21 Randolph Ave, Suite 301
Toronto, ON, M6P 4G4

T: 905-672-echo (3246)
F: 905-612-0201
Toll Free: 1 -866-echolog (324-6564)

Technical Report

echologics
A Mueller TECHNOLOGIES COMPANY

Title: Condition Assessment and Remaining Service Life Analysis of Asbestos Cement Water Mains - Phase 4

Client: [CLIENT]

Report Classification: Draft

Date: February 3, 2020

This page is intentionally left blank

Executive Summary

In 2017, the [CLIENT] (the City) engaged with Echologics to complete a comprehensive condition assessment program to gain valuable evidence based pipe condition assessment information on critical components of the City's potable water network and its transmission and distribution water mains. Echologics successfully tested 8.4 miles in phase 1 (FY 2016/17), 15.3 miles in phase 2 (FY 2017/18) and 9.7 miles in phase 3 (FY 2018/19) of this program. The water mains tested included cement mortar-lined and coated steel and asbestos cement pipes. The current project is phase 4 (FY 2019/20) of the condition assessment program in which Echologics tested 10 miles of asbestos cement water mains.

The primary objectives of this comprehensive condition assessment program were as follows:

- *Determine the remaining structural condition of critical water mains tested within the City's water network*
- *Integration of collected assessment data into the City's existing asset management desktop model to increase confidence of the decision-making matrix; and*
- *Along with condition assessment analysis, to simultaneously investigate the system for the existence of any potential leaks and reduce non-revenue water loss*

The pipes included in the scope of phase 4 as well as previous phases were selected by the City's existing desktop model as critical water mains that may require rehabilitation or replacement.

<u>Project Observations and Results</u>

Echologics tested approximately 10 miles of 6-inch to 16-inch diameter asbestos cement water mains. Echologics' field personnel completed the field work between September 9th, 2019 and September 19th, 2019.

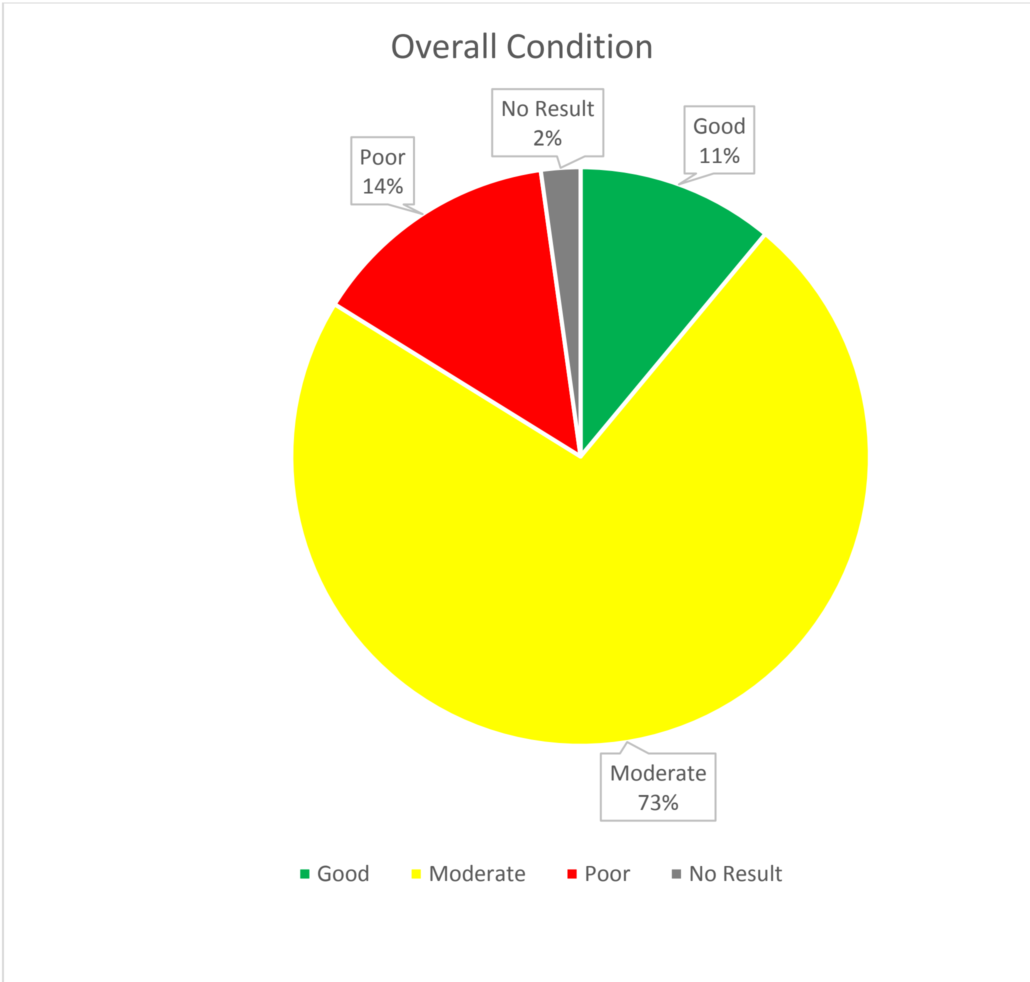
One suspected leak was identified at the time of testing. Although a positive correlation was observed on three different occasions, no other additional evidence such as flowing water, wet ground in the vicinity of the noise was found. The City is encouraged to perform additional investigations to verify the presence of a suspected leak at this location.

For the phase 4 ePulse® condition assessment 136 pipe segments were tested to determine the average remaining structural wall thickness and compared to the original nominal wall thickness to estimate the average structural wall loss. Each pipe segment was also assigned a rating *category as per the table below. The Echolife® analysis was also performed on all segments to estimate the remaining service life of each pipe segment under current operating and site conditions. Echolife® analysis combines the ePulse® results along with measured operating conditions such as soil loading, traffic loading, operating pressure and maximum estimated surge pressure.*

Change in Hoop Thickness	***Description***	***Color Code***
Less than 10%	*Good*	*Green*
10% to 30%	*Moderate*	*Yellow*
Greater than 30%	*Poor*	*Red*
No Results (NR)	*NR*	*Grey*

The following table and chart summarizes the results from the 136 pipe segments.

General Information	***Segment Count***	***136***
	Length Tested (ft)	*53,270 ft (10 miles)*
Condition Qualitative Category	***Good Segments***	*15 (11%)*
	Moderate Segments	*99 (73%)*
	Poor Segments	*19 (14%)*
	No Results Segments	*3 (2%)*
Condition Remaining Service Life (RSL)	***RSL Exceeded***	*46*
	RSL Less than 10 yrs.	*7*
	RSL between 10-50 yrs.	*43*
	RSL over 50 yrs.	*37*



Overall Condition
No Result
2%
Good
11%
Poor
14%
Moderate
73%
Good
Moderate
Poor
No Result

Table of Contents

1. Project Background

The need for comprehensive condition assessment of our buried and aging water infrastructure is ever increasing. Most water utilities across North America are struggling with budget and efficient management of the required renewal plans of their buried water assets that have reached the end of their service life. One of the primary concerns to water utility asset managers is prioritizing the limited renewal budgets (to the assets that require it the most). This is where an effective condition assessment program can help. According to the Water Research Foundation[1], the objectives of an effective condition assessment should include:

- Reduce the number and cost of failures, by identifying high-risk assets and enabling cost-effective, targeted, proactive remedies;
- Extend the lives of assets, by distinguishing those that are merely old from those that are truly impaired; and
- Generally reduce uncertainties, enabling confident answers to questions from the public and others.

Echologics understands that these objectives hold true for the [CLIENT] and their asset management program. Most cities and utilities currently use an asset management desktop model (AMDM) to prioritize water main renewal efforts. Typically AMDM's primary focus is water main failure/break history coupled with additional parameters such as hydraulic capacity, criticality and surrounding parallel asset infrastructure renewal efforts (i.e. – storm/sanitary sewer or road renewal projects) to set the renewal priority.

However, it is understood that every desktop assessment model is missing a critical parameter, namely: "actual evidence based condition of the subject water mains". By adding the current water main structural condition to the desktop assessment, it would provide a high level of confidence to the any utility that the prioritization of water mains scheduled for future renewals represents the best value for the currently available capital dollars.

---

[1] Ellison, D., Bell, G., Reiber, S., Spencer, D., & al., e. (2014). Answers to Challenging Infrastructure Management Questions. Water Research Foundation and EPA, Infrastructure. Washington, D.C.: Water Research Foundation. Retrieved from http://www.waterrf.org/PublicReportLibrary/4367.pdf

As such, the [CLIENT] contracted Echologics, LLC (Echologics) in 2017 to complete a comprehensive program to gain valuable evidence based condition assessment information on segments of their mortar lined and coated steel and asbestos cement water mains. Echologics successfully completed phases 1, 2 and 3 of this program in 2017 and 2018. The current undertaking completed in 2019 is phase 4 of the testing program. This comprehensive testing program is expected to assist the City in both calibrating their own AMDM and identify the current condition of their buried pipes.

The primary objectives of phase 4 were as follows:

- Determine the remaining structural condition of the water mains tested
- Determine the remaining service lives of the water mains tested
- Along with condition assessment measurements, simultaneously investigate the system for the existence of any potential leaks

To achieve these objectives, Echologics utilized its patented ePulse® technology to assess the condition of the selected water mains. The Echolife® remaining service life analysis was also performed based on the ePulse® results. In addition to condition assessment, leak detection was performed simultaneously with this survey. Based on the results, the City will be able to make informed decisions on replacement and rehabilitation for end of service water mains. This report provides detailed information on how the above objectives have been met.

The City's water supply is a blend of groundwater from six city wells and one imported water connection originating from [LOCATION] and the [LOCATION]. Groundwater comes from a natural underground aquifer that is replenished with water from the [LOCATION], local rainfall, and imported water. The City owns and operates [AMOUNT AND VOLUME OF] reservoirs, [DISTANCE] of distribution piping and [NUMBER] of service connections. The scope of water mains selected for phase 4 is primarily made up of distribution mains within residential neighborhoods.

The City selected water mains located on several streets which were divided into 5 sites.
Figure 1 and Table 1 below shows the sites and the relevant details.

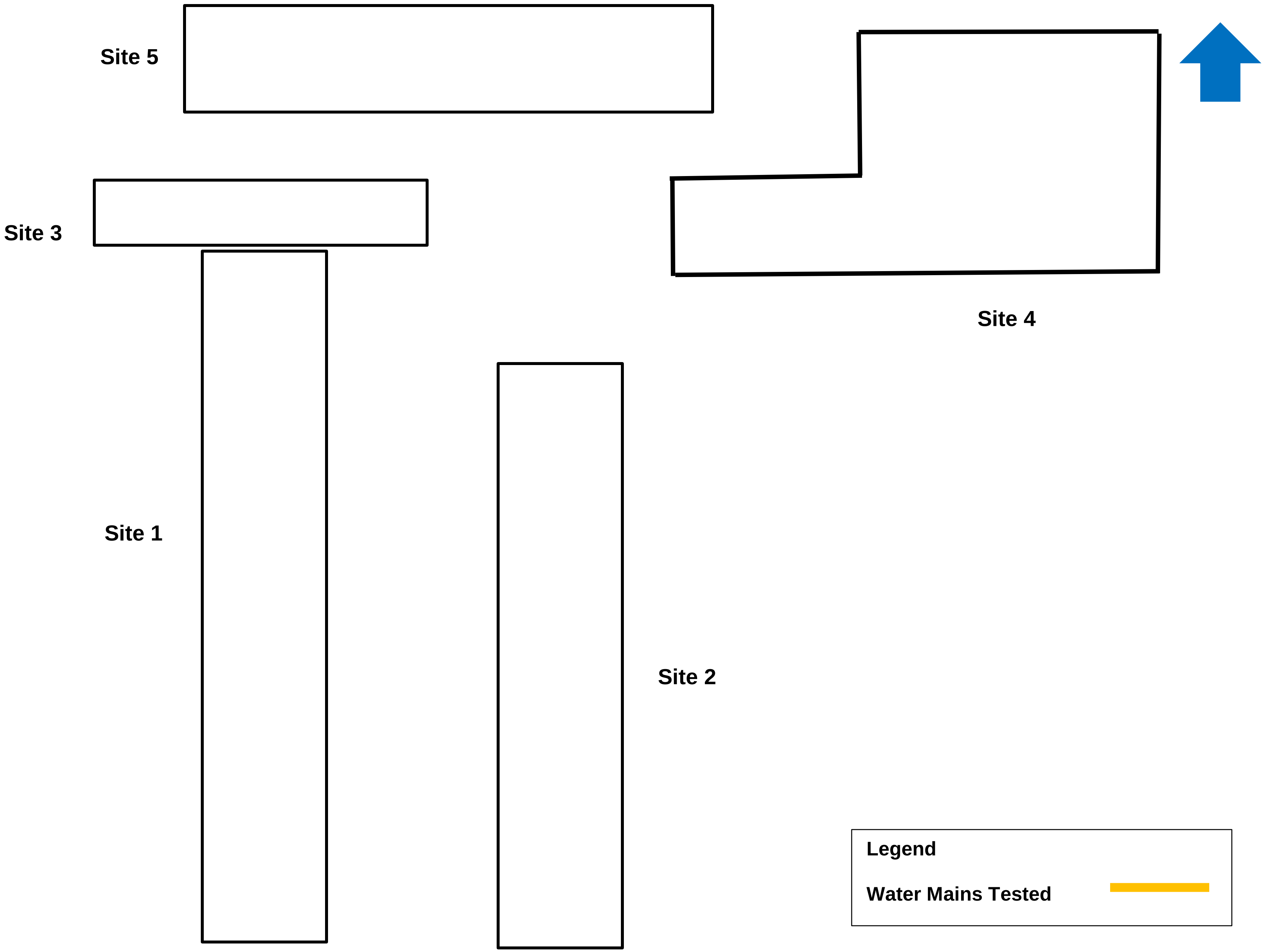


Figure 1: Water Pipe Network Overview and Locations of Mains Tested

Echologics field crews began field tests began on September 9th, 2019 and required 9 workdays to complete the data collection. Table 1 lists the different sites and the pipe segments that were tested within them.

Table 1: Sites Surveyed

Site	Test Segment #	Pipe Diameter	Installation Year	Length Tested
				ft
Site 1				
	27-46, 60, 62-67	8	1963-1973	10,855
Site 2				
	1-15, 52-57	8,12,16	1965-1974	7,969
Site 3				
	16-26, 58-61	8	1965-1973	5,202
Site 4				
	47-51,68-71	8,12	1965-1971	3,994
	106-108	8	1963-1964	1,422
	109-113	8	1963-1964	1,972
	115-116	8	1972	640
	117-118	8	1972	482
	119-122	8	1963	1,361
	123-126	6,8	1977	1,318
	127-128	8	1966	680
	129-130	8	1966	1,145
	72-82, 104-105	8	1971-1989	5,675
	134-136	8	1972	1,232
Site 5				
	83-87	8	1973	1,310
	88	8	1973	513
	89-90	8	1973	526
	91-93	6,8	1973	1,238
	94-96	8	1963	1,146
	97-101	8	1963	2,007
	102-103	8	1963	1,070

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. Additionally, the percentage of wall thickness loss is calculated by comparing the measured thickness to the design thickness of the pipe. In accordance to previous phases of the condition assessment program, Echologics assumed pressure class 150 for the asbestos cement pipes tested. Table 2 lists the nominal thicknesses for the various pipe diameters tested.

Table 2: Pipe Properties

Pipe Material	**Pressure Class**	**Internal Diameter**	**Nominal Thickness**
		(in)	**(in)**
Asbestos Cement	150	6	0.66
Asbestos Cement	150	8	0.76
Asbestos Cement	150	12	1.09
Asbestos Cement	150	16	1.36

2. Results

2.1 Leak Detection

Echologics defines a leak as a point along a pipe that is likely losing water to the surrounding soil and environment. For a leak to be classified as discovered, a field technician must acquire three pieces of evidence that confirms the existence and location of it. These include, positive correlation, acoustic noise, and physical evidence of moisture in the surrounding area (if available). Similarly, Echologics defines a Point of Interest (POI) as evidence of some form of noise or energy on the pipe while there is not enough evidence to classify a point of interest as a leak. For additional detail on these terms, please refer to appendix B1.

Echologics field personnel identified suspected leak while testing Segment 24. Table 3 below contains a summary of information of this discovery.

Table 3: Water Main Leak Details

Item ID	Leak Type	Type of Leak	Estimated Size	Site Name	Segment #	Distance from Ref. Point	Reference Point
			(GPM)			(ft)	
1	POI	Small	29.3		24	82	Valve Echo-Vlv-C3-111

Site Reference Name:
Segment No.: 24
Estimated Leak Size: 29.3 GPM
Location on network: 82 feet east of valve “Echo-Vlv-C3-111”
Location notes: Leak/flow noise was audible using ground-sounding method on September 11, 21019 when listening on the lateral valve at _______

Echologics correlated a noise source within segment 24 on three different occasions. This noise source was 82 feet east of the Echo-Vlv-C3-111 on [LOCATION]. Echologics field crew attempted to ground sound and look for evidence of water or wet ground at the location. Initially no leak noise was audible at the suspected leak location and neither any evidence of water was found.

Echologics field crew returned for additional tests and identified the same noise source at this location on two different occasions. The noise was also confirmed via ground sounding at the valve on nearby Walnut Street. Therefore, Echologics suspects this noise source to be a small main leak and recommends that it be further investigated. If confirmed as a leak, according to the AWWA M36 Water Audit and Loss Control Program, Echologics conservatively estimated a leakage rate of 29.3 GPM with a measured operating pressure of 82 psi. Figure 2 shows the location of the suspected leak within the network.

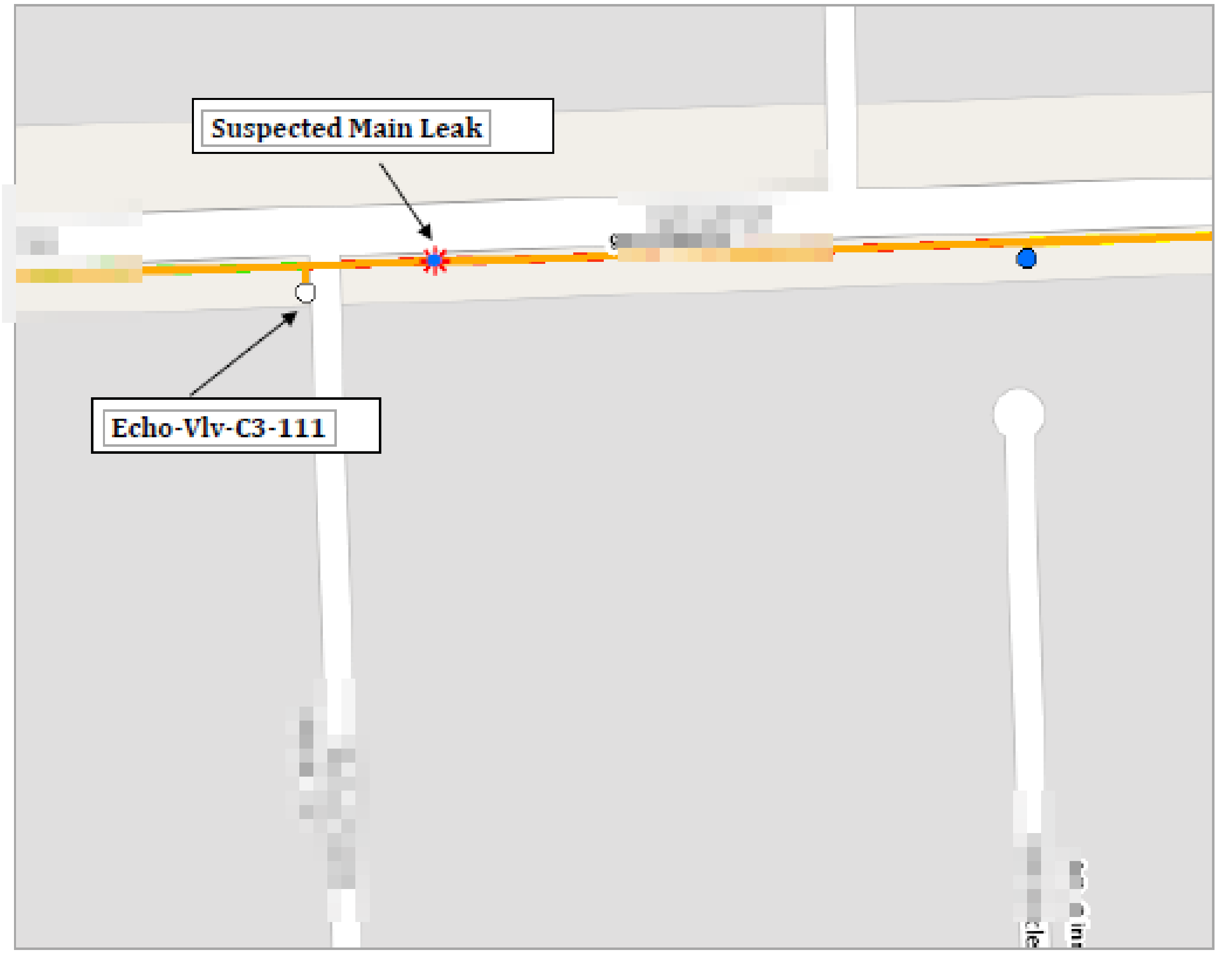


Figure 2: Suspected Leak within Segment 24 on [STREET]

2.2 ePulse® Condition Assessment

ePulse® measures the mean remaining wall thickness of the main. The technology combines acoustic data measured in the field with information about a pipe's manufacturing to calculate its current hoop thickness (measured thickness). The pipe's material, internal diameter, and modulus of elasticity are all critical variables in this calculation. The percentage of wall thickness loss is calculated by comparing the measured thickness to the design or nominal thickness. The results are also presented as a qualitative category indicating the expected condition of the main. Table 4 shows these qualitative condition categories. Results marked "NR" indicate that no result was attainable on a pipe segment.

Table 4: Qualitative Categories and Color Coding

Change in Hoop Thickness	Description	Color Code	Condition Description
Less than 10%	Good	Green	Minor levels of degradation and/or isolated areas with minor loss of structural thickness **Low Priority.**
10% to 30%	Moderate	Yellow	Considerable levels degradation and loss of structural thickness. Moderate levels of cement leeched away from asbestos matrix. **Medium Priority.**
Greater than 30%	Poor	Red	Significant degradation and loss of structural thickness. Substantial levels of cement leeched away from asbestos matrix **High Priority.**
No Results (NR)	NR	Grey	No result obtained

The segments presented in this report are numbered in the order they were tested. Therefore, segment numbers on a particular street or site may not be sequential. Table 5 lists the ePulse® results, pertinent information for each segment, their location and facility IDs of fittings where sensors were attached.

