	200	100	1967	8.9	90	15.2	11.2	-26%
28	Hwy 2	99.1	AC	200	100	1967	8.9	90	15.2	9.9	-35%

Appendix B Interpretation of Results

B.1 EchoWave™ Leak Detection

When Echologics discovers a noise on a main, it can be classified as a leak or a point of interest (POI). If further investigation reveals negative results, it is classified as no leak discovered. Within all Echologics reports, if no mention is made of leaks on a given section, it may be assumed that the result of the test is no leak discovered.

No Leak Discovered

When a negative correlation is matched with poor coherence, it is concluded that no leak was detected. This indicates that the LeakFinder system is not identifying a noise source of any sort, and that there is no other evidence of leakage. Where possible, leak simulations are performed to confirm the absence of leaks and to ensure equipment functionality.

Point of Interest (POI)

A Point of Interest (POI) designation indicates that some, but not all, of the criteria for a positive leak detection result are met. This could mean that a strong correlation is observed but coherence is poor, or that there is no confirmation of leak noise through other test methods such as ground sounding or secondary correlation tests. This does not indicate a conclusive leak, however it is recommended that the client perform a secondary investigation. This will confirm the presence and location of the leak, as there is evidence of some form of noise inside the pipe.

Leak

Three pieces of conclusive evidence must be acquired for a Point of Interest to be upgraded to a Leak. This includes but is not limited to the following methods of detection:

- leak correlation
- ground sounding
- acoustic sounding of fittings
- visual observation of moving water
- confirmation of chlorine residuals in stagnant water

Several criteria must be met for audio recordings in order to provide a positive leak detection result. This includes but is not limited to:

- a clean distinctive correlation peak
- an observable coherence level
- similar frequency spectra in each channel
- a minimum amount of clipping in the time signal

In some instances, more than one correlation test can be used as evidence to conclusively identify a leak. For instance, a field specialist can perform multiple correlation tests with sensors mounted to different pipe fittings.

B.2 ePulse™ Condition Assessment

ePulse™ condition assessment measures the current average minimum structural thickness (for asbestos cement or metallic mains) or current average structural stiffness (for reinforced concrete). Where the original nominal thickness (or stiffness) is available, results are also presented as a percentage loss, and as a category indicating a qualitative description of the expected condition of the main.

Qualitative Condition Description Categories

The colour coding and descriptions in Table B.2-1 are used for the results presented in all ePulse™ condition assessment reports.

Table B.2-1: Color Coding and Wall Thickness Loss Qualitative Descriptions

Change in Wall Thickness	Description	Color Code	Description		
			Asbestos Cement Mains	Metallic Mains	Concrete Composite Mains
Less than 10%	Good	Green	Minor levels of degradation and/or isolated areas with minor loss of structural thickness	Minor levels of uniform corrosion or some localized areas with pitting corrosion.	Minor levels of uniform interior or exterior concrete degradation or localized areas with severe degradation. Minor possibility of corrosion of steel cylinder or reinforcement.
10% to 30%	Moderate	Yellow	Considerate levels degradation and loss of structural thickness. Moderate levels of cement leached away from asbestos matrix.	Considerate levels of uniform surface or internal corrosion and/or localized areas of pitting corrosion.	Considerate levels of degradation and loss of wall stiffness. Some corrosion of steel cylinder and reinforcement.
Greater than 30%	Poor	Red	Significant degradation and loss of structural thickness. Substantial levels of cement leached away from asbestos matrix.	Significant uniform corrosion and/or numerous areas of localized pitting corrosion.	Significant degradation and loss of wall stiffness and corrosion of steel cylinder and reinforcement.

These descriptions are based on Echologics' experience and with validation of our results through the exhumation of pipe samples that we have tested. Following the table, more detail is provided as to the expected condition of different types of main in each condition category, along with examples of validation of the ePulse™ method on each type of main.

Distribution of Degradation within Segments

Each ePulse™ result represents an average pipe wall condition within a Segment between two sensor attachment points. Pipe wall conditions may vary within a Segment. The condition at any one point within the segment may not reflect the average conditions within that Segment.