Table 5: ePulse® Pipe Condition Assessment Results

Segment #	Street Name	Blue Fitting	White Fitting	Pipe Material	Pipe Diameter	Segment Length	Nominal Thickness	Measured Thickness	% Loss
						ft	in	in	
1		Echo-Vlv-E7-157	Echo-Vlv-E7-179	Asbestos Cement	8	304	0.76	0.66	-13
2		Echo-Vlv-E7-217	Echo-Vlv-E7-179	Asbestos Cement	8	564	0.76	0.67	-12
3		Echo-Vlv-E7-217	Echo-Vlv-E7-249	Asbestos Cement	8	571	0.76	0.69	-9
4		Echo-Vlv-E7-157	Echo-Vlv-E7-135	Asbestos Cement	16	276	1.36	0.77	-43
5		Echo-Vlv-F5-289	Echo-Vlv-F5-267	Asbestos Cement	16	251	1.36	1.09	-20
6		Echo-Vlv-F5-242	Echo-Vlv-F5-267	Asbestos Cement	16	285	1.36	0.87	-36
7		Echo-Vlv-F5-242	Echo-Vlv-F5-197	Asbestos Cement	16	392	1.36	1.04	-24
8		Echo-Vlv-F5-159	Echo-Vlv-F5-197	Asbestos Cement	16	512	1.36	1.05	-23
9		Echo-Vlv-F5-159	Echo-Vlv-F5-127	Asbestos Cement	12	527	1.09	0.83	-24
10		Echo-Vlv-E4-280	Echo-Vlv-F4-244	Asbestos Cement	12	307	1.09	0.87	-20
11		Echo-Vlv-F4-234	Echo-Vlv-F4-244	Asbestos Cement	12	301	1.09	0.76	-30
12		Echo-Vlv-F4-234	Echo-Vlv-F4-211	Asbestos Cement	12	334	1.09	0.83	-24
13		Echo-Vlv-F4-190	Echo-Vlv-F4-211	Asbestos Cement	12	350	1.09	0.90	-17
14		Echo-Vlv-F4-190	Echo-Vlv-F4-157	Asbestos Cement	12	316	1.09	0.82	-25
15		Echo-Vlv-F4-119	Echo-Vlv-F4-157	Asbestos Cement	12	351	1.09	0.81	-26
16		Echo-Vlv-D2-260	Echo-Vlv-D2-256	Asbestos Cement	8	153	0.76	0.57	-25
17		Echo-Vlv-D2-262	Echo-Vlv-D2-256	Asbestos Cement	8	568	0.76	0.63	-17
18		Echo-Vlv-D2-262	Echo-Vlv-D2-271	Asbestos Cement	8	313	0.76	0.66	-13
19		Echo-Vlv-D2-266	Echo-Vlv-D2-271	Asbestos Cement	8	281	0.76	0.51	-33
20		Echo-Vlv-D2-266	Echo-Vlv-D2-264	Asbestos Cement	8	277	0.76	0.65	-14
21		Echo-Vlv-D2-269	Echo-Vlv-D2-264	Asbestos Cement	8	292	0.76	0.63	-17
22		Echo-Vlv-D2-269	Echo-Vlv-D2-265	Asbestos Cement	8	217	0.76	0.47	-38
23		Echo-Vlv-C2-239	Echo-Vlv-C3-111	Asbestos Cement	8	503	0.76	0.70	-8
24		Echo-Vlv-C3-108	Echo-Vlv-C3-111	Asbestos Cement	8	320	0.76	0.48	-37

Segment #	Street Name	Blue Fitting	White Fitting	Pipe Material	Pipe Diameter	Segment Length	Nominal Thickness	Measured Thickness	% Loss
						ft	in	in	
25		Echo-Vlv-C3-108	Echo-Vlv-C3-105	Asbestos Cement	8	295	0.76	0.66	-13
26		Echo-Vlv-C3-100	Echo-Vlv-C3-105	Asbestos Cement	8	391	0.76	0.68	-11
27		Echo-Vlv-D3-237	Echo-Vlv-D3-199	Asbestos Cement	8	514	0.76	0.69	-9
28		Echo-Vlv-D3-173	Echo-Vlv-D3-199	Asbestos Cement	8	559	0.76	0.66	-13
29		Echo-Vlv-D3-173	Echo-Vlv-D3-143	Asbestos Cement	8	487	0.76	0.60	-21
30		Echo-Vlv-D3-130	Echo-Vlv-D3-143	Asbestos Cement	8	256	0.76	0.60	-21
31		Echo-Vlv-D3-130	Echo-Vlv-D3-105	Asbestos Cement	8	356	0.76	0.50	-34
32		Echo-Vlv-C7-166	Echo-Vlv-C7-182	Asbestos Cement	8	365	0.76	0.48	-37
33		Echo-Vlv-C7-206	Echo-Vlv-C7-182	Asbestos Cement	8	384	0.76	0.52	-32
34		Echo-Vlv-C7-206	Echo-Vlv-C7-226	Asbestos Cement	8	312	0.76	0.69	-9
35		Echo-Vlv-D7-247	Echo-Vlv-C7-226	Asbestos Cement	8	264	0.76	0.70	-8
36		Echo-Vlv-C7-166	Echo-2[1]	Asbestos Cement	8	534	0.76	0.48	-37
37		Echo-Vlv-C7-129	Echo-2[1]	Asbestos Cement	8	182	0.76	NR[4]	NR[4]
38		Echo-Vlv-C7-129	Echo-Vlv-D7-115	Asbestos Cement	8	194	0.76	NR[4]	NR[4]
39		Echo-Vlv-C6-139	Echo-Vlv-C6-119	Asbestos Cement	8	576	0.76	0.61	-20
40		Echo-Vlv-C6-139	Echo-Vlv-C6-158	Asbestos Cement	8	244	0.76	0.50	-34
41		Echo-Vlv-C6-187	Echo-Vlv-C6-158	Asbestos Cement	8	360	0.76	0.65	-14
42		Echo-Vlv-C6-187	Pothole[3]	Asbestos Cement	8	596	0.76	0.60	-21
43		Echo-Vlv-C5-131	Echo-Vlv-D5-119	Asbestos Cement	8	675	0.76	0.60	-21
44		Echo-Vlv-C5-131	Echo-Vlv-C5-158	Asbestos Cement	8	384	0.76	0.61	-20
45		Echo-Vlv-D5-180	Echo-Vlv-C5-158	Asbestos Cement	8	517	0.76	0.64	-16
46		Echo-Vlv-D5-180	Echo-Vlv-C5-252	Asbestos Cement	8	511	0.76	0.77	0[2]
47		Pothole[3]	Echo-Vlv-G3-101	Asbestos Cement	8	552	0.76	0.69	-9
48		Echo-Vlv-G3-100	Echo-Vlv-G3-101	Asbestos Cement	8	278	0.76	0.64	-16
49		Echo-Vlv-G3-100	Echo-Vlv-G3-102	Asbestos Cement	8	512	0.76	0.63	-17
50		Echo-Vlv-G3-105	Echo-Vlv-G3-102	Asbestos Cement	12	501	1.09	0.93	-15

Segment #	Street Name	Blue Fitting	White Fitting	Pipe Material	Pipe Diameter	Segment Length	Nominal Thickness	Measured Thickness	% Loss
						ft	in	in	
51		Echo-Vlv-H3-102	Echo-Vlv-H3-103	Asbestos Cement	8	600	0.76	0.70	-8
52		Echo-Vlv-E7-270	Echo-Vlv-E7-249	Asbestos Cement	8	467	0.76	0.70	-8
53		Echo-Vlv-E7-103	Echo-Vlv-E7-135	Asbestos Cement	8	471	0.76	0.49	-36
54		Echo-Vlv-F5-242	Echo-Vlv-F5-307	Asbestos Cement	16	411	1.36	1.07	-21
55		Echo-Vlv-F4-290	Echo-Vlv-F5-127	Asbestos Cement	16	281	1.36	1.07	-21
56		Echo-Vlv-F4-290	Echo-Vlv-E4-280	Asbestos Cement	12	359	1.09	0.81	-26
57		Echo-Vlv-F4-119	Echo-Vlv-F4-101	Asbestos Cement	12	299	1.09	0.82	-25
58		Echo-Vlv-D2-260	Echo-Vlv-D2-251	Asbestos Cement	8	437	0.76	0.57	-25
59		Echo-Vlv-C3-100	Echo-Vlv-C3-101	Asbestos Cement	8	393	0.76	0.61	-20
60		Echo-Vlv-D3-105	Echo-Vlv-C3-101	Asbestos Cement	8	205	0.76	0.69	-9
61		Echo-Vlv-C2-239	Echo-Vlv-C2-249	Asbestos Cement	8	762	0.76	0.65	-14
62		Echo-Vlv-D3-237	Echo-Vlv-C3-264	Asbestos Cement	8	355	0.76	0.63	-17
63		Echo-Vlv-D7-247	Echo-Vlv-C7-261	Asbestos Cement	8	216	0.76	0.24	-68
64		Echo-Vlv-C6-251	Echo-Vlv-D7-115	Asbestos Cement	8	375	0.76	NR[4]	NR[4]
65		Echo-Vlv-C6-251	Pothole[3]	Asbestos Cement	8	571	0.76	0.59	-22
66		Echo-Vlv-D5-220	Echo-Vlv-C6-119	Asbestos Cement	8	450	0.76	0.65	-14
67		Echo-Vlv-D5-220	Echo-Vlv-C5-252	Asbestos Cement	8	413	0.76	0.36	-53
68		Pothole[3]	Echo-Vlv-F3-100	Asbestos Cement	8	648	0.76	0.64	-16
69		Echo-Vlv-G3-105	Echo-Vlv-H3-101	Asbestos Cement	12	201	1.09	0.85	-22
70		Echo-Vlv-H2-331	Echo-Vlv-H3-100	Asbestos Cement	8	276	0.76	0.65	-14
71		Echo-Vlv-H2-331	Echo-Vlv-H3-102	Asbestos Cement	8	426	0.76	0.54	-29
72		Echo-Vlv-H2-330	Echo-Vlv-H3-120	Asbestos Cement	8	494	0.76	0.61	-20
73		Echo-Vlv-H2-330	Echo-Vlv-H2-281	Asbestos Cement	8	533	0.76	0.69	-9
74		Echo-Vlv-H2-225	Echo-Vlv-H2-250	Asbestos Cement	8	419	0.76	0.58	-24
75		Echo-Vlv-H2-225	Echo-Vlv-H2-181	Asbestos Cement	8	529	0.76	0.61	-20
76		Echo-Vlv-J2-120	Echo-Vlv-H1-149	Asbestos Cement	8	499	0.76	0.56	-26

Segment #	Street Name	Blue Fitting	White Fitting	Pipe Material	Pipe Diameter	Segment Length	Nominal Thickness	Measured Thickness	% Loss
						ft	in	in	
77		Echo-Vlv-J2-120	Echo-Vlv-H2-181	Asbestos Cement	8	259	0.76	0.70	-8
78		Echo-Vlv-H2-281	Echo-Vlv-H2-250	Asbestos Cement	8	374	0.76	0.60	-21
79		Pothole[3]	Echo-Vlv-H3-120	Asbestos Cement	8	549	0.76	0.66	-13
80		Pothole[3]	Echo-Vlv-H3-158	Asbestos Cement	8	493	0.76	0.63	-17
81		Echo-Vlv-H3-189	Echo-Vlv-H3-158	Asbestos Cement	8	511	0.76	0.60	-21
82		Echo-Vlv-H3-189	Echo-Vlv-H3-220	Asbestos Cement	8	388	0.76	0.58	-24
83		Echo-Vlv-D1-150	Echo-Vlv-D1-154	Asbestos Cement	8	209	0.76	0.50	-34
84		Echo-Vlv-D1-152	Echo-Vlv-D1-154	Asbestos Cement	8	260	0.76	0.62	-18
85		Echo-Vlv-D1-152	Echo-Vlv-D1-151	Asbestos Cement	8	324	0.76	0.56	-26
86		Echo-Vlv-D1-134	Echo-Vlv-D1-151	Asbestos Cement	8	303	0.76	0.66	-13
87		Echo-Vlv-D1-134	Echo-Vlv-D1-129	Asbestos Cement	8	214	0.76	0.58	-24
88		Echo-Vlv-D1-114	Echo-Vlv-D1-116	Asbestos Cement	6	513	0.66	0.52	-21
89		Echo-Vlv-D1-100	Echo-Vlv-D1-104	Asbestos Cement	6	230	0.66	0.49	-26
90		Echo-Vlv-D1-108	Echo-Vlv-D1-104	Asbestos Cement	6	296	0.66	0.45	-32
91		Echo-Vlv-D1-124	Echo-Vlv-E1-112	Asbestos Cement	6	306	0.76	0.64	-16
92		Echo-Vlv-E1-108	Echo-Vlv-E1-112	Asbestos Cement	8	461	0.76	0.63	-17
93		Echo-Vlv-E1-108	Echo-Vlv-E1-107	Asbestos Cement	8	471	0.76	0.61	-20
94		Echo-Vlv-F1-107	Echo-Vlv-F1-109	Asbestos Cement	8	378	0.76	0.60	-21
95		Echo-Vlv-F1-103	Echo-Vlv-F1-109	Asbestos Cement	8	375	0.76	0.54	-29
96		Echo-Vlv-F1-103	Echo-Vlv-F1-106	Asbestos Cement	8	393	0.76	0.66	-13
97		Echo-Vlv-F1-146	Echo-Vlv-F1-152	Asbestos Cement	8	406	0.76	0.54	-29
98		Echo-Vlv-F1-151	Echo-Vlv-F1-152	Asbestos Cement	8	564	0.66	0.49	-26
99		Echo-Vlv-E1-128	Echo-Vlv-E1-116	Asbestos Cement	6	332	0.66	0.50	-24
100		Echo-Vlv-E1-118	Echo-Vlv-E1-116	Asbestos Cement	6	365	0.66	0.48	-27
101		Echo-Vlv-E1-118	Echo-Vlv-E1-123	Asbestos Cement	6	340	0.66	0.47	-29
102		Echo-Vlv-E1-105	Echo-Vlv-E1-104	Asbestos Cement	6	539	0.66	0.55	-17

Segment #	Street Name	Blue Fitting	White Fitting	Pipe Material	Pipe Diameter	Segment Length	Nominal Thickness	Measured Thickness	% Loss
						ft	in	in	
103		Echo-Vlv-E1-102	Echo-Vlv-E1-104	Asbestos Cement	6	531	0.66	0.44	-33
104		Echo-Vlv-J2-155	Echo-Vlv-J2-156	Asbestos Cement	8	411	0.76	0.61	-20
105		Echo-Vlv-J2-157	Echo-Vlv-J2-156	Asbestos Cement	8	216	0.76	0.70	-8
106		Echo-Vlv-H2-200	Echo-Vlv-H2-240	Asbestos Cement	8	525	0.76	0.59	-22
107		Echo-Vlv-H2-279	Echo-Hyd-H2-147	Asbestos Cement	8	610	0.76	0.59	-22
108		Echo-Vlv-H2-279	Echo-Vlv-H2-301	Asbestos Cement	8	287	0.76	0.71	-7
109		Echo-Vlv-H2-302	Echo-Vlv-H2-158	Asbestos Cement	8	550	0.76	0.64	-16
110		Echo-Vlv-H2-233	Echo-Hyd-H2-158	Asbestos Cement	8	498	0.76	0.65	-14
111		Echo-Vlv-H2-233	Echo-Vlv-H2-199	Asbestos Cement	8	398	0.76	0.67	-12
112		Echo-Vlv-H2-163	Echo-Hyd-H2-133	Asbestos Cement	8	405	0.76	0.59	-22
113		Echo-Vlv-H2-163	Echo-Hyd-H2-112	Asbestos Cement	8	355	0.76	0.63	-17
114		Echo-Vlv-H2-130	Echo-Vlv-H2-135	Asbestos Cement	8	316	0.76	0.63	-17
115		Echo-Vlv-H2-124	Echo-Vlv-H2-125	Asbestos Cement	8	326	0.76	0.58	-24
116		Echo-Vlv-H2-120	Echo-Vlv-H2-125	Asbestos Cement	8	314	0.76	0.67	-12
117		Echo-Vlv-H2-124	Echo-Vlv-H2-136	Asbestos Cement	8	255	0.76	0.63	-17
118		Echo-Vlv-H2-158	Echo-Vlv-H2-136	Asbestos Cement	8	227	0.76	0.67	-12
119		Echo-Vlv-H2-306	Echo-Vlv-H2-301	Asbestos Cement	8	225	0.76	0.68	-11
120		Echo-Vlv-H2-306	Echo-Vlv-H2-308	Asbestos Cement	8	444	0.76	0.65	-14
121		Echo-Vlv-H2-312	Echo-Vlv-H2-308	Asbestos Cement	8	385	0.76	0.61	-20
122		Echo-Vlv-H2-312	Echo-Vlv-H2-303	Asbestos Cement	8	307	0.76	0.67	-12
123		Echo-Vlv-J2-124	Echo-Vlv-J2-127	Asbestos Cement	6	151	0.66	0.47	-29
124		Echo-Vlv-J2-122	Echo-Vlv-J2-127	Asbestos Cement	8	369	0.76	0.72	-5
125		Echo-Vlv-J2-122	Echo-Vlv-J2-131	Asbestos Cement	8	419	0.76	0.61	-20
126		Echo-Vlv-J2-137	Echo-Vlv-J2-131	Asbestos Cement	8	379	0.76	0.66	-13
127		Echo-Vlv-J1-103	Echo-Vlv-J1-101	Asbestos Cement	8	314	0.76	0.61	-20
128		Echo-Vlv-J1-105	Echo-Vlv-J1-101	Asbestos Cement	8	366	0.76	0.54	-29

Segment #	Street Name	Blue Fitting	White Fitting	Pipe Material	Pipe Diameter	Segment Length	Nominal Thickness	Measured Thickness	% Loss
						ft	in	in	
129		Echo-Vlv-J1-105	Echo-Vlv-J1-110	Asbestos Cement	8	560	0.76	0.68	-11
130		Echo-Vlv-J2-117	Echo-Vlv-J1-110	Asbestos Cement	8	585	0.76	0.65	-14
131		Echo-Vlv-H2-111	Echo-Vlv-H2-134	Asbestos Cement	8	232	0.76	0.65	-14
132		Echo-Vlv-H2-173	Echo-Vlv-H2-134	Asbestos Cement	8	324	0.76	0.57	-25
133		Echo-Vlv-H2-173	Echo-Vlv-H2-209	Asbestos Cement	8	447	0.76	0.31	-59
134		Echo-Vlv-H1-113	Echo-Vlv-H1-107	Asbestos Cement	8	356	0.76	0.34	-55
135		Echo-Vlv-H1-104	Echo-Vlv-H1-107	Asbestos Cement	8	452	0.76	0.37	-51
136		Echo-Vlv-H1-104	Echo-Vlv-H1-112	Asbestos Cement	8	424	0.76	0.66	-13

Note:

1. This appurtenance is missing from the City’s GIS data
2. Segment showed measured thickness greater than the nominal thickness. The percentage loss is capped at zero
3. Potholes were excavated to the crown of the pipe to provide sensor attachment points in absence of existing appurtenances.
4. A result was unattainable on this segment due to poor acoustic wave propagation. Echologics suspects the presence of PVC repairs within this segment.

2.2.1 General Observation of Condition Assessment Results

Echologics tested 53,270 feet of pipe during this phase 4 project. All the segments tested consisted of various diameter asbestos cement pipes. Table 6 below summarizes the results based on percentage loss in wall thickness:

- Good condition–: Echologics identified 15 segments (11% of total) in good condition with less than a 10% loss in original wall thickness
- Moderate Condition: Echologics identified 99 segments (73% of total) in moderate condition with between 10% to 30% loss in original wall thickness
- Poor Condition: Echologics identified 19 segments (14%) in poor condition with over 30% loss in original wall thickness
- There were also 3 segments (2%) that did not yield any results due to poor acoustic wave propagation. Analysis of the acoustic signals suggests the presence of PVC repairs within these segments.

Table 6: Summary of ePulse® Pipe Condition Assessment Results

General Information	**Segment Count**	136
	Length Tested (ft)	53,270
Condition	**Good Segments**	15 (11%)
	Moderate Segments	99 (73%)
	Poor Segments	19 (14%)
	No Results Segments	3 (2%)

Observation of the entire data set of the 136 segments tested shows that the majority of segments appeared to be in moderate condition with wall thickness losses between 10% and 30%. There were also 19 segments (14%) that appeared to be poor condition. These segments are expected to have experienced significant degradation and loss of structural thickness. These segments should be prioritized while making rehabilitation or replacement decision making.

There was one segment (segments 46) that showed a measured thicknesses greater than the nominal thickness of the pipe. According to the City's GIS data this segment consisted of 8-inch asbestos cement pipe. For segment 46 the difference in measured thickness from the nominal thickness falls within the pipe manufacturers' tolerance limits.

There were also 3 segments (segments 37, 38 and 64) that provided no result (“NR”) either due to inadequate correlation or very slow acoustic velocities. Both these phenomenon are associated with the presence of PVC or other plastic material within these segments. Echologics suspects there are PVC materials in these segments.

In section 2.3 the remaining service life analysis results provides further insight into long term fitness for service of the segments tested.

Figure 3 shows the results breakdown by condition category for the entire project scope.