The ePulse™ method tests the average structural thickness of the pipe, which is not the same as the average thickness of the pipe. ePulse™ measures a pipe's hoop stiffness: its resistance to axi-symmetric expansion under the tiny pressure variations caused by sound waves. Material properties are then used to calculate the pipe wall thickness which would provide exactly this hoop stiffness. This is referred to as the average structural thickness.

To obtain this same value mechanically, you would need to: divide a pipe into hoops; measure the thinnest section of structural material around the circumference of each hoop (i.e. graphite, tuberculation product, or asbestos cement with the calcium leached out would not be counted); and then average these.

For example, any of the following descriptions will hold true for a pipe with a loss of 25%:

1. Circumferentially uniform loss of 25% along the entire Segment.
2. Circumferentially uniform loss of 50% along half of the Segment, but 0% loss along the other half of the Segment.
3. Loss of 25% at the crown of the pipe along the entire Segment, but 0% loss along any other point in the circumference along the entire Segment.

These descriptions hold true for asbestos cement, metallic and reinforced concrete mains.

Condition Interpretation in Asbestos Cement Mains

As asbestos cement pipes age and degrade, they will not lose actual thickness, but will lose structural thickness as the calcium leaches out of the asbestos cement matrix. This portion of the asbestos cement will become soft, and will no longer bear a structural load, and therefore does not contribute to the structural thickness. The ePulse™ method measures the remaining structural thickness (also known as the effective thickness), as illustrated in Figure B.2-1, rather

than the actual physical wall thickness (which will generally remain at the nominal thickness).

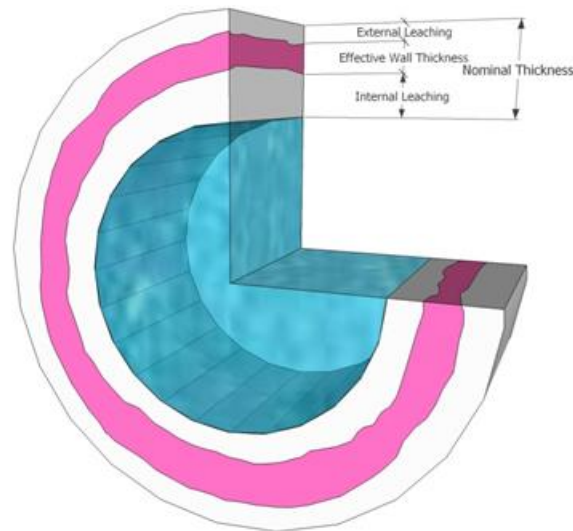


Figure B.2-1: Structural Thickness in Asbestos Cement Pipe

Case Study: Sweetwater Authority

Echologics and MEI-Charlton (MEIC) were engaged by the Sweetwater Authority to assess the condition of asbestos cement mains in Chula Vista, California. Seven samples were taken and the mains surveyed ranging from 6 inch to 12 inch in diameter and pressure class 150.

Each firm used its own methods to assess the condition of the water mains. Echologics employed acoustic based condition assessment technology and mathematical formulas to model the critical loads, while MEI-Charlton Inc. examined the extent of cement leaching in the pipe samples using a phenolphthalein indicator. MEI-Charlton Inc. also determined the critical loads of the pipe by utilizing V-shaped three- edge bearing test and hydrostatic strength test in accordance with ASTM C296 and ASTM C500. The results of Echologics' thickness measurements and the thickness of the phenolphthalein tests are summarized below in Figure B.2-2.

Overall, the ePulse™ results closely matched the average thicknesses shown by the coupon samples. In all cases, the ePulse™ results are slightly thinner than those shown in the couple samples. This is attributed to two main factors:

1. The coupon sample measurements may not have accurately captured the minimum circumferential thickness.

2. While the phenolphthalein test provides a clear line of “structural” versus “non-structural” material, it is in fact possible to have partial leaching within the “structural” material. The ePulse™ method would capture this, whereas dye testing of samples would not.