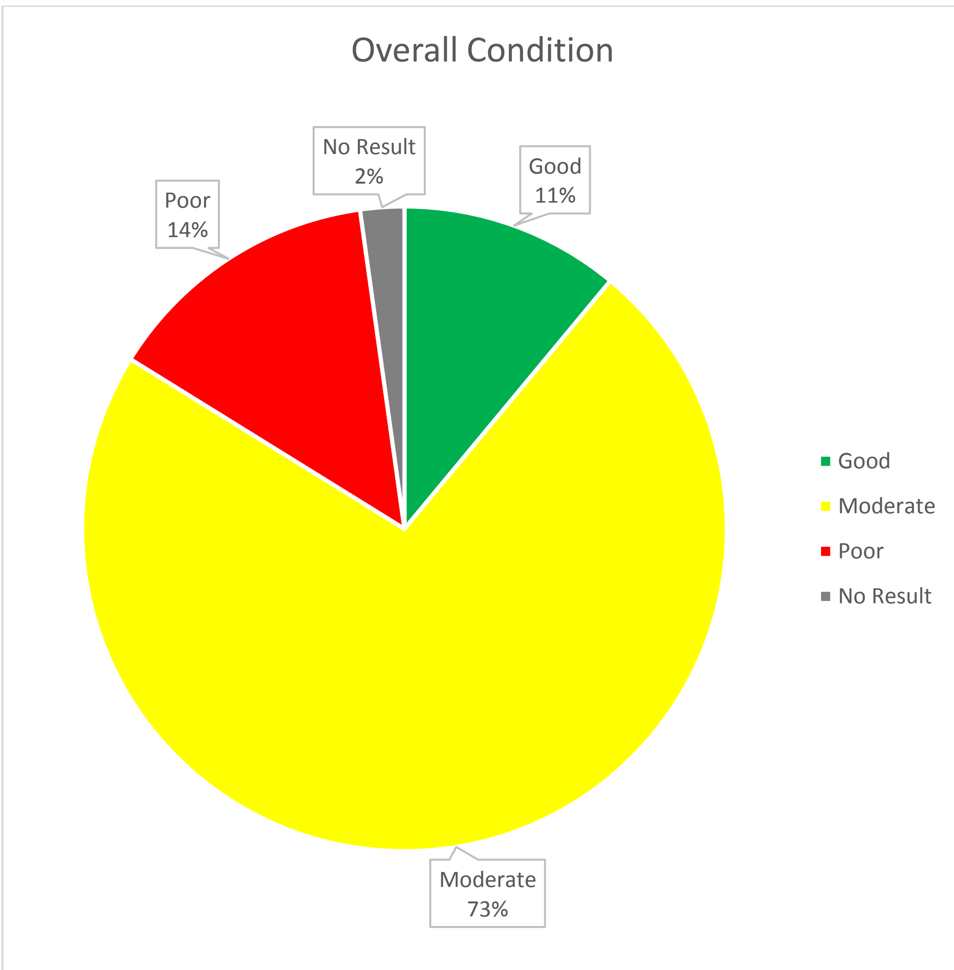


Figure 3: Overall Condition of Scope by Segment (%)

In the sections below the results are broken down and discussed further for each of the sites listed in Table 1.

2.2.2 Results Breakdown for Different Sites

Site 1 Results

There were 32 segments tested in Site 1 on [STREET] This site contained 10,855 feet of 8-inch asbestos cement pipes, the majority of which appeared to be moderate condition.

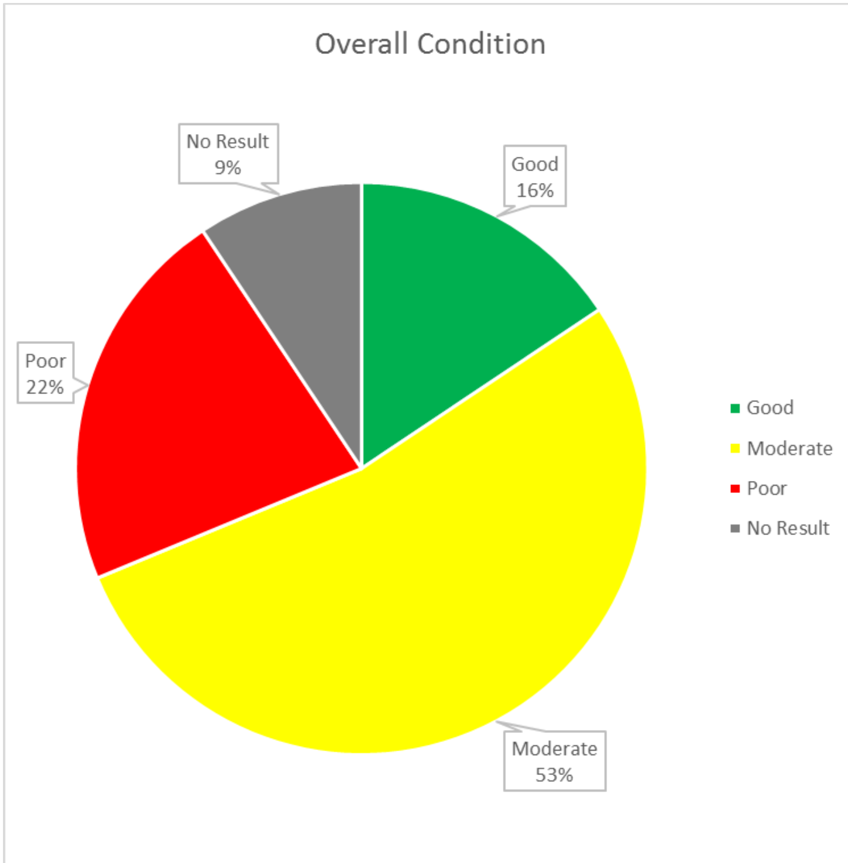


Figure 4: Overall Condition of Site 1

Site 2

There were 21 segments tested in Site 2 on [STREET]. This site contained 7,929 feet of 8-inch, 12-inch and 16-inch asbestos cement pipes, the majority of which appeared to be moderate condition.

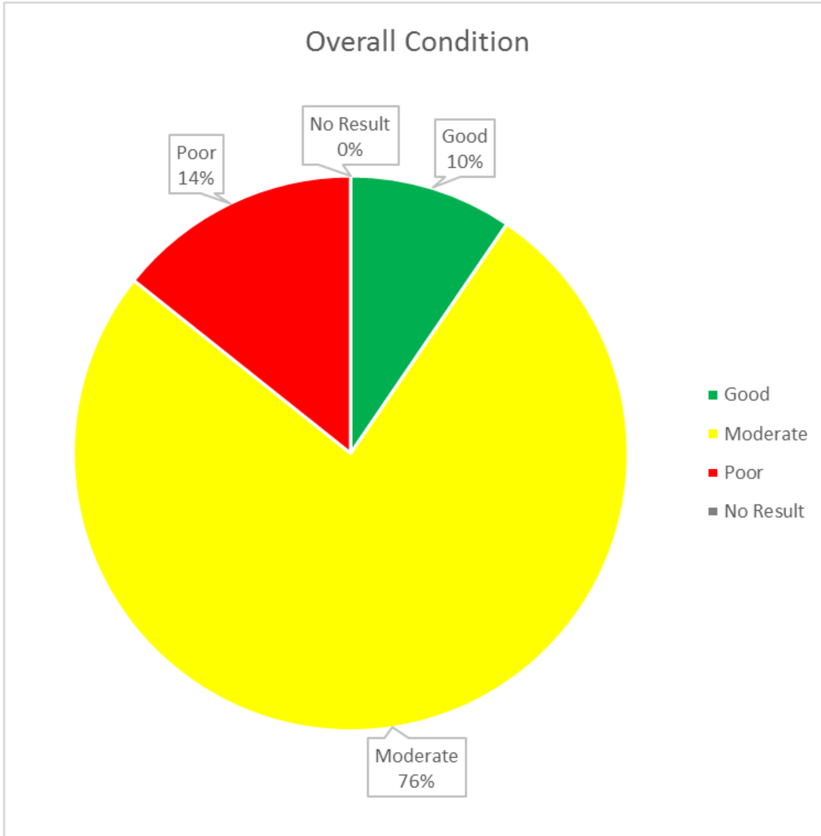


Figure 5: Overall Condition of Site 2

Site 3

There were 14 segments tested in Site 3 on [STREET]. This site contained 5,202 feet of 8-inch, asbestos cement pipes, the majority of which appeared to be moderate condition.

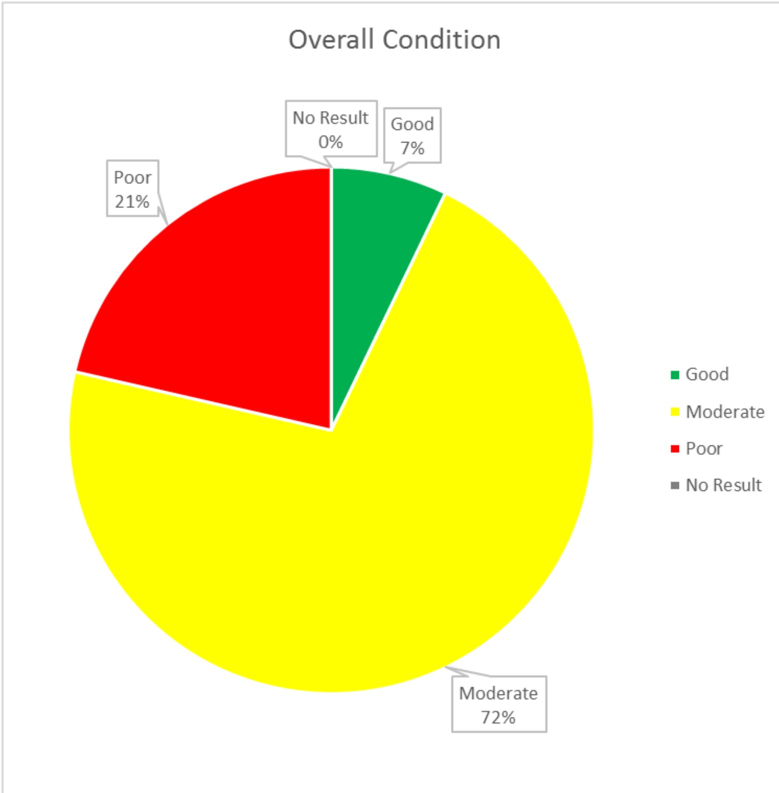


Figure 6: Overall Condition of Site 3

Site 4

There were 49 segments tested in Site 4. These segments were located on several streets containing 19,919 feet of 8-inch and 12-inch asbestos cement pipes, the majority of which appeared to be moderate condition.

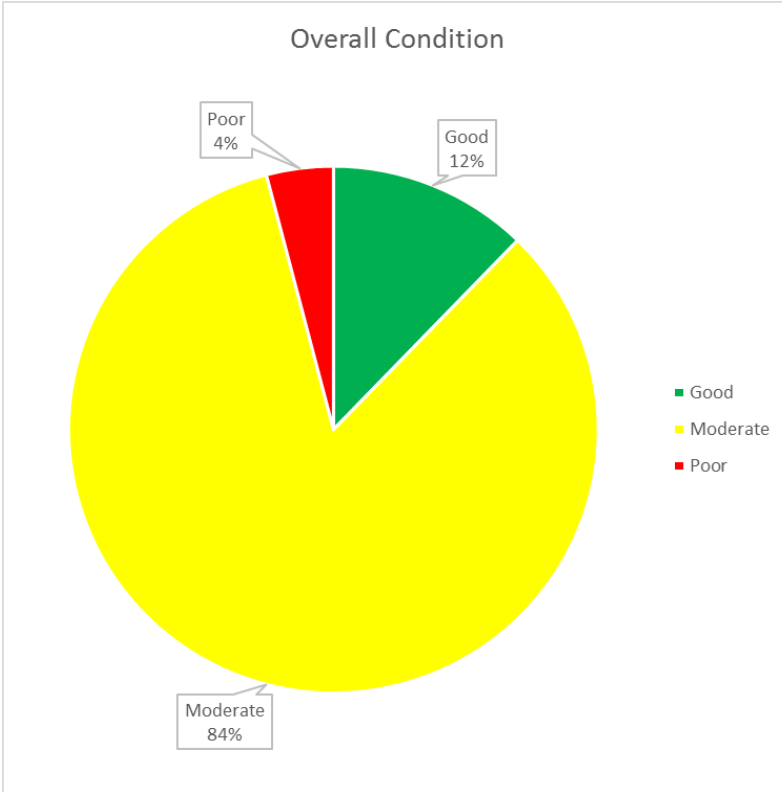


Figure 7: Overall Condition of Site 4

Site 5

There were 49 segments tested in Site 4. These segments were located on several streets containing 19,919 feet of 8-inch and 12-inch asbestos cement pipes, the majority of which appeared to be moderate condition with the remaining in poor condition.

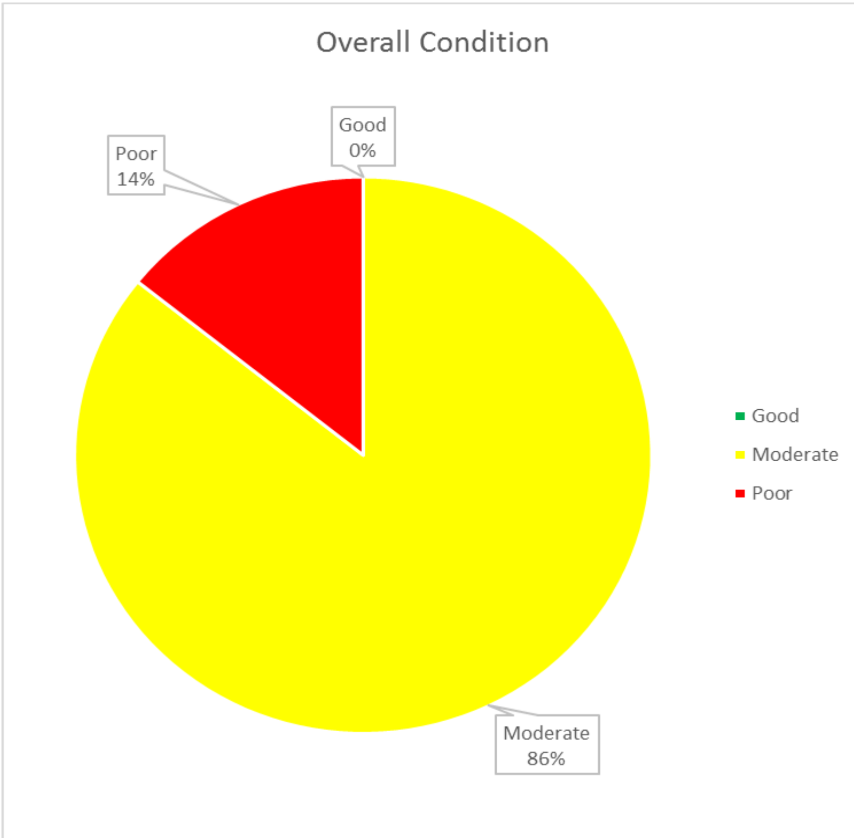


Figure 8: Overall Condition of Site 5

2.2.3 Results Breakdown for All Pipe Diameters

Figure 9 shows the distribution of the ePulse® condition assessment results for various diameter pipes. The overall distribution of segments in different condition closely matched the distribution for 8-inch pipes. This is due to the fact that 108 out of the total 136 segments tested in the scope consisted of 8-inch asbestos cement pipe.

Figure 9 shows the distribution of pipe conditions for different diameter pipes. Figure 10 shows average phase 4 percentage degradation for all pipe diameter.

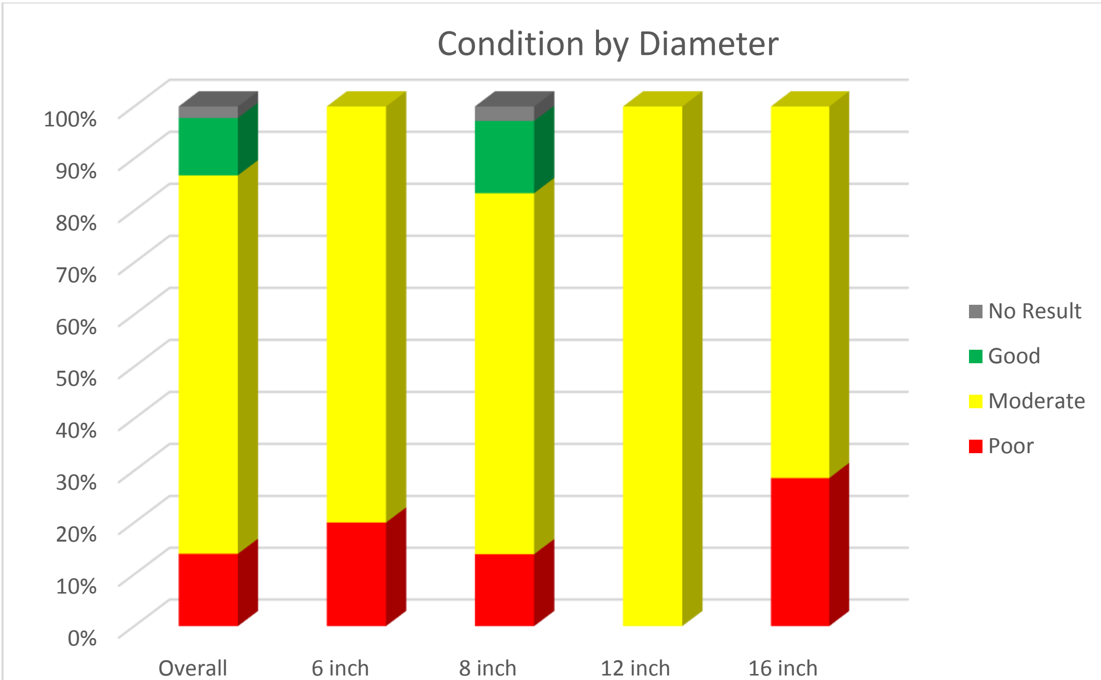


Figure 9: Distribution of Condition for Different Diameter

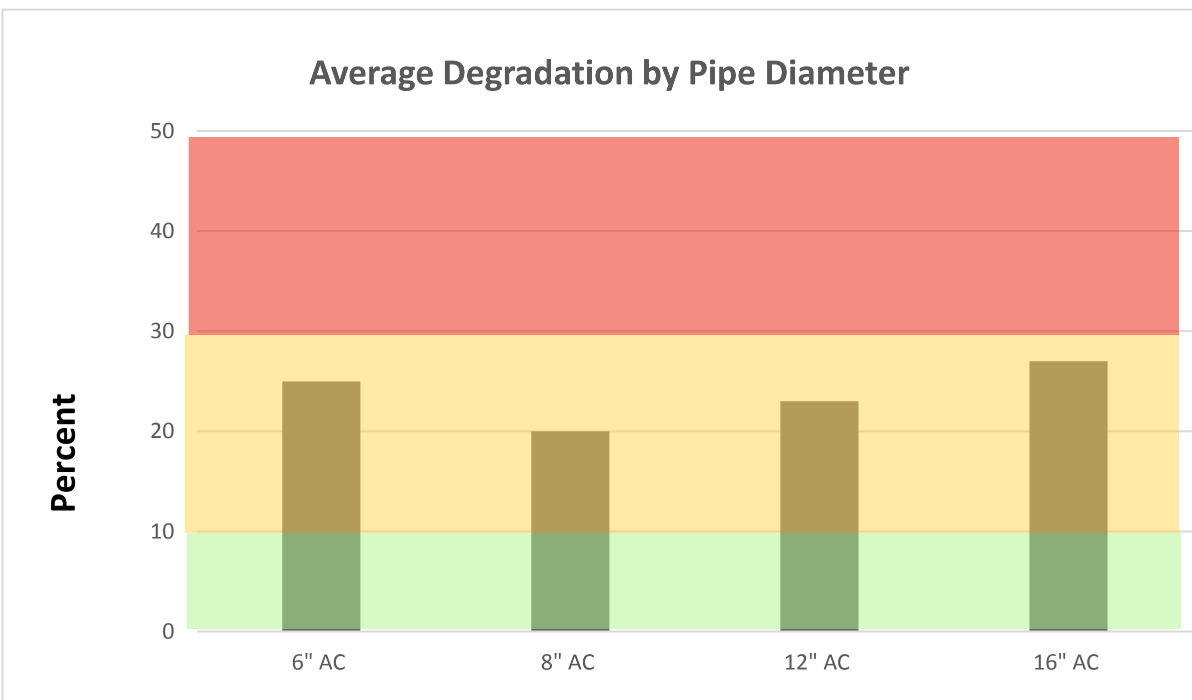


Figure 10: Average Phase 4 Percentage Degradation for All Pipe Diameter

2.3 EchoLife® Remaining Service Life Results

Table 7 shows the remaining service life (RSL) calculations for the asbestos cement pipe segments tested. Table 8 lists the assumptions made in the remaining service life analysis. Echologics has estimated the remaining service life based on ePulse® mean wall thickness measurements. It is important to note that higher levels of degradation may exist on smaller lengths of pipe within a given segment.

Table 7: Echolife® Remaining Service Life Analysis Results

Segment #	Street Name	Pipe Diameter	Segment Length	Measured Pressure	Pipe Age	Nominal Thickness	Measured Thickness	% Loss	Loss Rate	RSL
			ft	psi	yr	in	in		in/yr	yrs
1		8	304	85	45	0.76	0.66	-13	0.002	50+
2		8	564	85	45	0.76	0.67	-12	0.002	50+
3		8	571	85	54	0.76	0.69	-9	0.001	50+
4		16	276	85	53	1.36	0.77	-43	0.011	Exceeded RSL
5		16	251	85	53	1.36	1.09	-20	0.005	1 to 9
6		16	285	85	53	1.36	0.87	-36	0.009	Exceeded RSL
7		16	392	85	48	1.36	1.04	-24	0.007	Exceeded RSL
8		16	512	85	52	1.36	1.05	-23	0.006	Exceeded RSL
9		12	527	85	52	1.09	0.83	-24	0.005	Exceeded RSL
10		12	307	80	49	1.09	0.87	-20	0.004	20 to 29
11		12	301	80	52	1.09	0.76	-30	0.006	Exceeded RSL
12		12	334	80	52	1.09	0.83	-24	0.005	10 to 19
13		12	350	80	45	1.09	0.90	-17	0.004	30 to 39
14		12	316	80	45	1.09	0.82	-25	0.006	Exceeded RSL
15		12	351	80	45	1.09	0.81	-26	0.006	Exceeded RSL

Segment #	Street Name	Pipe Diameter	Segment Length	Measured Pressure	Pipe Age	Nominal Thickness	Measured Thickness	% Loss	Loss Rate	RSL
			ft	psi	yr	in	in		in/yr	yrs
16		8	153	80	51	0.76	0.57	-25	0.004	10 to 19
17		8	568	80	51	0.76	0.63	-17	0.003	40 to 49
18		8	313	80	51	0.76	0.66	-13	0.002	50+
19		8	281	80	51	0.76	0.51	-33	0.005	Exceeded RSL
20		8	277	80	51	0.76	0.65	-14	0.002	50+
21		8	292	80	51	0.76	0.63	-17	0.003	40 to 49
22		8	217	80	46	0.76	0.47	-38	0.006	Exceeded RSL
23		8	503	80	54	0.76	0.70	-8	0.001	50+
24		8	320	80	54	0.76	0.48	-37	0.005	Exceeded RSL
25		8	295	80	54	0.76	0.66	-13	0.002	50+
26		8	391	80	54	0.76	0.68	-11	0.001	50+
27		8	514	80	47	0.76	0.69	-9	0.001	50+
28		8	559	80	54	0.76	0.66	-13	0.002	50+
29		8	487	80	54	0.76	0.60	-21	0.003	Exceeded RSL
30		8	256	80	56	0.76	0.60	-21	0.003	Exceeded RSL
31		8	356	80	56	0.76	0.50	-34	0.005	Exceeded RSL
32		8	365	80	56	0.76	0.48	-37	0.005	Exceeded RSL
33		8	384	80	56	0.76	0.52	-32	0.004	Exceeded RSL
34		8	312	80	56	0.76	0.69	-9	0.001	50+
35		8	264	80	50	0.76	0.70	-8	0.001	50+
36		8	534	80	54	0.76	0.48	-37	0.005	Exceeded RSL
37		8	182	80	54	0.76	NR[1]	NR[1]	NR[1]	NR[1]
38		8	194	80	54	0.76	NR[1]	NR[1]	NR[1]	NR[1]

Segment #	Street Name	Pipe Diameter	Segment Length	Measured Pressure	Pipe Age	Nominal Thickness	Measured Thickness	% Loss	Loss Rate	RSL
			ft	psi	yr	in	in		in/yr	yrs
39		8	576	80	54	0.76	0.61	-20	0.003	30 to 39
40		8	244	80	54	0.76	0.50	-34	0.005	Exceeded RSL
41		8	360	80	54	0.76	0.65	-14	0.002	50+
42		8	596	80	54	0.76	0.60	-21	0.003	20 to 29
43		8	675	80	55	0.76	0.60	-21	0.003	30 to 39
44		8	384	80	55	0.76	0.61	-20	0.003	40 to 49
45		8	517	80	55	0.76	0.64	-16	0.002	50+
46		8	511	80	55	0.76	0.77	0	0.000	50+
47		8	552	75	50	0.76	0.69	-9	0.001	50+
48		8	278	75	50	0.76	0.64	-16	0.002	50+
49		8	512	75	50	0.76	0.63	-17	0.003	40 to 49
50		12	501	75	50	1.09	0.93	-15	0.003	50+
51		8	600	75	50	0.76	0.70	-8	0.001	50+
52		8	467	85	54	0.76	0.70	-8	0.001	20 to 29
53		8	471	85	53	0.76	0.49	-36	0.005	Exceeded RSL
54		16	411	85	50	1.36	1.07	-21	0.006	Exceeded RSL
55		16	281	85	50	1.36	1.07	-21	0.006	1 to 9
56		12	359	80	49	1.09	0.81	-26	0.006	10 to 19
57		12	299	80	45	1.09	0.82	-25	0.006	1 to 9
58		8	437	80	51	0.76	0.57	-25	0.004	10 to 19
59		8	393	80	54	0.76	0.61	-20	0.003	40 to 49
60		8	205	80	46	0.76	0.69	-9	0.002	20 to 29
61		8	762	80	54	0.76	0.65	-14	0.002	50+
62		8	355	80	47	0.76	0.63	-17	0.003	40 to 49

Segment #	Street Name	Pipe Diameter	Segment Length	Measured Pressure	Pipe Age	Nominal Thickness	Measured Thickness	% Loss	Loss Rate	RSL
			ft	psi	yr	in	in		in/yr	yrs
63		8	216	80	47	0.76	0.24	-68	0.011	Exceeded RSL
64		8	375	80	47	0.76	NR[1]	NR[1]	NR[1]	NR[1]
65		8	571	80	54	0.76	0.59	-22	0.003	30 to 39
66		8	450	80	54	0.76	0.65	-14	0.002	50+
67		8	413	80	54	0.76	0.36	-53	0.007	Exceeded RSL
68		8	648	75	54	0.76	0.64	-16	0.002	Exceeded RSL
69		12	201	75	48	1.09	0.85	-22	0.005	Exceeded RSL
70		8	276	75	48	0.76	0.65	-14	0.002	50+
71		8	426	75	48	0.76	0.54	-29	0.005	1 to 9
72		8	494	71	48	0.76	0.61	-20	0.003	30 to 39
73		8	533	71	48	0.76	0.69	-9	0.001	50+
74		8	419	71	48	0.76	0.58	-24	0.004	Exceeded RSL
75		8	529	71	30	0.76	0.61	-20	0.005	Exceeded RSL
76		8	499	71	30	0.76	0.56	-26	0.007	1 to 9
77		8	259	71	30	0.76	0.70	-8	0.002	20 to 29
78		8	374	71	30	0.76	0.60	-21	0.005	10 to 19
79		8	549	71	30	0.76	0.66	-13	0.003	50+
80		8	493	71	30	0.76	0.63	-17	0.004	40 to 49
81		8	511	71	30	0.76	0.60	-21	0.005	20 to 29
82		8	388	71	30	0.76	0.58	-24	0.006	Exceeded RSL
83		8	209	71	46	0.76	0.50	-34	0.006	Exceeded RSL
84		8	260	71	46	0.76	0.62	-18	0.003	Exceeded RSL
85		8	324	71	46	0.76	0.56	-26	0.004	Exceeded RSL

Segment #	Street Name	Pipe Diameter	Segment Length	Measured Pressure	Pipe Age	Nominal Thickness	Measured Thickness	% Loss	Loss Rate	RSL
			ft	psi	yr	in	in		in/yr	yrs
86		8	303	71	46	0.76	0.66	-13	0.002	1 to 9
87		8	214	71	46	0.76	0.58	-24	0.004	10 to 19
88		6	513	71	46	0.66	0.52	-21	0.003	40 to 49
89		6	230	71	46	0.66	0.49	-26	0.004	30 to 39
90		6	296	71	46	0.66	0.45	-32	0.005	10 to 19
91		6	306	71	46	0.76	0.64	-16	0.003	50+
92		8	461	71	46	0.76	0.63	-17	0.003	Exceeded RSL
93		8	471	71	46	0.76	0.61	-20	0.003	Exceeded RSL
94		8	378	68	46	0.76	0.60	-21	0.003	Exceeded RSL
95		8	375	68	46	0.76	0.54	-29	0.005	Exceeded RSL
96		8	393	68	46	0.76	0.66	-13	0.002	50+
97		8	406	68	55	0.76	0.54	-29	0.004	10 to 19
98		8	564	68	56	0.66	0.49	-26	0.003	Exceeded RSL
99		6	332	68	56	0.66	0.50	-24	0.003	40 to 49
100		6	365	68	56	0.66	0.48	-27	0.003	30 to 39
101		6	340	68	56	0.66	0.47	-29	0.003	20 to 29
102		6	539	68	56	0.66	0.55	-17	0.002	50+
103		6	531	68	56	0.66	0.44	-33	0.004	10 to 19
104		8	411	68	56	0.76	0.61	-20	0.003	30 to 39
105		8	216	68	56	0.76	0.70	-8	0.001	50+
106		8	525	70	56	0.76	0.59	-22	0.003	Exceeded RSL

Segment #	Street Name	Pipe Diameter	Segment Length	Measured Pressure	Pipe Age	Nominal Thickness	Measured Thickness	% Loss	Loss Rate	RSL
			ft	psi	yr	in	in		in/yr	yrs
107		8	610	70	56	0.76	0.59	-22	0.003	Exceeded RSL
108		8	287	70	56	0.76	0.71	-7	0.001	50+
109		8	550	70	56	0.76	0.64	-16	0.002	Exceeded RSL
110		8	498	70	56	0.76	0.65	-14	0.002	1 to 9
111		8	398	70	56	0.76	0.67	-12	0.002	10 to 19
112		8	405	70	55	0.76	0.59	-22	0.003	50+
113		8	355	70	55	0.76	0.63	-17	0.002	Exceeded RSL
114		8	316	70	55	0.76	0.63	-17	0.002	Exceeded RSL
115		8	326	70	47	0.76	0.58	-24	0.004	Exceeded RSL
116		8	314	70	47	0.76	0.67	-12	0.002	10 to 19
117		8	255	70	47	0.76	0.63	-17	0.003	Exceeded RSL
118		8	227	70	47	0.76	0.67	-12	0.002	10 to 19
119		8	225	71	56	0.76	0.68	-11	0.001	20 to 29
120		8	444	71	56	0.76	0.65	-14	0.002	20 to 29
121		8	385	71	56	0.76	0.61	-20	0.003	Exceeded RSL
122		8	307	71	56	0.76	0.67	-12	0.002	50+
123		6	151	60	42	0.66	0.47	-29	0.005	20 to 29
124		8	369	60	42	0.76	0.72	-5	0.001	50+
125		8	419	60	42	0.76	0.61	-20	0.004	30 to 39
126		8	379	60	42	0.76	0.66	-13	0.002	50+
127		8	314	65	53	0.76	0.61	-20	0.003	40 to 49
128		8	366	65	53	0.76	0.54	-29	0.004	10 to 19
129		8	560	65	53	0.76	0.68	-11	0.002	50+

Segment #	Street Name	Pipe Diameter	Segment Length	Measured Pressure	Pipe Age	Nominal Thickness	Measured Thickness	% Loss	Loss Rate	RSL
			ft	psi	yr	in	in		in/yr	yrs
130		8	585	65	53	0.76	0.65	-14	0.002	50+
131		8	232	70	47	0.76	0.65	-14	0.002	50+
132		8	324	70	47	0.76	0.57	-25	0.004	10 to 19
133		8	447	70	47	0.76	0.31	-59	0.010	Exceeded RSL
134		8	356	65	47	0.76	0.34	-55	0.009	Exceeded RSL
135		8	452	65	47	0.76	0.37	-51	0.008	Exceeded RSL
136		8	424	65	47	0.76	0.66	-13	0.002	50+
Note: 1. A result was unattainable due to poor acoustic wave propagation. Echologics suspects the presence of PVC repairs within this segment.										

2.3.1 Asbestos Cement EchoLife® Assumptions

In addition to the pipe specification assumptions mentioned in section 1, the EchoLife® calculations also incorporate water pressure and external loading conditions. External load is calculated using the Marston equation plus H-20 traffic load with a safety factor of 2. To account for water pressure, Echologics recorded operating pressure values using fire hydrants at ePulse® test sites. The measured pressure plus a surge pressure of 50 psi with a safety factor of 2.5 is used for the calculations. A detailed table of assumptions can be found below in Table 8.

Table 8: Echolife® AC Assumptions

Pipe Information	Estimate or Assumption	Source
Soil Density	120 lbs/ft^3 (conservative)	Construction Guide for Soils & Foundations. Richard G. Ahlvin, Vernon Allen Smoots. Page 76, Section 12.3: Dry Density
Bedding Type	Class C: Granular - lightly compacted bedding (conservative). Load Factor = 1.5	Annual Book of ASTM Standards 2003. Section 4: Construction. Author: American Society for Testing & Materials. Page 8
Pipe Depth	Between 1 feet to 6 feet	Measured on site
Surge Pressure	50 psi	Assumed based on Echologics' experience
Safety Factor on Pressure	2	Pumping Station Design: Revised 3rd Edition. Garr M. Jones, Robert L. Banks. Section 4-6, Asbestos Cement Pipes; Available Sizes & Thicknesses. Page 4.24
Safety Factor on External load	2.5	Buried Pipe Design Third Edition. A. P. Moser & Steven Folkman. Table 5.3, Page 252
Rupture modulus of AC	5000-6000 psi. 5000 psi is most conservative and has been used	Buried Pipe Design Third Edition. A. P. Moser & Steven Folkman. Table 5.1, Page 248
Tensile strength of AC	3000-4000 psi. 3000 psi is most conservative and has been used	Buried Pipe Design Third Edition. A. P. Moser & Steven Folkman. Table 5.1, Page 248

3 Conclusions and Recommendations

3.1 Conclusions

Echologics successfully completed phase 4 (FY 2019/20) of the condition assessment program for the [CITY] on pipe wall condition, leak detection and remaining service life analysis of 53,270 feet of asbestos cement pipes. The main conclusions that can be drawn from this project are as follows:

A. Only 19 segments (14%) out of 136 segments appeared to be in poor condition and should be prioritized. The RSL analysis suggests:

   a. 17 of these segments have exceeded their remaining service life

   b. 2 segments (segments 90 and 103) have between 10 and 19 years of remaining service life

B. A majority of the segments (99 segments or 73%) tested appear to be in moderate condition and is expected to have experienced considerable levels of structural wall thickness loss. The RSL analysis suggests:

   a. 29 of these segments have exceeded their remaining service life

   b. 7 of these segments have remaining service life of between 1 year and 9 years

   c. 25 of these segments have remaining service life of over 50 years

   d. the remaining segments in moderate condition have between 10 and 49 years of service life

C. One suspected leak was identified within Segment 24 on Heil Avenue. This should be further investigated to verify the presence of a leak

D. 3 segments (segment 37, 38 and 64) did not yield results due to presence of suspected PVC or plastic pipe repairs in them

Segments identified in poor condition and segments estimated to have exceeded their remaining service life will allow the City to concentrate their replacement and rehabilitation planning efforts in an efficient and cost effective way. Investigating and repairing the main leak detected will results in a significant saving in NRW and energy costs related to water treatment.

3.2 Recommendations and Next Steps

Based on the results of the condition assessment and leak detection tests for this project, Echologics offers the following overall program recommendations and next steps:

A. To maximize the value of the data gathered, Echologics recommends cross referencing break history, pipe criticality (or other primary indicators of pipe condition) with measurements of structural pipe wall condition (ePulse®) and RSL analysis.
   Echologics has also worked with utilities around the world to design custom solutions to integrate within various asset management systems, for example, a 1-5 rating system analogous to the standard sewer inspection PACP has been used that incorporates pipe-loading conditions.

B. So far, Echologics has assessed a 43.4 miles of the City's potable water pipe network and identified a considerable number of segments that appeared to be in poor condition. These segments should be prioritized in future asset management and improvement plans. Considering these segments are a significant percentage of the City's water network, the City may also consider pipe rehabilitation as an option to reduce costs associated with water main replacement. Utilizing "evidence based" condition assessment data is a proactive approach to asset management.

C. Echologics understands that the City may consider exhuming and examining samples from water mains that are scheduled for replacement as part of their capital replacement program. If the City moves forward with this exercise, Echologics recommends taking samples from segments that were identified to be in poor condition to verify extent of degradation. Echologics has worked through pipe sample testing with utilities around the world and would be happy to guide the City through this process if required.

D. The City may consider implementing a remote leak detection monitoring system. A leak detection monitoring system conducts a survey every 24 hours in the area where it is implemented. Industry research has indicated that leaks are the most common early indicators of pipe condition change and are typically a precursor to main breaks or failure. A remote leak detection system can alert the City at the earliest onset of a leak, enabling them to take proactive actions before a sudden and catastrophic main break occurs.

It is important to note that structural pipe condition is one of many factors in evaluating a pipes suitability for service, but should not be the only consideration used in replacement and deferral decisions. Other important factors that should be considered may include pipe-loading conditions, hydraulic capacity of the pipe, road repair/renewal schedules, consequence of pipe failure, customer complaints, rate of degradation etc. With this is mind, Echologics further recommends the following actions for the three condition categories.

Good Condition Pipe – DEFER / LOW PRIORITY

The condition assessment results suggest the mains in this category are in good structural condition and do not need attention in the near future unless they are under higher than normal loading conditions. The results suggest that pipes in this category have a remaining wall thickness within 10% of the nominal wall thickness. Echologics suggests the City continue with its standard maintenance programs for these mains. Common industry practice is follow up condition assessment testing in approximately 10 years depending on consequence of failure to allow measurement of the rate of change of condition with time. If these mains require rehabilitation for other reasons such as low pressure or poor water quality complaints, then cleaning and lining may be an option to consider. The use and benefits of cathodic protection to slow or even stop the “aging” process of external corrosion may also be of interest.

When interpreting ePulse® results, asset owners should understand the following:

1. Leaks can still occur on water mains with good pipe wall condition for reasons other than pipe wall degradation, such as pressure transients, leaks at joints, leaks on service connections, winter weather (freeze/thaw), poor installation, etc.
2. If a leak is detected on these segments, a repair should be sufficient for remediation, because the majority of the remaining pipe wall is in good structural condition.
3. The need for future assessment of these pipes should take into account consequence of failure. Depending on the consequence of failure, it may be beneficial to equip these pipelines with a continuously monitoring leak detection system. For example, a non-redundant main servicing a hospital may benefit from immediate detection of leaks as soon as they develop.

Moderate Condition Pipe – MONITOR / MEDIUM PRIORITY

The results suggest that the pipes in this category are in moderate condition (medium priority) and should be monitored depending on pipe loading conditions. It is important to note pipes in this category may show a reduced capacity to withstand loading conditions, especially on pipes that are approaching 30% loss in wall thickness.

Depending on the criticality of the main, Echologics recommends monitoring these pipes. The following are some of possible monitoring methods:

1. For mains without an internal lining, cleaning and lining can often extend the life of moderate condition mains as well as adding cathodic protection.
2. Regularly scheduled, traditional leak detection surveys. These are a relatively inexpensive option capable of finding many leaks within a system. However, this method can be fairly labor intensive and may not prevent catastrophic failures on high consequence pipelines.
3. A permanent leak monitoring system that is capable of finding most leaks on a pipeline including small leaks before they turn into catastrophic failures.
4. A follow-up condition assessment survey to measure the rate of decay and update the condition of the mains. A common practice is to reassess these mains in 5 years depending on consequence of failure. An analysis of the results can be used to determine the decay rates for these mains. The current decay rate may have an impact on the remaining service life of the mains. Measuring this can allow for improved asset management.

Poor Condition Pipe – ADDRESS / HIGH PRIORITY

The results indicate that pipes in this category are in poor condition and likely in need of immediate attention. Depending on pipe loading condition, these pipes are at higher risk of experiencing leaks and catastrophic failures and should be addressed as soon as possible. As noted above, other important factors should also be considered when preparing a remediation or replacement plan.

In most cases, pipe segments that fall within this category have reached or are close to the end of their useful life. Actions such as structural lining, slip-lining, and/or full replacement should be investigated as a likely immediate requirement.

Such actions as continuous leak monitoring, cathodic protection and/or cleaning and lining will most likely not offer tremendous value or extend the life of the water main in a cost effective manner.

Each water network will have its own dominant degradation mechanism, as well as unique local considerations.

Each water network will have its own dominant degradation mechanism, as well as unique local considerations. Echologics recommends that the City use the results presented in this report in combination with other data and information available from additional services. This additional asset information may include:

- **Soil Corrosivity**. This comparison will help determine if external corrosion due to aggressive soil is a significant degradation mechanism for these mains.
- **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.

Comparing Echologics' results with some of the aforementioned datasets, will allow for the City to direct their rehabilitation efforts in a cost effective manner by creating a global rehabilitation picture which takes all sources of degradation into consideration.

4 Disclaimer

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.

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 spread over 5 distinct work sites. An overview map of the sites with color coded results are shown in Figure A. 1-1 followed by Table A. 1-1 with retailed results. The subsequent sections presents detailed information broken down by categories.

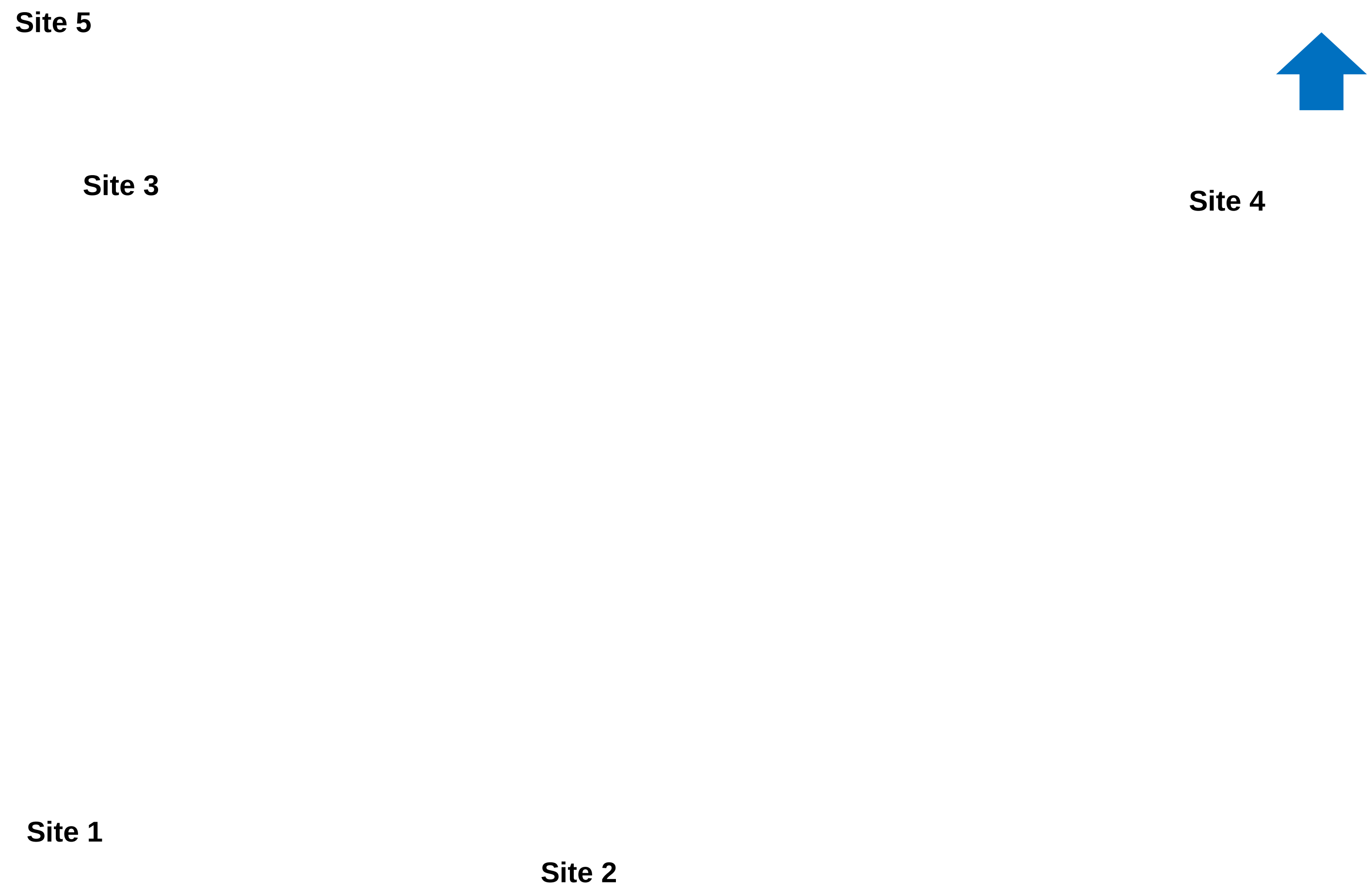


Figure A. 1-1: Overview of the Sites and Color Coded Results

Table A. 1-1: Detailed ePulse® Condition Assessment Results for All Segments

Segment #	Street Name	Blue Fitting	White Fitting	Pipe Material	Pipe Diameter	Segment Length	Nominal Thickness	Measured Thickness	% Loss
					in	ft	in	in	
1		Echo-Vlv-E7-157	Echo-Vlv-E7-179	Asbestos Cement	8	304	0.76	0.66	-13
2		Echo-Vlv-E7-217	Echo-Vlv-E7-179	Asbestos Cement	8	564	0.76	0.67	-12
3		Echo-Vlv-E7-217	Echo-Vlv-E7-249	Asbestos Cement	8	571	0.76	0.69	-9
4		Echo-Vlv-E7-157	Echo-Vlv-E7-135	Asbestos Cement	16	276	1.36	0.77	-43
5		Echo-Vlv-F5-289	Echo-Vlv-F5-267	Asbestos Cement	16	251	1.36	1.09	-20
6		Echo-Vlv-F5-242	Echo-Vlv-F5-267	Asbestos Cement	16	285	1.36	0.87	-36
7		Echo-Vlv-F5-242	Echo-Vlv-F5-197	Asbestos Cement	16	392	1.36	1.04	-24
8		Echo-Vlv-F5-159	Echo-Vlv-F5-197	Asbestos Cement	16	512	1.36	1.05	-23
9		Echo-Vlv-F5-159	Echo-Vlv-F5-127	Asbestos Cement	12	527	1.09	0.83	-24
10		Echo-Vlv-E4-280	Echo-Vlv-F4-244	Asbestos Cement	12	307	1.09	0.87	-20
11		Echo-Vlv-F4-234	Echo-Vlv-F4-244	Asbestos Cement	12	301	1.09	0.76	-30
12		Echo-Vlv-F4-234	Echo-Vlv-F4-211	Asbestos Cement	12	334	1.09	0.83	-24
13		Echo-Vlv-F4-190	Echo-Vlv-F4-211	Asbestos Cement	12	350	1.09	0.9	-17
14		Echo-Vlv-F4-190	Echo-Vlv-F4-157	Asbestos Cement	12	316	1.09	0.82	-25
15		Echo-Vlv-F4-119	Echo-Vlv-F4-157	Asbestos Cement	12	351	1.09	0.81	-26
16		Echo-Vlv-D2-260	Echo-Vlv-D2-256	Asbestos Cement	8	153	0.76	0.57	-25
17		Echo-Vlv-D2-262	Echo-Vlv-D2-256	Asbestos Cement	8	568	0.76	0.63	-17
18		Echo-Vlv-D2-262	Echo-Vlv-D2-271	Asbestos Cement	8	313	0.76	0.66	-13
19		Echo-Vlv-D2-266	Echo-Vlv-D2-271	Asbestos Cement	8	281	0.76	0.51	-33
20		Echo-Vlv-D2-266	Echo-Vlv-D2-264	Asbestos Cement	8	277	0.76	0.65	-14
21		Echo-Vlv-D2-269	Echo-Vlv-D2-264	Asbestos Cement	8	292	0.76	0.63	-17
22		Echo-Vlv-D2-269	Echo-Vlv-D2-265	Asbestos Cement	8	217	0.76	0.47	-38
23		Echo-Vlv-C2-239	Echo-Vlv-C3-111	Asbestos Cement	8	503	0.76	0.7	-8
24		Echo-Vlv-C3-108	Echo-Vlv-C3-111	Asbestos Cement	8	320	0.76	0.48	-37