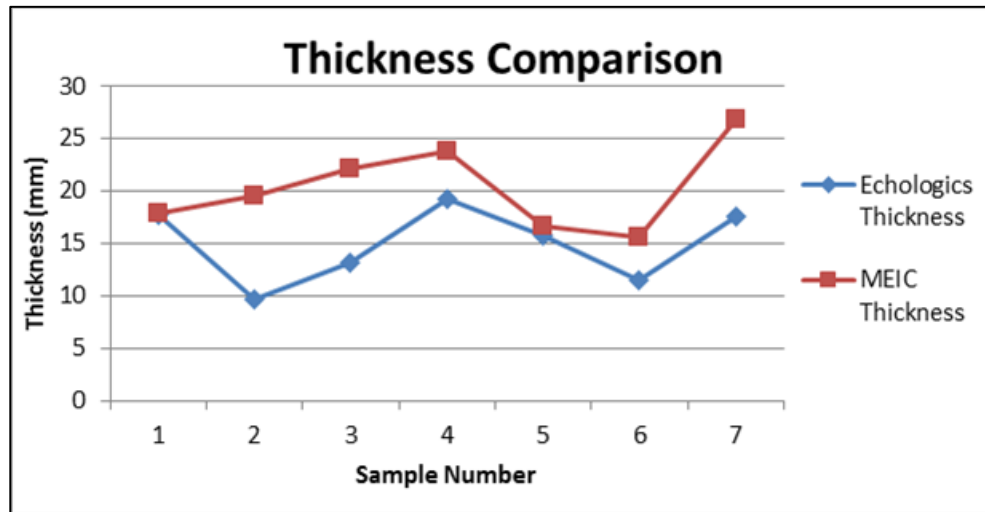


Figure B.2-2: Validation of ePulse™ Results on Asbestos Cement Pipe

In order to compare the different methods of thickness measurements the minimum thicknesses provided for MEIC and the thicknesses measured by Echologics were used to estimate the burst pressure of the pipe. The same assumptions and material properties were used in both calculations, only the thicknesses were varied. The results of these calculations, along with the results of the burst strength test are presented below in Figure B.2-3.