Segment #	Street Name	Blue Fitting	White Fitting	Pipe Material	Pipe Diameter	Segment Length	Nominal Thickness	Measured Thickness	% Loss
					in	ft	in	in	
25		Echo-Vlv-C3-108	Echo-Vlv-C3-105	Asbestos Cement	8	295	0.76	0.66	-13
26		Echo-Vlv-C3-100	Echo-Vlv-C3-105	Asbestos Cement	8	391	0.76	0.68	-11
27		Echo-Vlv-D3-237	Echo-Vlv-D3-199	Asbestos Cement	8	514	0.76	0.69	-9
28		Echo-Vlv-D3-173	Echo-Vlv-D3-199	Asbestos Cement	8	559	0.76	0.66	-13
29		Echo-Vlv-D3-173	Echo-Vlv-D3-143	Asbestos Cement	8	487	0.76	0.6	-21
30		Echo-Vlv-D3-130	Echo-Vlv-D3-143	Asbestos Cement	8	256	0.76	0.6	-21
31		Echo-Vlv-D3-130	Echo-Vlv-D3-105	Asbestos Cement	8	356	0.76	0.5	-34
32		Echo-Vlv-C7-166	Echo-Vlv-C7-182	Asbestos Cement	8	365	0.76	0.48	-37
33		Echo-Vlv-C7-206	Echo-Vlv-C7-182	Asbestos Cement	8	384	0.76	0.52	-32
34		Echo-Vlv-C7-206	Echo-Vlv-C7-226	Asbestos Cement	8	312	0.76	0.69	-9
35		Echo-Vlv-D7-247	Echo-Vlv-C7-226	Asbestos Cement	8	264	0.76	0.7	-8
36		Echo-Vlv-C7-166	Echo-2[1]	Asbestos Cement	8	534	0.76	0.48	-37
37		Echo-Vlv-C7-129	Echo-2[1]	Asbestos Cement	8	182	0.76	NR[4]	NR[4]
38		Echo-Vlv-C7-129	Echo-Vlv-D7-115	Asbestos Cement	8	194	0.76	NR[4]	NR[4]
39		Echo-Vlv-C6-139	Echo-Vlv-C6-119	Asbestos Cement	8	576	0.76	0.61	-20
40		Echo-Vlv-C6-139	Echo-Vlv-C6-158	Asbestos Cement	8	244	0.76	0.5	-34
41		Echo-Vlv-C6-187	Echo-Vlv-C6-158	Asbestos Cement	8	360	0.76	0.65	-14
42		Echo-Vlv-C6-187	Pothole[3]	Asbestos Cement	8	596	0.76	0.6	-21
43		Echo-Vlv-C5-131	Echo-Vlv-D5-119	Asbestos Cement	8	675	0.76	0.6	-21
44		Echo-Vlv-C5-131	Echo-Vlv-C5-158	Asbestos Cement	8	384	0.76	0.61	-20
45		Echo-Vlv-D5-180	Echo-Vlv-C5-158	Asbestos Cement	8	517	0.76	0.64	-16
46		Echo-Vlv-D5-180	Echo-Vlv-C5-252	Asbestos Cement	8	511	0.76	0.77	0[2]
47		Pothole[3]	Echo-Vlv-G3-101	Asbestos Cement	8	552	0.76	0.69	-9
48		Echo-Vlv-G3-100	Echo-Vlv-G3-101	Asbestos Cement	8	278	0.76	0.64	-16
49		Echo-Vlv-G3-100	Echo-Vlv-G3-102	Asbestos Cement	8	512	0.76	0.63	-17
50		Echo-Vlv-G3-105	Echo-Vlv-G3-102	Asbestos Cement	12	501	1.09	0.93	-15

Segment #	Street Name	Blue Fitting	White Fitting	Pipe Material	Pipe Diameter	Segment Length	Nominal Thickness	Measured Thickness	% Loss
					in	ft	in	in	
51		Echo-Vlv-H3-102	Echo-Vlv-H3-103	Asbestos Cement	8	600	0.76	0.7	-8
52		Echo-Vlv-E7-270	Echo-Vlv-E7-249	Asbestos Cement	8	467	0.76	0.7	-8
53		Echo-Vlv-E7-103	Echo-Vlv-E7-135	Asbestos Cement	8	471	0.76	0.49	-36
54		Echo-Vlv-F5-242	Echo-Vlv-F5-307	Asbestos Cement	16	411	1.36	1.07	-21
55		Echo-Vlv-F4-290	Echo-Vlv-F5-127	Asbestos Cement	16	281	1.36	1.07	-21
56		Echo-Vlv-F4-290	Echo-Vlv-E4-280	Asbestos Cement	12	359	1.09	0.81	-26
57		Echo-Vlv-F4-119	Echo-Vlv-F4-101	Asbestos Cement	12	299	1.09	0.82	-25
58		Echo-Vlv-D2-260	Echo-Vlv-D2-251	Asbestos Cement	8	437	0.76	0.57	-25
59		Echo-Vlv-C3-100	Echo-Vlv-C3-101	Asbestos Cement	8	393	0.76	0.61	-20
60		Echo-Vlv-D3-105	Echo-Vlv-C3-101	Asbestos Cement	8	205	0.76	0.69	-9
61		Echo-Vlv-C2-239	Echo-Vlv-C2-249	Asbestos Cement	8	762	0.76	0.65	-14
62		Echo-Vlv-D3-237	Echo-Vlv-C3-264	Asbestos Cement	8	355	0.76	0.63	-17
63		Echo-Vlv-D7-247	Echo-Vlv-C7-261	Asbestos Cement	8	216	0.76	0.24	-68
64		Echo-Vlv-C6-251	Echo-Vlv-D7-115	Asbestos Cement	8	375	0.76	NR[4]	NR[4]
65		Echo-Vlv-C6-251	Pothole[3]	Asbestos Cement	8	571	0.76	0.59	-22
66		Echo-Vlv-D5-220	Echo-Vlv-C6-119	Asbestos Cement	8	450	0.76	0.65	-14
67		Echo-Vlv-D5-220	Echo-Vlv-C5-252	Asbestos Cement	8	413	0.76	0.36	-53
68		Pothole[3]	Echo-Vlv-F3-100	Asbestos Cement	8	648	0.76	0.64	-16
69		Echo-Vlv-G3-105	Echo-Vlv-H3-101	Asbestos Cement	12	201	1.09	0.85	-22
70		Echo-Vlv-H2-331	Echo-Vlv-H3-100	Asbestos Cement	8	276	0.76	0.65	-14
71		Echo-Vlv-H2-331	Echo-Vlv-H3-102	Asbestos Cement	8	426	0.76	0.54	-29
72		Echo-Vlv-H2-330	Echo-Vlv-H3-120	Asbestos Cement	8	494	0.76	0.61	-20
73		Echo-Vlv-H2-330	Echo-Vlv-H2-281	Asbestos Cement	8	533	0.76	0.69	-9
74		Echo-Vlv-H2-225	Echo-Vlv-H2-250	Asbestos Cement	8	419	0.76	0.58	-24
75		Echo-Vlv-H2-225	Echo-Vlv-H2-181	Asbestos Cement	8	529	0.76	0.61	-20
76		Echo-Vlv-J2-120	Echo-Vlv-H1-149	Asbestos Cement	8	499	0.76	0.56	-26

Segment #	Street Name	Blue Fitting	White Fitting	Pipe Material	Pipe Diameter	Segment Length	Nominal Thickness	Measured Thickness	% Loss
					in	ft	in	in	
77		Echo-Vlv-J2-120	Echo-Vlv-H2-181	Asbestos Cement	8	259	0.76	0.7	-8
78		Echo-Vlv-H2-281	Echo-Vlv-H2-250	Asbestos Cement	8	374	0.76	0.6	-21
79		Pothole[3]	Echo-Vlv-H3-120	Asbestos Cement	8	549	0.76	0.66	-13
80		Pothole[3]	Echo-Vlv-H3-158	Asbestos Cement	8	493	0.76	0.63	-17
81		Echo-Vlv-H3-189	Echo-Vlv-H3-158	Asbestos Cement	8	511	0.76	0.6	-21
82		Echo-Vlv-H3-189	Echo-Vlv-H3-220	Asbestos Cement	8	388	0.76	0.58	-24
83		Echo-Vlv-D1-150	Echo-Vlv-D1-154	Asbestos Cement	8	209	0.76	0.5	-34
84		Echo-Vlv-D1-152	Echo-Vlv-D1-154	Asbestos Cement	8	260	0.76	0.62	-18
85		Echo-Vlv-D1-152	Echo-Vlv-D1-151	Asbestos Cement	8	324	0.76	0.56	-26
86		Echo-Vlv-D1-134	Echo-Vlv-D1-151	Asbestos Cement	8	303	0.76	0.66	-13
87		Echo-Vlv-D1-134	Echo-Vlv-D1-129	Asbestos Cement	8	214	0.76	0.58	-24
88		Echo-Vlv-D1-114	Echo-Vlv-D1-116	Asbestos Cement	6	513	0.66	0.52	-21
89		Echo-Vlv-D1-100	Echo-Vlv-D1-104	Asbestos Cement	6	230	0.66	0.49	-26
90		Echo-Vlv-D1-108	Echo-Vlv-D1-104	Asbestos Cement	6	296	0.66	0.45	-32
91		Echo-Vlv-D1-124	Echo-Vlv-E1-112	Asbestos Cement	6	306	0.76	0.64	-16
92		Echo-Vlv-E1-108	Echo-Vlv-E1-112	Asbestos Cement	8	461	0.76	0.63	-17
93		Echo-Vlv-E1-108	Echo-Vlv-E1-107	Asbestos Cement	8	471	0.76	0.61	-20
94		Echo-Vlv-F1-107	Echo-Vlv-F1-109	Asbestos Cement	8	378	0.76	0.6	-21
95		Echo-Vlv-F1-103	Echo-Vlv-F1-109	Asbestos Cement	8	375	0.76	0.54	-29
96		Echo-Vlv-F1-103	Echo-Vlv-F1-106	Asbestos Cement	8	393	0.76	0.66	-13
97		Echo-Vlv-F1-146	Echo-Vlv-F1-152	Asbestos Cement	8	406	0.76	0.54	-29
98		Echo-Vlv-F1-151	Echo-Vlv-F1-152	Asbestos Cement	8	564	0.66	0.49	-26
99		Echo-Vlv-E1-128	Echo-Vlv-E1-116	Asbestos Cement	6	332	0.66	0.5	-24
100		Echo-Vlv-E1-118	Echo-Vlv-E1-116	Asbestos Cement	6	365	0.66	0.48	-27
101		Echo-Vlv-E1-118	Echo-Vlv-E1-123	Asbestos Cement	6	340	0.66	0.47	-29
102		Echo-Vlv-E1-105	Echo-Vlv-E1-104	Asbestos Cement	6	539	0.66	0.55	-17

Segment #	Street Name	Blue Fitting	White Fitting	Pipe Material	Pipe Diameter	Segment Length	Nominal Thickness	Measured Thickness	% Loss
					in	ft	in	in	
103		Echo-Vlv-E1-102	Echo-Vlv-E1-104	Asbestos Cement	6	531	0.66	0.44	-33
104		Echo-Vlv-J2-155	Echo-Vlv-J2-156	Asbestos Cement	8	411	0.76	0.61	-20
105		Echo-Vlv-J2-157	Echo-Vlv-J2-156	Asbestos Cement	8	216	0.76	0.7	-8
106		Echo-Vlv-H2-200	Echo-Vlv-H2-240	Asbestos Cement	8	525	0.76	0.59	-22
107		Echo-Vlv-H2-279	Echo-Hyd-H2-147	Asbestos Cement	8	610	0.76	0.59	-22
108		Echo-Vlv-H2-279	Echo-Vlv-H2-301	Asbestos Cement	8	287	0.76	0.71	-7
109		Echo-Vlv-H2-302	Echo-Vlv-H2-158	Asbestos Cement	8	550	0.76	0.64	-16
110		Echo-Vlv-H2-233	Echo-Hyd-H2-158	Asbestos Cement	8	498	0.76	0.65	-14
111		Echo-Vlv-H2-233	Echo-Vlv-H2-199	Asbestos Cement	8	398	0.76	0.67	-12
112		Echo-Vlv-H2-163	Echo-Hyd-H2-133	Asbestos Cement	8	405	0.76	0.59	-22
113		Echo-Vlv-H2-163	Echo-Hyd-H2-112	Asbestos Cement	8	355	0.76	0.63	-17
114		Echo-Vlv-H2-130	Echo-Vlv-H2-135	Asbestos Cement	8	316	0.76	0.63	-17
115		Echo-Vlv-H2-124	Echo-Vlv-H2-125	Asbestos Cement	8	326	0.76	0.58	-24
116		Echo-Vlv-H2-120	Echo-Vlv-H2-125	Asbestos Cement	8	314	0.76	0.67	-12
117		Echo-Vlv-H2-124	Echo-Vlv-H2-136	Asbestos Cement	8	255	0.76	0.63	-17
118		Echo-Vlv-H2-158	Echo-Vlv-H2-136	Asbestos Cement	8	227	0.76	0.67	-12
119		Echo-Vlv-H2-306	Echo-Vlv-H2-301	Asbestos Cement	8	225	0.76	0.68	-11
120		Echo-Vlv-H2-306	Echo-Vlv-H2-308	Asbestos Cement	8	444	0.76	0.65	-14
121		Echo-Vlv-H2-312	Echo-Vlv-H2-308	Asbestos Cement	8	385	0.76	0.61	-20
122		Echo-Vlv-H2-312	Echo-Vlv-H2-303	Asbestos Cement	8	307	0.76	0.67	-12
123		Echo-Vlv-J2-124	Echo-Vlv-J2-127	Asbestos Cement	6	151	0.66	0.47	-29
124		Echo-Vlv-J2-122	Echo-Vlv-J2-127	Asbestos Cement	8	369	0.76	0.72	-5
125		Echo-Vlv-J2-122	Echo-Vlv-J2-131	Asbestos Cement	8	419	0.76	0.61	-20
126		Echo-Vlv-J2-137	Echo-Vlv-J2-131	Asbestos Cement	8	379	0.76	0.66 Ave	-13
127		Echo-Vlv-J1-103	Echo-Vlv-J1-101	Asbestos Cement	8	314	0.76	0.61	-20
128		Echo-Vlv-J1-105	Echo-Vlv-J1-101	Asbestos Cement	8	366	0.76	0.54	-29

Segment #	Street Name	Blue Fitting	White Fitting	Pipe Material	Pipe Diameter	Segment Length	Nominal Thickness	Measured Thickness	% Loss
					in	ft	in	in	
129		Echo-Vlv-J1-105	Echo-Vlv-J1-110	Asbestos Cement	8	560	0.76	0.68	-11
130		Echo-Vlv-J2-117	Echo-Vlv-J1-110	Asbestos Cement	8	585	0.76	0.65	-14
131		Echo-Vlv-H2-111	Echo-Vlv-H2-134	Asbestos Cement	8	232	0.76	0.65	-14
132		Echo-Vlv-H2-173	Echo-Vlv-H2-134	Asbestos Cement	8	324	0.76	0.57	-25
133		Echo-Vlv-H2-173	Echo-Vlv-H2-209	Asbestos Cement	8	447	0.76	0.31	-59
134		Echo-Vlv-H1-113	Echo-Vlv-H1-107	Asbestos Cement	8	356	0.76	0.34	-55
135		Echo-Vlv-H1-104	Echo-Vlv-H1-107	Asbestos Cement	8	452	0.76	0.37	-51
136		Echo-Vlv-H1-104	Echo-Vlv-H1-112	Asbestos Cement	8	424	0.76	0.66	-13

Note:

1. This appurtenance is missing from the City’s GIS data
2. Segment showed measured thickness greater than the nominal thickness. The percentage loss is capped at zero
3. Potholes were excavated to the crown of the pipe to provide sensor attachment points in absence of existing appurtenances.
4. A result was unattainable on this segment due to poor acoustic wave propagation. Echologics suspects the presence of PVC repairs within this segment.

Figure A. 1-2 shows the results breakdown by condition category for the entire project scope.

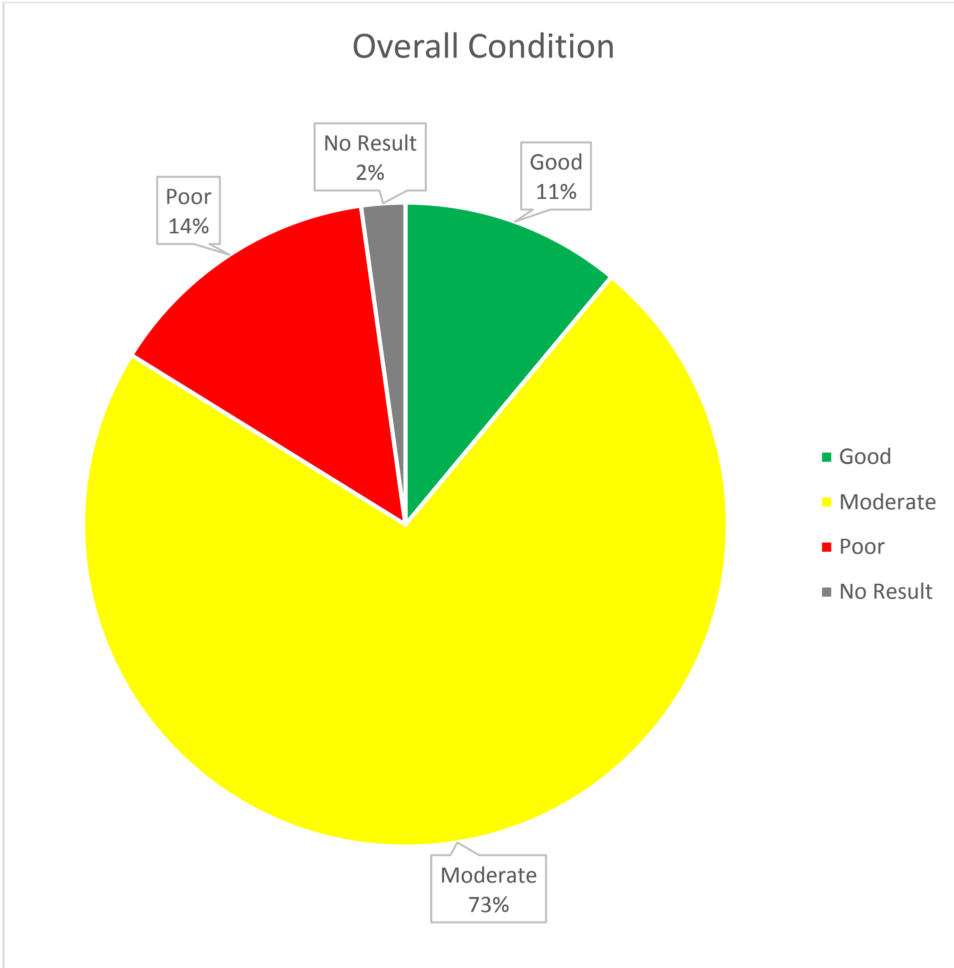


Figure A. 1-2: Overall Condition of Scope by Segment (%)

Results Breakdown for Different Sites

Site 1 Results

There were 32 segments tested in Site 1 on [STREET]. This site contained 10,855 feet of 8-inch asbestos cement pipes, the majority of which appeared to be moderate condition.

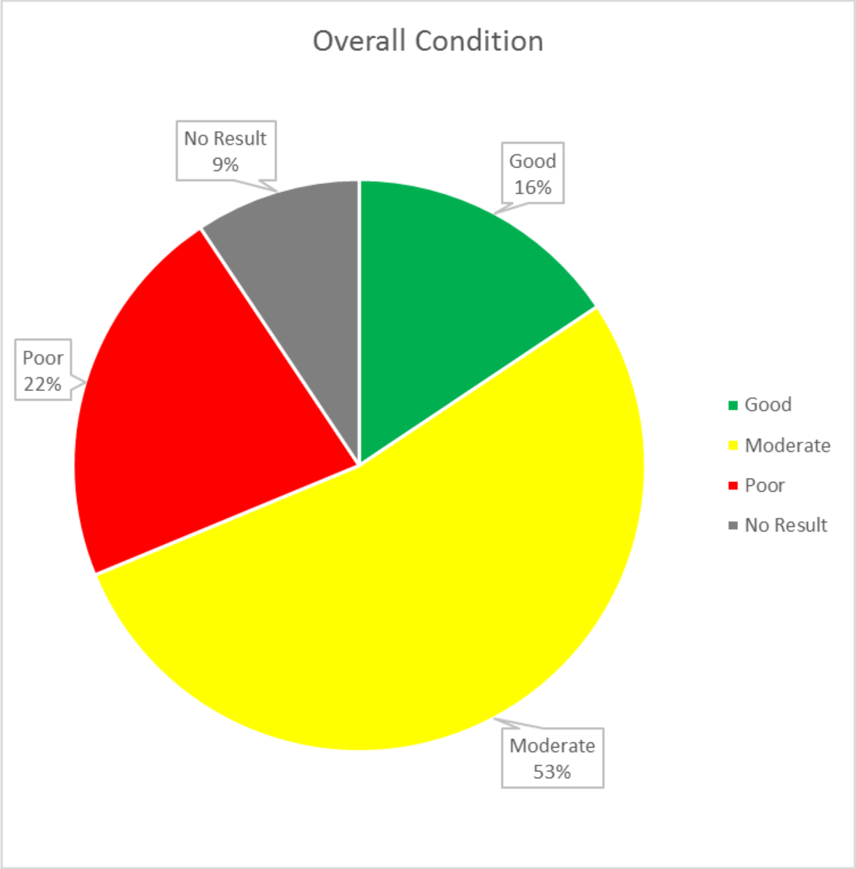


Figure A. 1-3: Overall Condition of Site 1

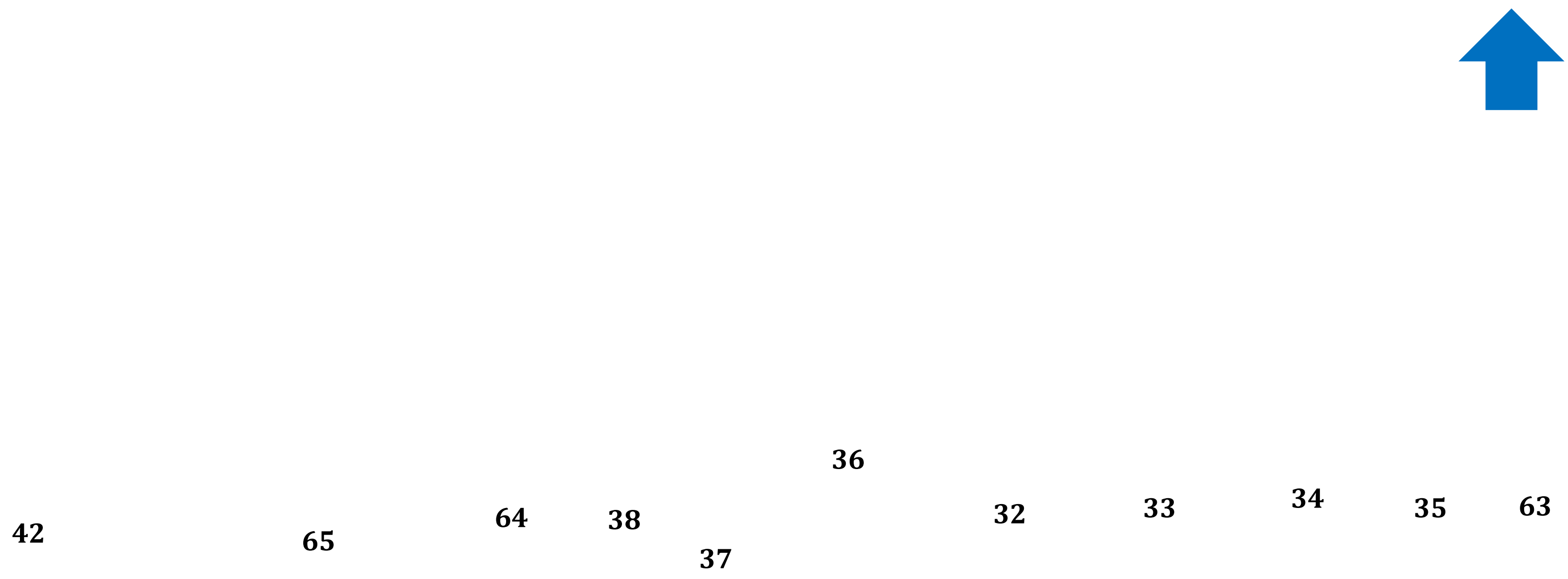


Figure A. 1-4a: Color Coded Map of Segments in Site 1

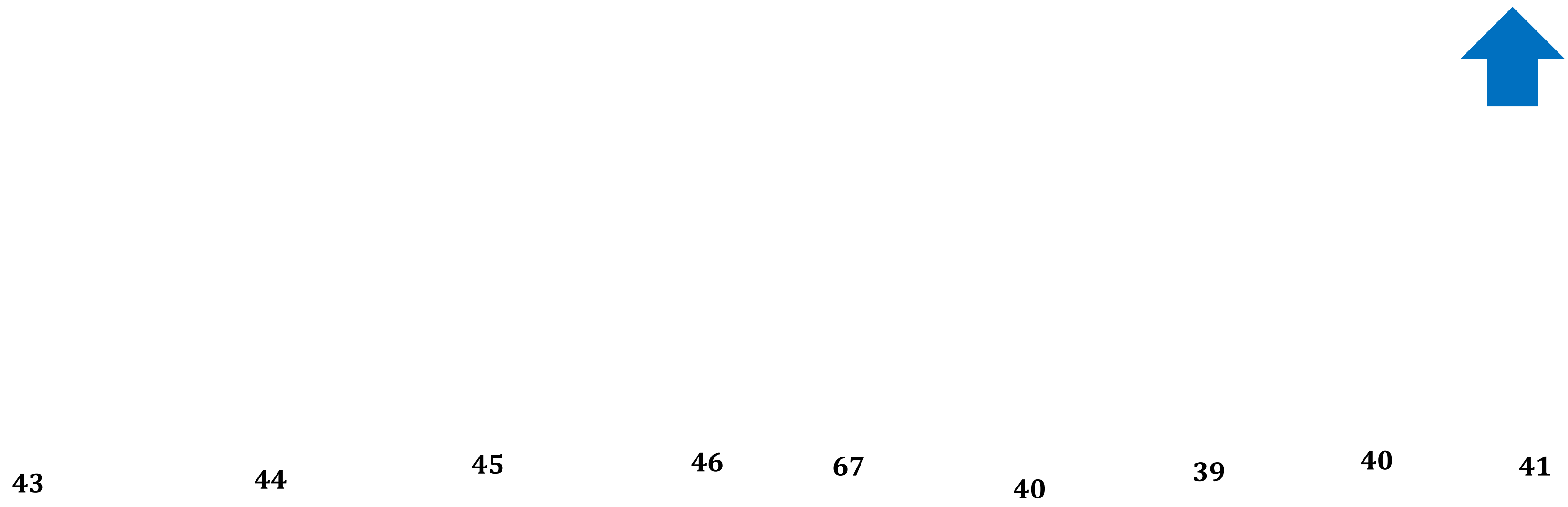


Figure A. 1-4b: Color Coded Map of Segments in Site 1

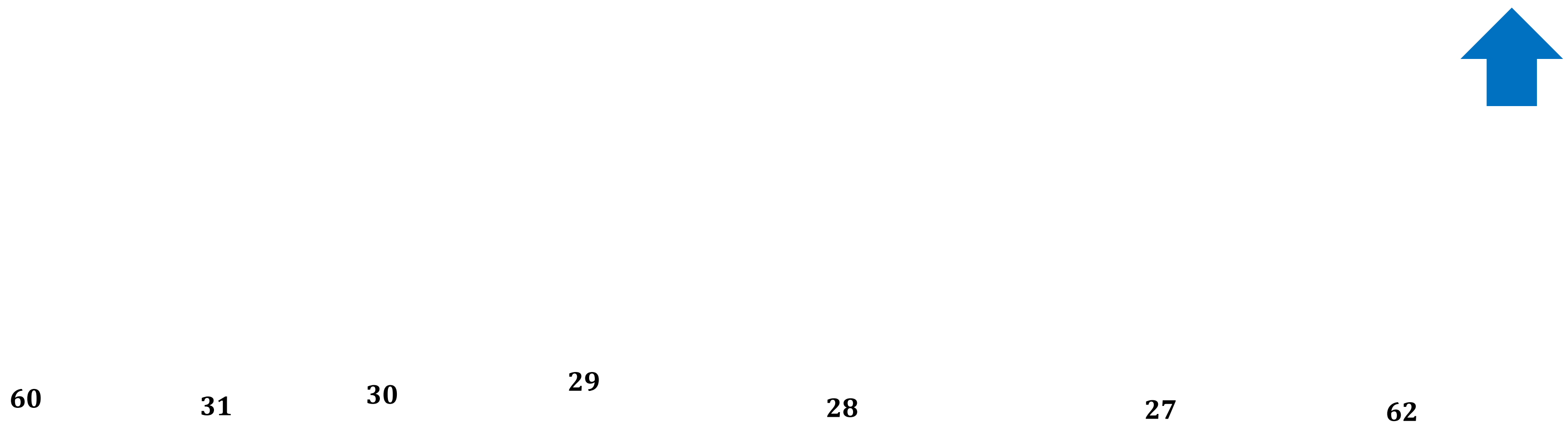


Figure A. 1-4c: Color Coded Map of Segments in Site 1

Site 2

There were 21 segments tested in Site 2 on STREET. This site contained 7,929 feet of 8-inch, 12-inch and 16-inch asbestos cement pipes, the majority of which appeared to be moderate condition.

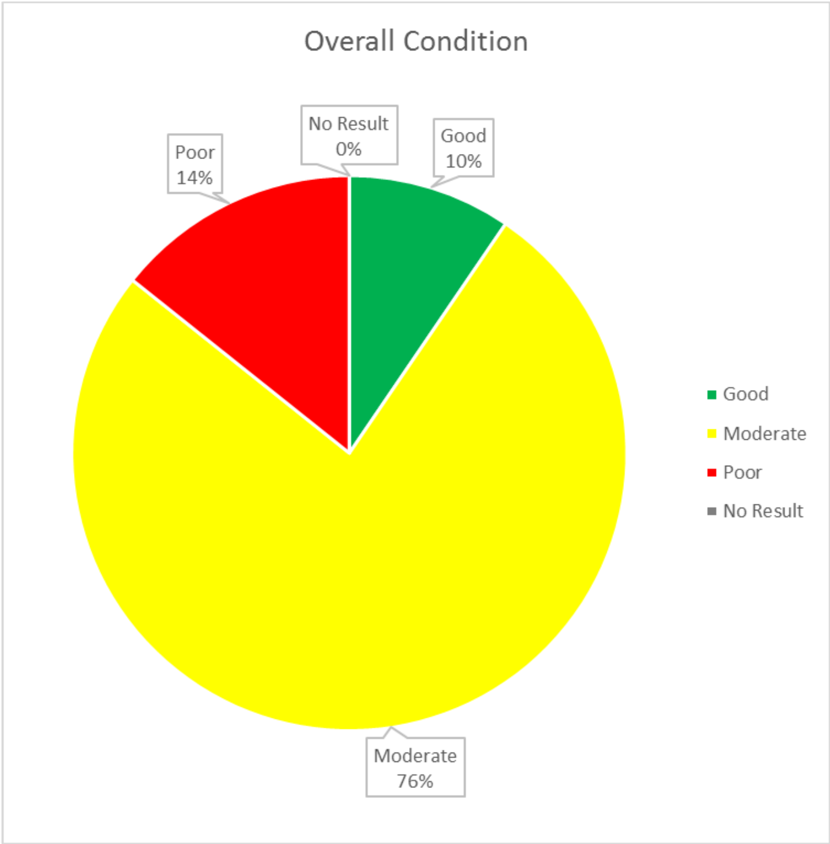


Figure A. 1-5: Overall Condition of Site 2

Figure A. 1-6a: Color Coded Map of Segments in Site 2

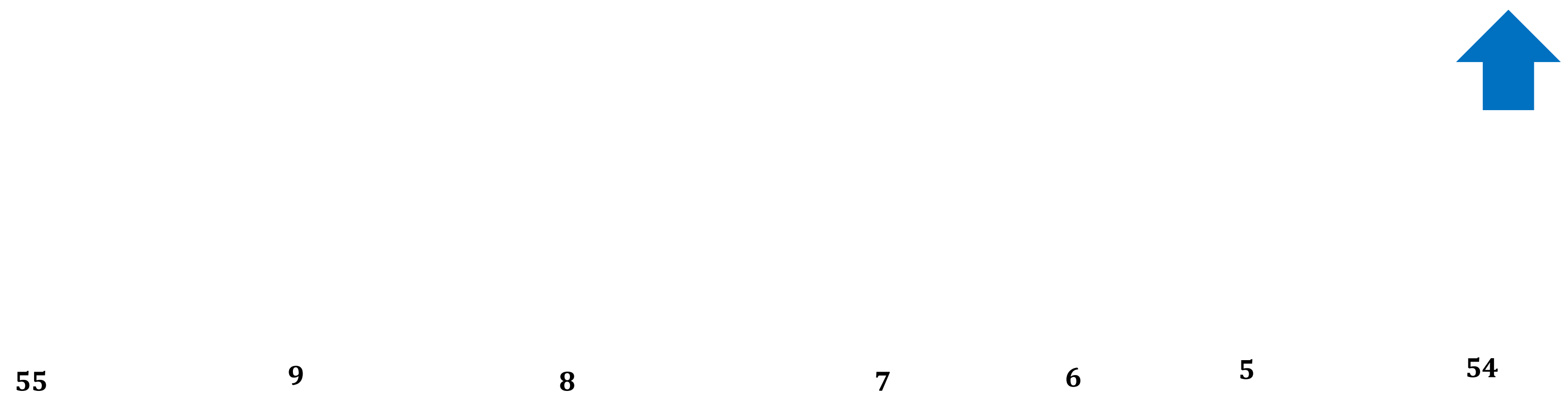


Figure A. 1-6b: Color Coded Map of Segments in Site 2

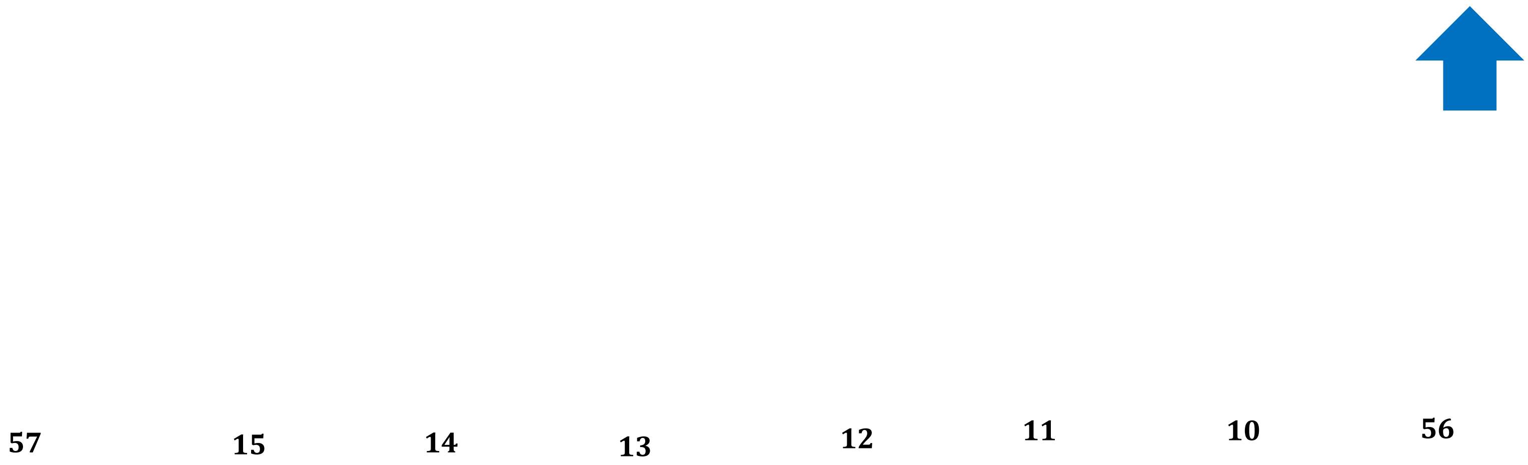


Figure A. 1-6c: Color Coded Map of Segments in Site 2

Site 3

There were 14 segments tested in Site 3 on [STREET]. This site contained 5,202 feet of 8-inch, asbestos cement pipes, the majority of which appeared to be moderate condition.

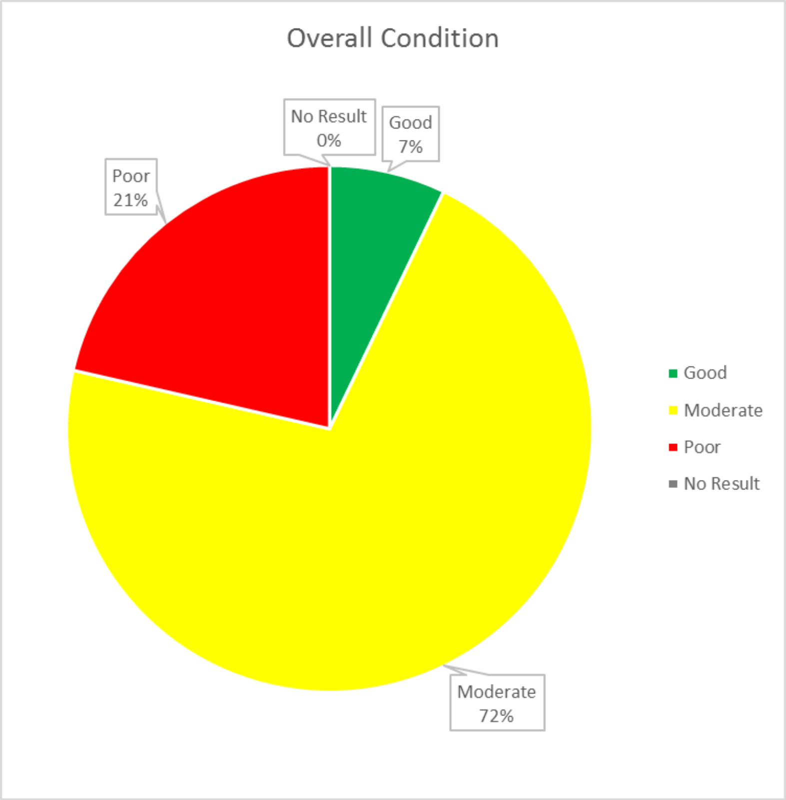


Figure A.1-7: Overall Condition of Site 3

Figure A. 1-8: Color Coded Map of Segments in Site 3

Site 4

There were 49 segments tested in Site 4. These segments were located on several streets contained 19,919 feet of 8-inch and 12-inch asbestos cement pipes, the majority of which appeared to be moderate condition.