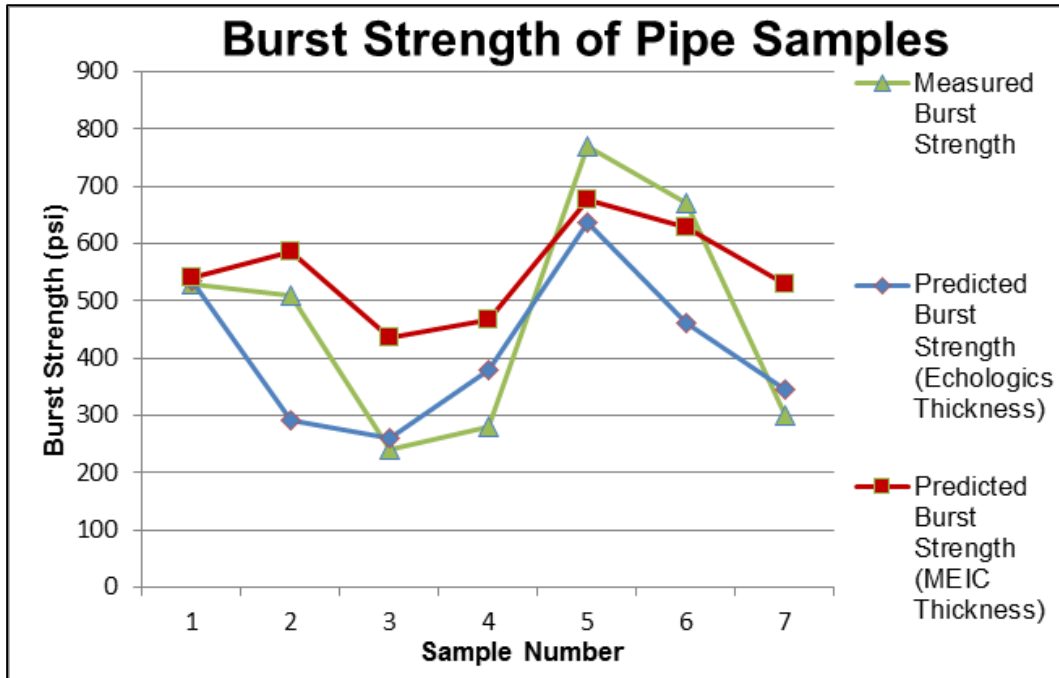


Figure B.2-3: Comparison of Different Methods of Determining Effective Thickness with respect to Burst Strength

It can be seen from Figure B.2-3 that both the thickness measured by Echologics and the thickness measured by MEIC were able to characterize the condition of the water mains. It is worth noting that the ePulse™ method was notably more accurate when the measured burst strengths were low (samples 3, 4, and 7), which highlights the predictive power of the method. The measured thicknesses were also compared against the crush strength of the samples. The results are shown below in Figure B.2-4. One can observe that both data sets have similar distributions. Further study is still required to accurately predict the critical crush strength of pipes given the thickness, loading conditions and material properties.

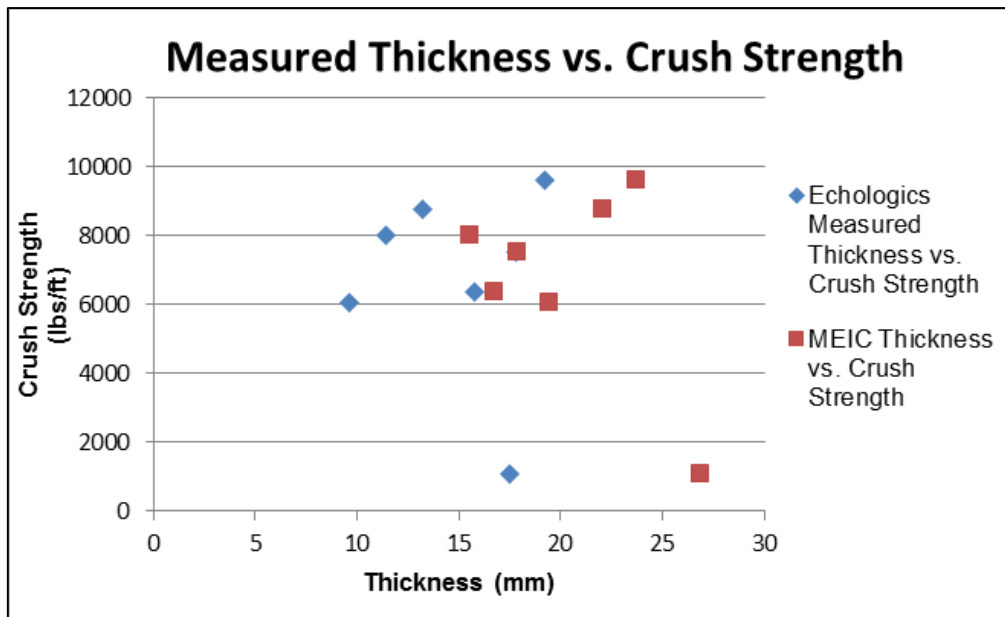


Figure B.2-4: Measured Crush Strength vs. Crush Strength

Appendix C Sensitivity Analyses and Considerations

Echologics is constantly committed to reducing error during every step of the testing process. There are factors that may introduce error into the analysis. These errors may be caused by one or more of the following: inaccurate distance measurements, variance in manufacturing tolerances, variance in the modulus of elasticity the material, unknown pipe repairs, or inadequate correlation signals.

Distance Measurement

An accurate distance measurement is crucial for an accurate assessment. In general, a 1% error in distance measurement can result to more than a 2% error in final percentage of wall thickness lost. For this reason, our preference is to use potholes or in-line valves, as these provide the most accurate distance measure, since it is a point-to-point measurement. As the number of bends and/or elevation changes between the sensor connection points increases, so does the potential error in the distance measurement.

Pipe Manufacturing Tolerances

Small differences in nominal specifications will occur between pipes due to differences in manufacturers and tolerances. These differences commonly range from between 5% and 10% depending on the manufacturer and the material. Furthermore, a contractor may have installed a pipe that exceeds the minimum specifications. Under these circumstances the measurements may show a pipe with a wall thickness that is greater than expected. This is particularly true of older pipes as their tolerances were not adhered to as strictly.

The material properties used for calculations are selected using conservative estimates. This provides for a worst-case scenario analysis.

Repair Clamps on Previous Leaks

Acoustic waves are primarily water borne. As such, a small number of repair clamps will have an insignificant effect on the test results, since the acoustic wave will bypass the clamps.

Modulus of Elasticity

A change in elastic modulus of 10% will cause a change in the calculated thickness by approximately 10%. The elastic modulus is known for common materials used in the manufacturing of pressure pipe, but this value can vary between manufacturers. It is dependent

on the manufacturing process and the quality of the material. The material properties used for calculations are selected using conservative estimates. This provides for a worst-case scenario analysis.

Unaccounted for Replacement of Pipe Sections during Repairs

Acoustic waves propagate differently depending upon the pipe material. This effect remains true for unaccounted for short pipe replacements with different materials, and can result in significant error. For example, a new 6 meter long (~20 feet) ductile iron repair in a 100 meter long (~328 feet) cast iron pipe section of average condition, will produce a small error of +3.5% in measured wall thickness. However, the same repair made with PVC pipe would produce an error of -41% in measured wall thickness.

Preferably, pipe sections selected for testing should be free of repaired sections. However, if this condition does not exist, the impact of the repaired pipe section can be accounted for, provided accurate information is available for the age, location, length, material type, and class of the repair pipe section.

Inadequate Correlation Signals

Inadequate correlation signals can sometimes occur in the field. The following are some of the conditions that may cause an inadequate correlation:

1. The presence of plastic repairs in metallic pipes which can cause poor propagation of sound.
2. Loose or worn components in fittings used for the measurements, such as valve or hydrant stems.
3. Large air pockets in the pipe which heavily attenuate acoustic signals.
4. Heavily tuberculated pipe, particularly old cast iron or unlined ductile iron pipes, which can attenuate the acoustic signals to such an extent that a correlation is of very low quality.

Appendix D Detailed Methodology

D.1 EchoWave™ Leak Detection

The methodology employed is known as the cross-correlation method. A correlator listens passively for noise created by a leak. If one is detected, it uses the time delay between each sensor to determine the position of the leak. The following procedure was used to conduct the leak detection survey:

1. For each location surveyed, the distance between the sensors was measured.
2. Sensors were mounted either directly on the pipe or were connected to the water column with Hydrophones.
3. A correlation measurement was performed without introducing noise (known as a background recording), and the signal was saved to the computer so that further analysis could be performed off-site. A preliminary analysis is performed on-site to determine if any leaks are present.

D.2 ePulse™ Average Wall Thickness Testing

A section of pipe is the length bracketed by two contact points on the main. An out-of-bracket noise source is located outside of that segment. A known noise source may be used to determine the acoustic wave velocity in a section of pipe. Knowing the distance between the sensors, the acoustic wave velocity (v) will be given by $v = d/t$, where d is the length of pipe between the sensors, and t is the time taken for the acoustic signal to propagate between the two sensors.

The following procedure is followed to conduct a pipe integrity data collection survey:

1. A leak detection survey is performed on the length of pipe to check for the presence of existing leaks. (Described in previous section)
2. A noise source is created “out-of-bracket”. A variety of different noise sources can be used including an existing leak noise, blow-off noise, pump noise, impulse noise, running a fire hydrant, tapping on a fire hydrant, or directly on the pipe.
3. A new correlation measurement is performed and stored as a wave file for further analysis and confirmation off-site. Data is analysed further to obtain an optimum correlation, ensuring an accurate velocity measurement.