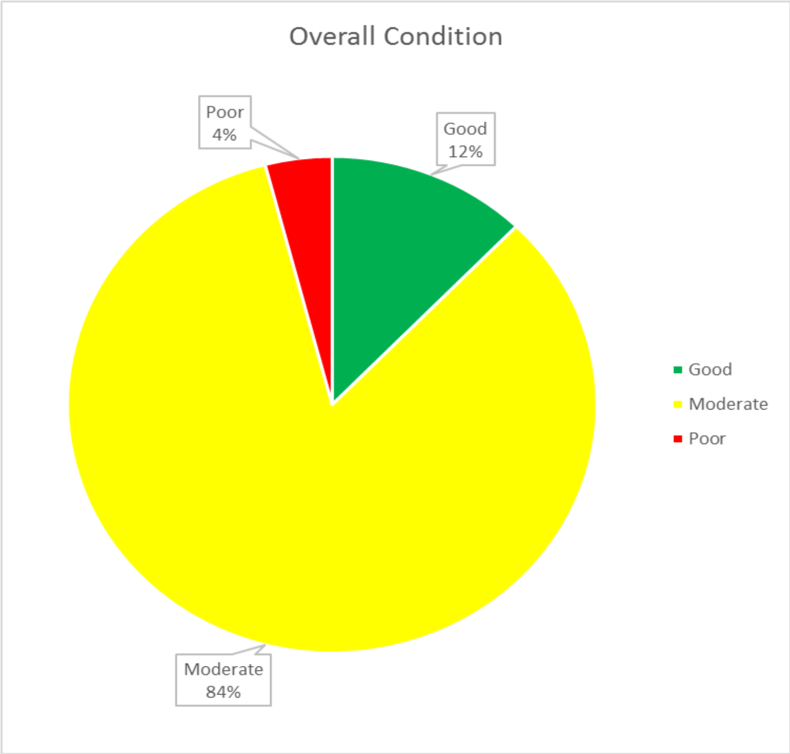


Figure A.1-9: Overall Condition of Site 4

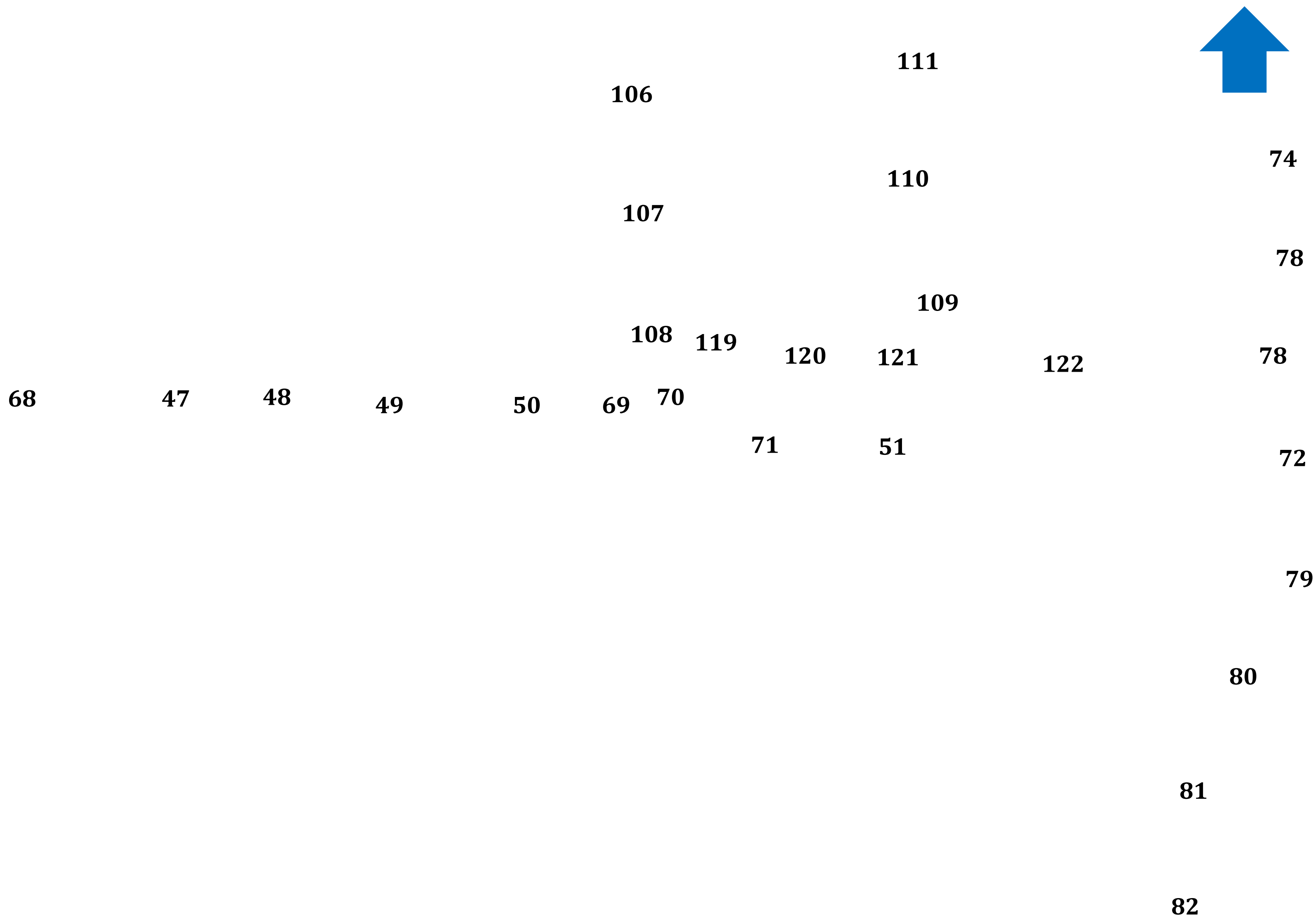


Figure A. 1-10a: Color Coded Map of Segments in Site 4

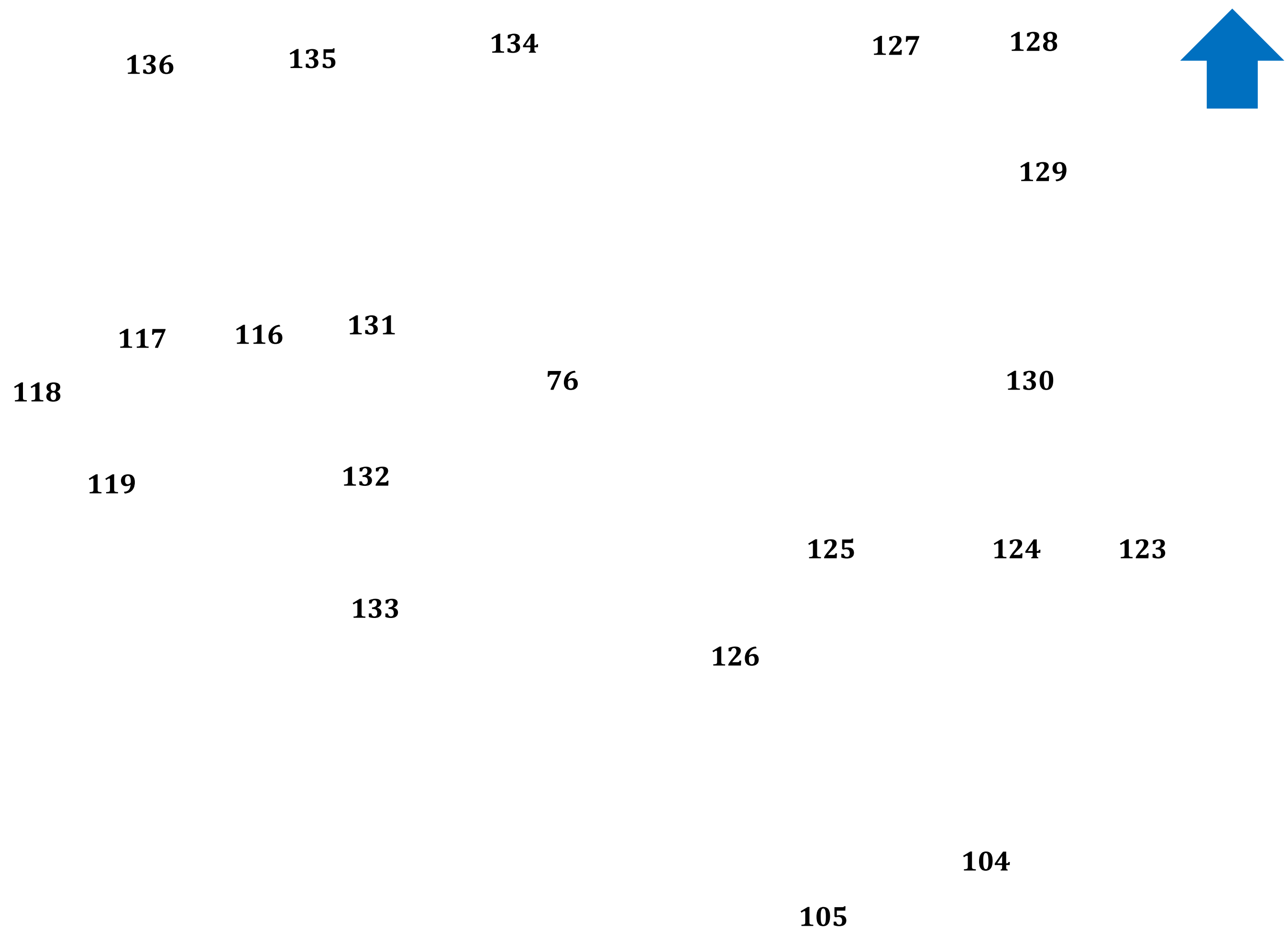


Figure A. 1-10b: Color Coded Map of Segments in Site 4

Site 5

There were 49 segments tested in Site 4. These segments were located on several streets contained 19,919 feet of 8-inch and 12-inch asbestos cement pipes, the majority of which appeared to be moderate condition.

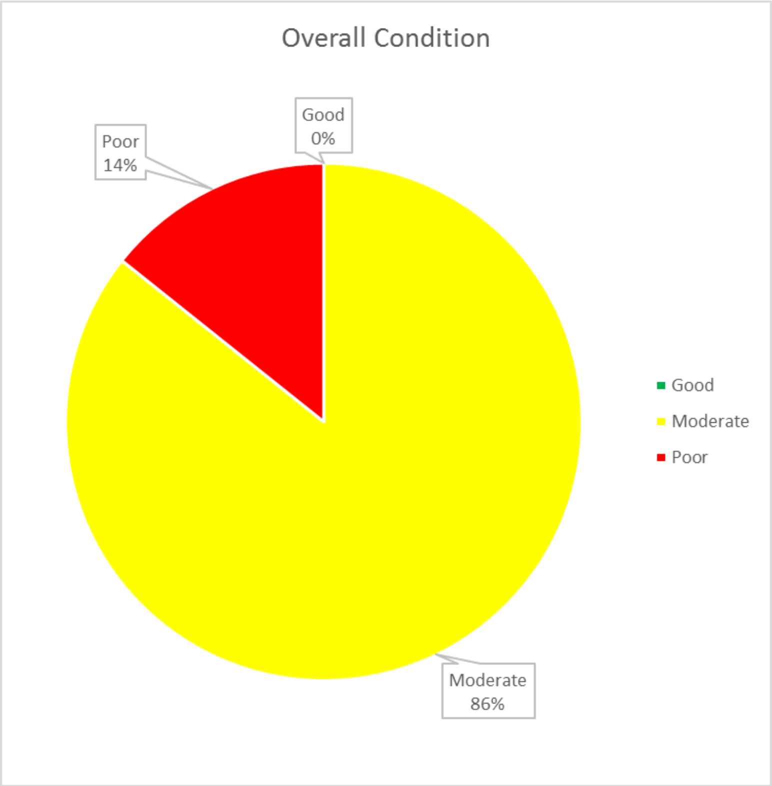


Figure A.1-11: Overall Condition of Site 5

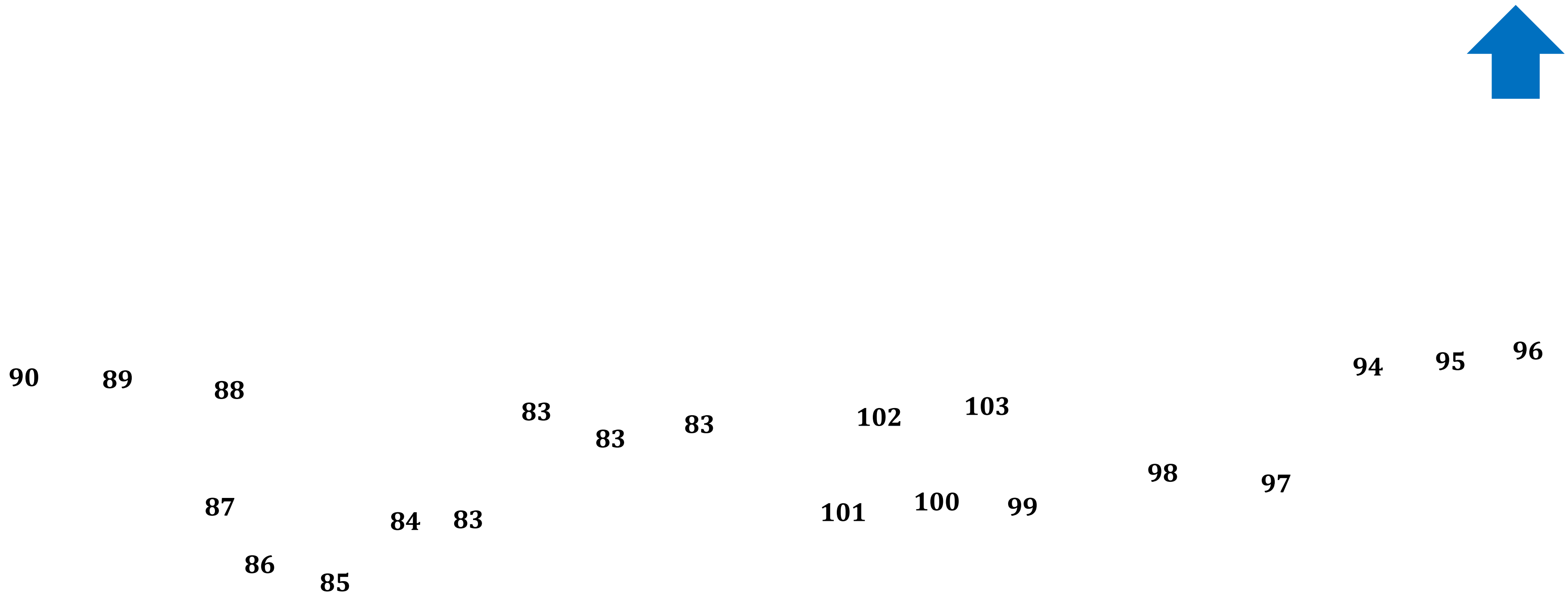


Figure A. 1-12: Color Coded Map of Segments in Site 5

Results Breakdown for All Pipe Diameters

Figure A. 1-13 shows the distribution of the ePulse® condition assessment results for various diameter pipes. The overall distribution of segments in different condition closely matched the distribution for 8-inch pipes. This is due to the fact that 108 out of the total 136 segments tested in the scope consisted of 8-inch asbestos cement pipe.

Figure A. 1-14 shows average phase 4 percentage degradation for all pipe diameter.

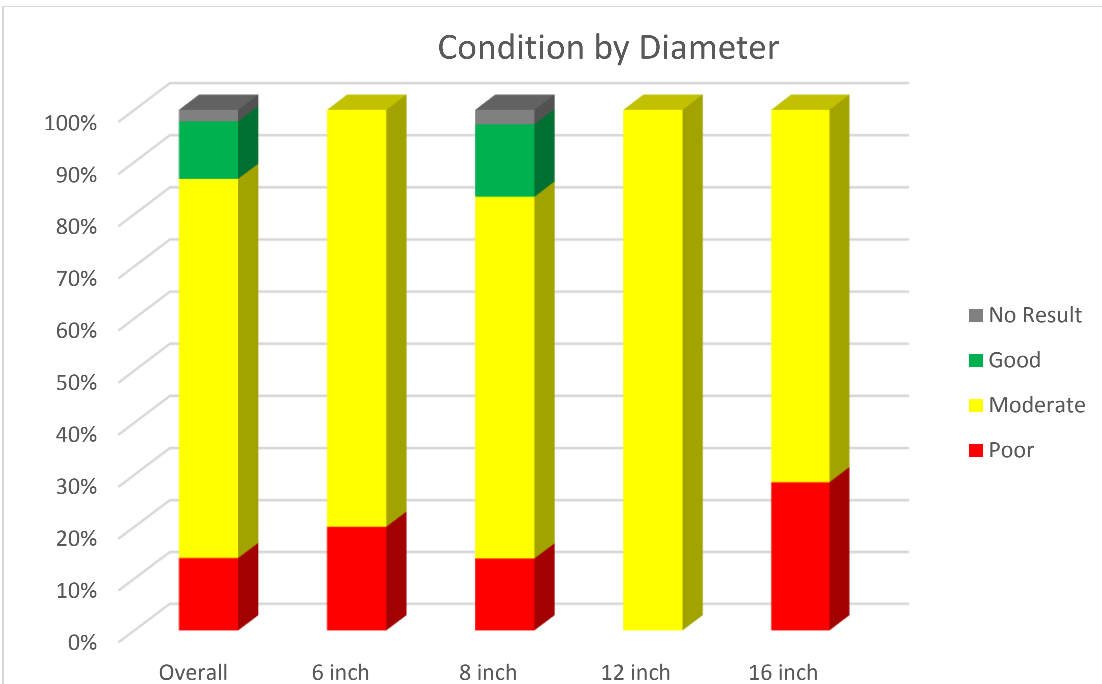


Figure A.1-13: Distribution of Condition for Different Diameter

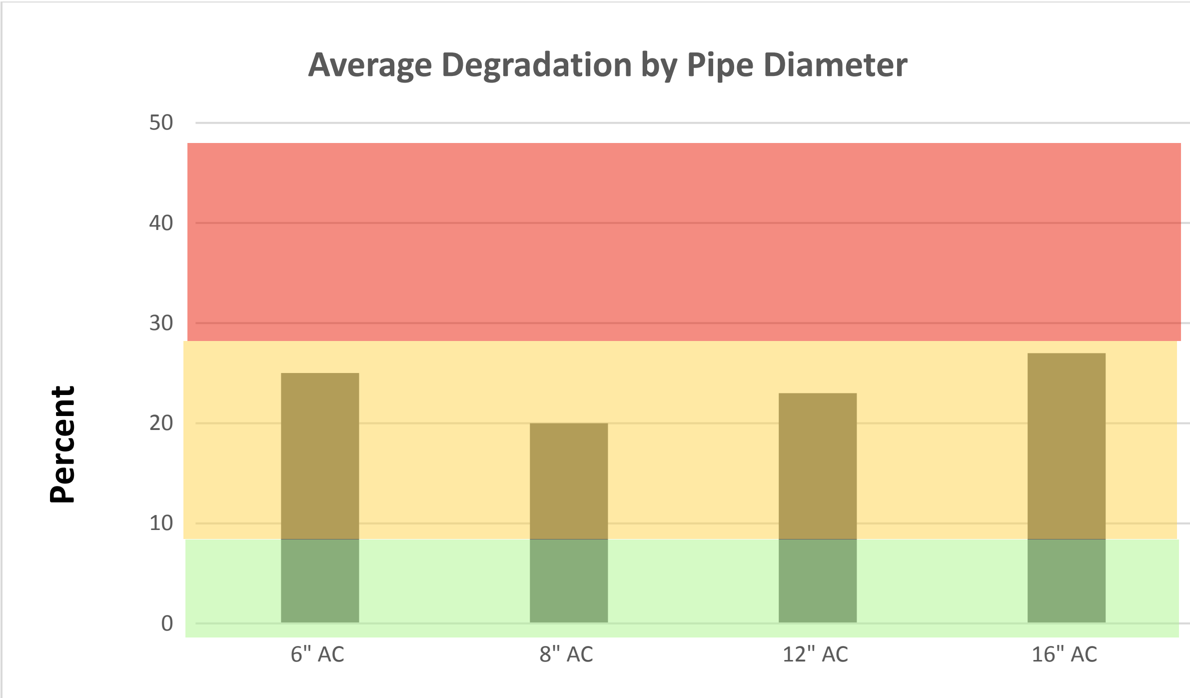


Figure A.1-14: Distribution Segment Condition by Burial Condition

A.2 EchoLife® Remaining Service Life Results

Table A.2-1 shows the remaining service life (RSL) calculation of asbestos cement pipe segments tested. Table A.2-2 list the assumptions made in the remaining service life analysis. Echologics' has predicted remaining service life values based on ePulse® mean minimum hoop thickness measurements. It is important to note that higher levels of degradation may exist on a smaller lengths of pipe within a given test segment.

Table A.2-1: Echolife® Remaining Service Life Analysis Results

Segment #	Street Name	Pipe Diameter	Segment Length	Measured Pressure	Pipe Age	Nominal Thickness	Measured Thickness	% Loss	Loss Rate	RSL
			ft	psi	yr	in	in		in/yr	yrs
1		8	304	85	45	0.76	0.66	-13	0.002	50+
2		8	564	85	45	0.76	0.67	-12	0.002	50+
3		8	571	85	54	0.76	0.69	-9	0.001	50+
4		16	276	85	53	1.36	0.77	-43	0.011	Exceeded RSL
5		16	251	85	53	1.36	1.09	-20	0.005	1 to 9
6		16	285	85	53	1.36	0.87	-36	0.009	Exceeded RSL
7		16	392	85	48	1.36	1.04	-24	0.007	Exceeded RSL
8		16	512	85	52	1.36	1.05	-23	0.006	Exceeded RSL
9		12	527	85	52	1.09	0.83	-24	0.005	Exceeded RSL
10		12	307	80	49	1.09	0.87	-20	0.004	20 to 29
11		12	301	80	52	1.09	0.76	-30	0.006	Exceeded RSL
12		12	334	80	52	1.09	0.83	-24	0.005	10 to 19
13		12	350	80	45	1.09	0.90	-17	0.004	30 to 39
14		12	316	80	45	1.09	0.82	-25	0.006	Exceeded RSL
15		12	351	80	45	1.09	0.81	-26	0.006	Exceeded RSL

Segment #	Street Name	Pipe Diameter	Segment Length	Measured Pressure	Pipe Age	Nominal Thickness	Measured Thickness	% Loss	Loss Rate	RSL
			ft	psi	yr	in	in		in/yr	yrs
16		8	153	80	51	0.76	0.57	-25	0.004	10 to 19
17		8	568	80	51	0.76	0.63	-17	0.003	40 to 49
18		8	313	80	51	0.76	0.66	-13	0.002	50+
19		8	281	80	51	0.76	0.51	-33	0.005	Exceeded RSL
20		8	277	80	51	0.76	0.65	-14	0.002	50+
21		8	292	80	51	0.76	0.63	-17	0.003	40 to 49
22		8	217	80	46	0.76	0.47	-38	0.006	Exceeded RSL
23		8	503	80	54	0.76	0.70	-8	0.001	50+
24		8	320	80	54	0.76	0.48	-37	0.005	Exceeded RSL
25		8	295	80	54	0.76	0.66	-13	0.002	50+
26		8	391	80	54	0.76	0.68	-11	0.001	50+
27		8	514	80	47	0.76	0.69	-9	0.001	50+
28		8	559	80	54	0.76	0.66	-13	0.002	50+
29		8	487	80	54	0.76	0.60	-21	0.003	Exceeded RSL
30		8	256	80	56	0.76	0.60	-21	0.003	Exceeded RSL
31		8	356	80	56	0.76	0.50	-34	0.005	Exceeded RSL
32		8	365	80	56	0.76	0.48	-37	0.005	Exceeded RSL
33		8	384	80	56	0.76	0.52	-32	0.004	Exceeded RSL
34		8	312	80	56	0.76	0.69	-9	0.001	50+
35		8	264	80	50	0.76	0.70	-8	0.001	50+
36		8	534	80	54	0.76	0.48	-37	0.005	Exceeded RSL
37		8	182	80	54	0.76	NR[1]	NR[1]	NR[1]	NR[1]
38		8	194	80	54	0.76	NR[1]	NR[1]	NR[1]	NR[1]

Segment #	Street Name	Pipe Diameter	Segment Length	Measured Pressure	Pipe Age	Nominal Thickness	Measured Thickness	% Loss	Loss Rate	RSL
			ft	psi	yr	in	in		in/yr	yrs
39		8	576	80	54	0.76	0.61	-20	0.003	30 to 39
40		8	244	80	54	0.76	0.50	-34	0.005	Exceeded RSL
41		8	360	80	54	0.76	0.65	-14	0.002	50+
42		8	596	80	54	0.76	0.60	-21	0.003	20 to 29
43		8	675	80	55	0.76	0.60	-21	0.003	30 to 39
44		8	384	80	55	0.76	0.61	-20	0.003	40 to 49
45		8	517	80	55	0.76	0.64	-16	0.002	50+
46		8	511	80	55	0.76	0.77	0	0.000	50+
47		8	552	75	50	0.76	0.69	-9	0.001	50+
48		8	278	75	50	0.76	0.64	-16	0.002	50+
49		8	512	75	50	0.76	0.63	-17	0.003	40 to 49
50		12	501	75	50	1.09	0.93	-15	0.003	50+
51		8	600	75	50	0.76	0.70	-8	0.001	50+
52		8	467	85	54	0.76	0.70	-8	0.001	20 to 29
53		8	471	85	53	0.76	0.49	-36	0.005	Exceeded RSL
54		16	411	85	50	1.36	1.07	-21	0.006	Exceeded RSL
55		16	281	85	50	1.36	1.07	-21	0.006	1 to 9
56		12	359	80	49	1.09	0.81	-26	0.006	10 to 19
57		12	299	80	45	1.09	0.82	-25	0.006	1 to 9
58		8	437	80	51	0.76	0.57	-25	0.004	10 to 19
59		8	393	80	54	0.76	0.61	-20	0.003	40 to 49
60		8	205	80	46	0.76	0.69	-9	0.002	20 to 29
61		8	762	80	54	0.76	0.65	-14	0.002	50+
62		8	355	80	47	0.76	0.63	-17	0.003	40 to 49