Wave Velocity Equation

The general form of the acoustic pipe integrity testing equation is shown below.

Equation 1: Wave Velocity - Thickness Model

$$v = v_o \times \sqrt{\frac{1}{\left[1 + \left(\frac{D_i}{t_r}\right) \times \left(\frac{K_l}{E}\right)\right]}}$$

- v : measured velocity
 v_o : propagation velocity in an infinite body of water
 D_i : pipe internal diameter
 K_l : bulk modulus of the liquid
 E : elastic modulus of the pipe wall
 t_r : residual thickness of the pipe

Bulk Modulus of Water Calibration

Different water sources often produce a different bulk modulus of water. The bulk modulus essentially represents the water's inherent resistance to compression, and is impacted by factors like water temperature, dissolved salts and entrained air. Echologics' field specialists calibrate the bulk modulus at each water company's water source. This requires performing a single test on a stretch of pipe with a known pipe wall condition. In practice, this generally means performing an additional test on a new section of pipe that has been installed within the past few years.

Appendix E Glossary of Terms

Sensor - Vibration measurement device. Sensors are mounted on pipes and pipe fittings to capture acoustic signals in the pipe.

Coherence - The measure of similar frequencies between the Blue and White sensors.

Correlation - The process of comparing two acoustic signals for similarity. LeakFinder uses correlation to judge the time delay between two signals. This allows LeakFinder to gage the location of leaks and the acoustic wave speed of the pipe.

Acoustic Wave Speed – The velocity sound propagates in the pipe. This is the speed that a coupled mode (water hammer) acoustic wave will travel along the pipe.

In-Bracket – A noise source that is between two sensors deployed by Echologics.

Out-of-Bracket – A noise source that is outside of the span of pipe between the Blue and White sensors.

Blue Station / White Station – The color of the transmitters that broadcast the signals measured by the sensors.

Site – A neighborhood or area that is surveyed.

Segment, or Pipe Segment – A section of pipe surveyed in one measurement. The length of the segment is the distance between two sensors.

GPS – Global Positioning System

GIS – Geographic Information System

PCCP – Pre-Stressed Concrete Cylinder Pipe: Pipe wall construction comprising of a concrete core, a steel cylinder and pre-stressed high tension wires.

BWP – Bar Wrapped Pipe: Pipe wall construction comprising of a concrete core, a steel cylinder and reinforcing steel bars.

SCI – Spun Cast Iron: Pipe wall construction comprising of spun cast iron.

PCI – Pit Cast Iron: Pipe wall construction comprising of pit cast iron.

DI – Ductile Iron: Pipe wall construction comprising of ductile iron.

AC – Asbestos Cement: Pipe wall construction comprising of asbestos cement.

Steel – Pipe wall construction comprising of steel.

CL – Concrete lined: Indicates whether or not a specific pipe type has some form of concrete lining. This abbreviation will typically follow a pipe type abbreviation Ex: DICL for ductile iron concrete lined.

Condition Assessment Specific Terms

ePulse™: A trademarked test method used by Echologics to assess the condition of a water main. The testing involves measuring acoustic wave speed along a pipe section and using other physical observations for input into a proprietary calculator. The result is presented as average minimum wall thickness or average minimum wall stiffness along the test section.

Leak Detection Specific Terms

EchoWave™: A trademarked test method used by Echologics to locate leaks on water mains of any material type or diameter. The testing involves placing two sensors on the pipe and recording acoustic data to a computer. Along with some physical information about the pipe, the acoustic data is analyzed with proprietary software and the location of any existing leaks is determined.

POI – Point of Interest indicates that there is evidence of some form of noise on the pipe that will need further investigation to confirm if the noise is produced by a leak.

No Leak Discovered – a negative correlation is matched with poor coherence concluding that no leak was detected.