Segment #	Street Name	Pipe Diameter	Segment Length	Measured Pressure	Pipe Age	Nominal Thickness	Measured Thickness	% Loss	Loss Rate	RSL
			ft	psi	yr	in	in		in/yr	yrs
63		8	216	80	47	0.76	0.24	-68	0.011	Exceeded RSL
64		8	375	80	47	0.76	NR[1]	NR[1]	NR[1]	NR[1]
65		8	571	80	54	0.76	0.59	-22	0.003	30 to 39
66		8	450	80	54	0.76	0.65	-14	0.002	50+
67		8	413	80	54	0.76	0.36	-53	0.007	Exceeded RSL
68		8	648	75	54	0.76	0.64	-16	0.002	Exceeded RSL
69		12	201	75	48	1.09	0.85	-22	0.005	Exceeded RSL
70		8	276	75	48	0.76	0.65	-14	0.002	50+
71		8	426	75	48	0.76	0.54	-29	0.005	1 to 9
72		8	494	71	48	0.76	0.61	-20	0.003	30 to 39
73		8	533	71	48	0.76	0.69	-9	0.001	50+
74		8	419	71	48	0.76	0.58	-24	0.004	Exceeded RSL
75		8	529	71	30	0.76	0.61	-20	0.005	Exceeded RSL
76		8	499	71	30	0.76	0.56	-26	0.007	1 to 9
77		8	259	71	30	0.76	0.70	-8	0.002	20 to 29
78		8	374	71	30	0.76	0.60	-21	0.005	10 to 19
79		8	549	71	30	0.76	0.66	-13	0.003	50+
80		8	493	71	30	0.76	0.63	-17	0.004	40 to 49
81		8	511	71	30	0.76	0.60	-21	0.005	20 to 29
82		8	388	71	30	0.76	0.58	-24	0.006	Exceeded RSL
83		8	209	71	46	0.76	0.50	-34	0.006	Exceeded RSL
84		8	260	71	46	0.76	0.62	-18	0.003	Exceeded RSL
85		8	324	71	46	0.76	0.56	-26	0.004	Exceeded RSL

Segment #	Street Name	Pipe Diameter	Segment Length	Measured Pressure	Pipe Age	Nominal Thickness	Measured Thickness	% Loss	Loss Rate	RSL
			ft	psi	yr	in	in		in/yr	yrs
86		8	303	71	46	0.76	0.66	-13	0.002	1 to 9
87		8	214	71	46	0.76	0.58	-24	0.004	10 to 19
88		6	513	71	46	0.66	0.52	-21	0.003	40 to 49
89		6	230	71	46	0.66	0.49	-26	0.004	30 to 39
90		6	296	71	46	0.66	0.45	-32	0.005	10 to 19
91		6	306	71	46	0.76	0.64	-16	0.003	50+
92		8	461	71	46	0.76	0.63	-17	0.003	Exceeded RSL
93		8	471	71	46	0.76	0.61	-20	0.003	Exceeded RSL
94		8	378	68	46	0.76	0.60	-21	0.003	Exceeded RSL
95		8	375	68	46	0.76	0.54	-29	0.005	Exceeded RSL
96		8	393	68	46	0.76	0.66	-13	0.002	50+
97		8	406	68	55	0.76	0.54	-29	0.004	10 to 19
98		8	564	68	56	0.66	0.49	-26	0.003	Exceeded RSL
99		6	332	68	56	0.66	0.50	-24	0.003	40 to 49
100		6	365	68	56	0.66	0.48	-27	0.003	30 to 39
101		6	340	68	56	0.66	0.47	-29	0.003	20 to 29
102		6	539	68	56	0.66	0.55	-17	0.002	50+
103		6	531	68	56	0.66	0.44	-33	0.004	10 to 19
104		8	411	68	56	0.76	0.61	-20	0.003	30 to 39
105		8	216	68	56	0.76	0.70	-8	0.001	50+
106		8	525	70	56	0.76	0.59	-22	0.003	Exceeded RSL

Segment #	Street Name	Pipe Diameter	Segment Length	Measured Pressure	Pipe Age	Nominal Thickness	Measured Thickness	% Loss	Loss Rate	RSL
			ft	psi	yr	in	in		in/yr	yrs
107		8	610	70	56	0.76	0.59	-22	0.003	Exceeded RSL
108		8	287	70	56	0.76	0.71	-7	0.001	50+
109		8	550	70	56	0.76	0.64	-16	0.002	Exceeded RSL
110		8	498	70	56	0.76	0.65	-14	0.002	1 to 9
111		8	398	70	56	0.76	0.67	-12	0.002	10 to 19
112		8	405	70	55	0.76	0.59	-22	0.003	50+
113		8	355	70	55	0.76	0.63	-17	0.002	Exceeded RSL
114		8	316	70	55	0.76	0.63	-17	0.002	Exceeded RSL
115		8	326	70	47	0.76	0.58	-24	0.004	Exceeded RSL
116		8	314	70	47	0.76	0.67	-12	0.002	10 to 19
117		8	255	70	47	0.76	0.63	-17	0.003	Exceeded RSL
118		8	227	70	47	0.76	0.67	-12	0.002	10 to 19
119		8	225	71	56	0.76	0.68	-11	0.001	20 to 29
120		8	444	71	56	0.76	0.65	-14	0.002	20 to 29
121		8	385	71	56	0.76	0.61	-20	0.003	Exceeded RSL
122		8	307	71	56	0.76	0.67	-12	0.002	50+
123		6	151	60	42	0.66	0.47	-29	0.005	20 to 29
124		8	369	60	42	0.76	0.72	-5	0.001	50+
125		8	419	60	42	0.76	0.61	-20	0.004	30 to 39
126		8	379	60	42	0.76	0.66	-13	0.002	50+
127		8	314	65	53	0.76	0.61	-20	0.003	40 to 49
128		8	366	65	53	0.76	0.54	-29	0.004	10 to 19
129		8	560	65	53	0.76	0.68	-11	0.002	50+

Segment #	Street Name	Pipe Diameter	Segment Length	Measured Pressure	Pipe Age	Nominal Thickness	Measured Thickness	% Loss	Loss Rate	RSL
			ft	psi	yr	in	in		in/yr	yrs
130		8	585	65	53	0.76	0.65	-14	0.002	50+
131		8	232	70	47	0.76	0.65	-14	0.002	50+
132		8	324	70	47	0.76	0.57	-25	0.004	10 to 19
133		8	447	70	47	0.76	0.31	-59	0.010	Exceeded RSL
134		8	356	65	47	0.76	0.34	-55	0.009	Exceeded RSL
135		8	452	65	47	0.76	0.37	-51	0.008	Exceeded RSL
136		8	424	65	47	0.76	0.66	-13	0.002	50+

Note: 1. A result was unattainable due to poor acoustic wave propagation. Echologics suspects the presence of PVC repairs within this segment.

A 2.1 Asbestos Cement EchoLife® Assumptions

In addition to the pipe specification assumptions mentioned in section 1, the EchoLife® calculations also incorporate water pressure and external loading conditions. External load is calculated using the Marston equation plus H-20 traffic load with a safety factor of 2. To account for water pressure, Echologics recorded operating pressure values using fire hydrants at ePulse® test sites. The measured pressure plus a surge pressure of 50 psi with a safety factor of 2.5 is used for the above EchoLife® calculations. A detailed table of assumptions can be found below in Table A.2-1.

Table A.2-1: Echolife® AC Assumptions

Pipe Information	Estimate or Assumption	Source
Soil Density	120 lbs/ft^3 (conservative)	Construction Guide for Soils & Foundations. Richard G. Ahlvin, Vernon Allen Smoots. Page 76, Section 12.3: Dry Density
Bedding Type	Class C: Granular - lightly compacted bedding (conservative). Load Factor = 1.5	Annual Book of ASTM Standards 2003. Section 4: Construction. Author: American Society for Testing & Materials. Page 8
Pipe Depth	Between 1 feet to 6 feet	Measured on site
Surge Pressure	50 psi	Assumed based on Echologics' experience
Safety Factor on Pressure	2	Pumping Station Design: Revised 3rd Edition. Garr M. Jones, Robert L. Banks. Section 4-6, Asbestos Cement Pipes; Available Sizes & Thicknesses. Page 4.24
Safety Factor on External load	2.5	Buried Pipe Design Third Edition. A. P. Moser & Steven Folkman. Table 5.3, Page 252
Rupture modulus of AC	5000-6000 psi. 5000 psi is most conservative and has been used	Buried Pipe Design Third Edition. A. P. Moser & Steven Folkman. Table 5.1, Page 248
Tensile strength of AC	3000-4000 psi. 3000 psi is most conservative and has been used	Buried Pipe Design Third Edition. A. P. Moser & Steven Folkman. Table 5.1, Page 248

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. In effect, there is no indication of a noise source of any sort, and therefore 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 City 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 mean minimum hoop thickness (for asbestos cement or metallic mains) or mean hoop 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 color-coding and descriptions in Table B.2-1: Color Coding and Hoop Thickness Loss Qualitative Descriptions are used for the results presented in all ePulse® condition assessment reports.

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

Change in Hoop Thickness	Description	Color Code	Description	
			Asbestos Cement Mains	Metallic 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.
10% to 30%	Moderate	Yellow	Considerable levels degradation and loss of structural thickness. Moderate levels of cement leeched away from asbestos matrix.	Considerable levels of uniform surface or internal corrosion and/or localized areas of pitting corrosion.
Greater than 30%	Poor	Red	Significant degradation and loss of structural thickness. Substantial levels of cement leeched away from asbestos matrix.	Significant uniform corrosion and/or numerous areas of localized pitting corrosion.

These descriptions are based on Echologics' experience and with validation of results through the exhumation of pipe samples surveyed. 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 condition within a segment between two sensor attachment points. Pipe 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 mean minimum hoop 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. The pipe is least able to resist this axi-symmetric expansion at the locations where the hoop thickness is at a minimum. Material properties are then used to calculate the hoop thickness which would provide exactly this stiffness. This is referred to as the mean minimum hoop 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 physical thickness, but will lose structural (or effective) 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 hoop thickness (also known as the effective hoop thickness), as illustrated in Figure B.2-1, rather than the actual physical hoop thickness (which will generally remain at the nominal hoop thickness).

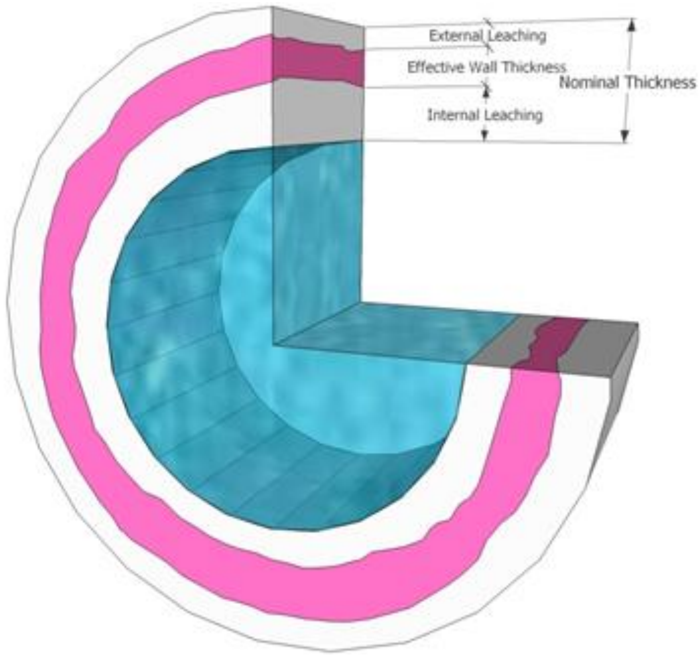


Figure B.2-1: Structural Hoop Thickness in Asbestos Cement Pipe

Condition Interpretation in Metallic Mains

Corrosion can occur in metallic pipes either in a localized area or in a generalized manner along the main. Examples of various levels of corrosion are presented in Figure B.2-5 below.

Most of the degradation is often caused by a combination of internal corrosion, soil aggressiveness and coating defects on the surface of the main. If no coating was present upon installation, then the degradation would be due to soil aggressiveness alone.

For cement mortar lined pipes, areas with higher losses may indicate the lining has been degraded to the point that the water column is now in contact with the metal, locally accelerating the degradation rate. This may also suggest that the soil loading conditions were such that the pipe experienced an over-deflection during its lifetime, causing damage to the interior lining.

When considering the water aggressiveness as a mechanism for corrosion, it can be assumed that the degradation is relatively uniform across the length of the main. If pipes are unlined (bare), internal degradation may be attributed to a combination of localized pitting, and the formation of tuberculation that can also be accompanied by the formation graphitic corrosion (leaching of iron from the metal matrix).

Localized corrosion is most likely due to isolated mechanisms such as direct current corrosion, or localized aggressive soil conditions. For cement lined pipes, areas with higher losses may indicate the lining has been degraded to the point that the water column is now in contact with the metal, locally accelerating the degradation rate.

6” CI pipe with 4.2% measured loss

6” CI pipe with 47% measured loss

6” CI pipe with 10% measured loss

18” CI pipe with 18.5% measured loss

Figure B.2-2: Examples of Different Levels of Corrosion in Metallic Pipe

Validation

As of the February 2016, a total of 104 ePulse® validation results have been provided to Echologics by our clients or third parties. Some clients have requested confidentiality, however we are able to present the result in aggregate.

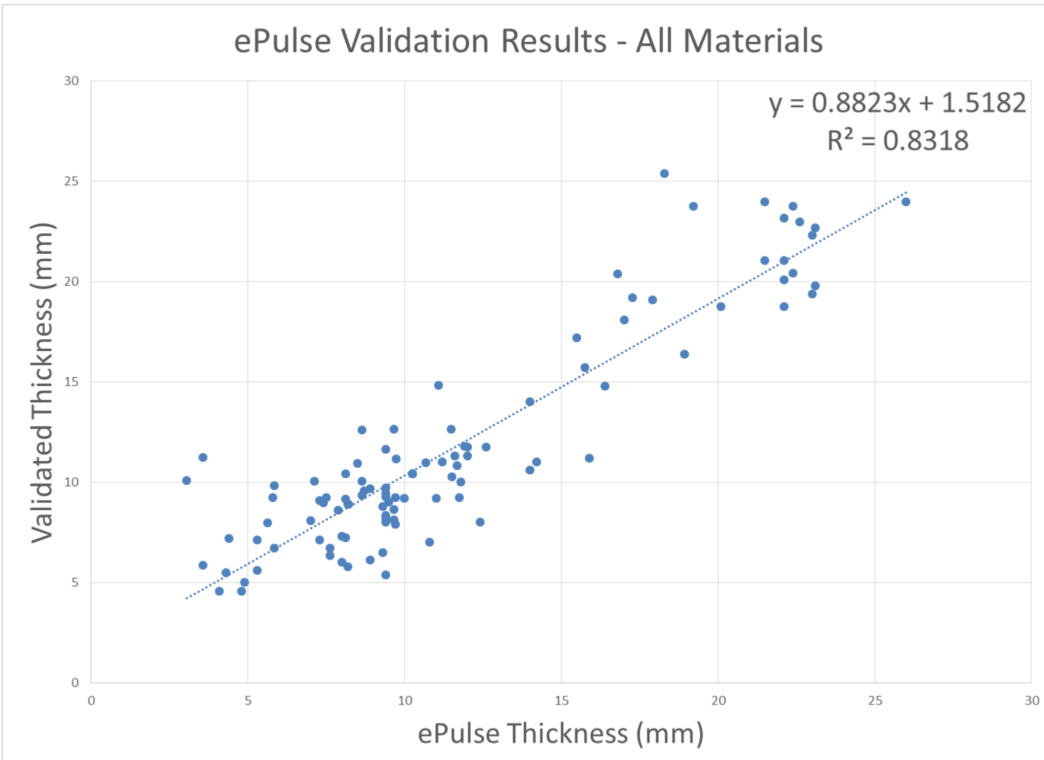


Figure B.2-3: ePulse® Validations On All Materials

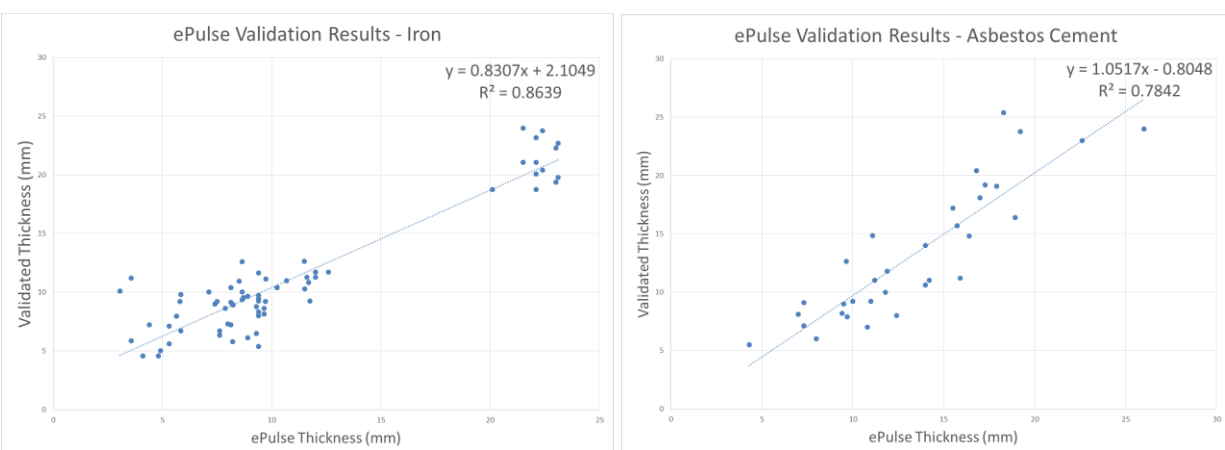


Figure B.2-4: ePulse® Validations On All Iron Pipes (left) and Asbestos Cement Pipes (right)

Two factors are worth attention in the charts.

The R^2 value is known as the coefficient of determination. This provides a measure of how well validation results are predicted by ePulse® results. It is the proportion of total variation of outcomes in validation results explained by the ePulse® results. An R^2 of 1 indicates that the data match perfectly, while an R^2 of 0 indicates that the ePulse® results cannot be used to predict the validated results at all. For non-destructive testing methods, an R^2 value above 0.5 represents strong predictive power.

The correlation coefficient R is the square root of the R^2 value. For example, an R^2 value of 0.5 means the same thing as a correlation of 0.71.

The equation ($y = \alpha + \beta x$) indicates how well calibrated the ePulse® measurements are, on average. Values of α close to zero, and of β close to 1, indicate good calibration. For non-destructive testing methods, a β greater than 0.5 and an α less than 25% of the average value represent good calibration.

Note that the variation between the ePulse® results and validation measurements is not the same thing as the error in the ePulse® results. It is actually the combination of the error in the ePulse® results **and** the random variation in point samples versus the true average.

Comparing ePulse® results to the results of validations will over-estimate the actual error in the ePulse® results. The reason for this is that the ePulse® results are averages over segments of about 100 m (300 ft) in length, whereas the validation results indicate the thickness at a one point or a small sub-segment. Each validation measurement will have a random error versus the true average over that segment. The difference between an ePulse measurement and a validation measurement can be understood as:

$$ePulse^{®} - Validated = (ePulse^{®} – True\_Average) + (True\_Average – Validated)$$

Even if the ePulse® results perfectly match the true average (ePulse® – True_Average = 0), we would still expect to see a difference between validation results and ePulse®:

$$ePulse^{®} - Validated = (True\_Average – Validated)$$

Actual pipe conditions will vary randomly along the sample, so the difference between the true average and validation results should be a normal distribution centered around zero. If ePulse® is effectively measuring the true average, we should see the same pattern in the difference between the ePulse® and Validated results. The actual distribution is shown in Figure 3, and appears to match the expected pattern.

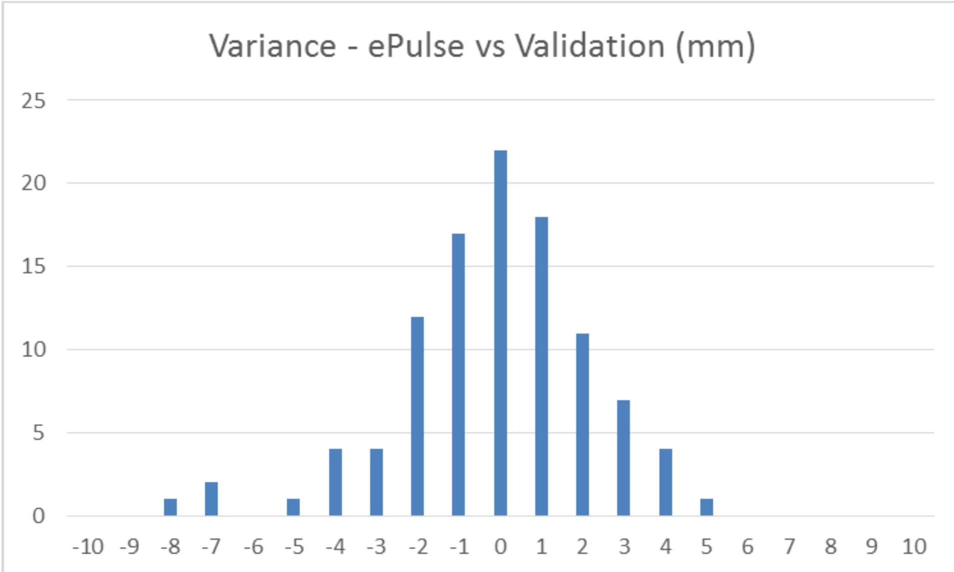


Figure B.2-5: Variance between ePulse® results and validation results

There are a small number of outliers, which likely represent errors in those ePulse® measurements. The remainder of the data match the expected normal distribution.

B.3 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 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 hoop 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 among 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 hoop thickness. However, the same repair made with PVC pipe would produce an error of -41% in measured hoop 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 C Detailed Methodology

C.1 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 sensors to determine the position of the leak. The following procedure was used to conduct the leak detection survey:

5. For each location surveyed, the distance between the sensors was measured.
6. Sensors were mounted either directly on the pipe or were connected to the water column with hydrophones.
7. 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.

C.2 ePulse® Mean Minimum Hoop 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 segment 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 an ePulse® data collection survey:

8. A leak detection survey is performed on the length of pipe to check for the presence of existing leaks. (Described in previous section)
9. 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.
10. 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 C.2-1: 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_0 : 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 material

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 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.

C.3 EchoLife® Detailed Methodology

C.3.1 Asbestos Cement Detailed EchoLife® Methodology

The EchoLife® method uses our patented ePulse® acoustic measurements of the mean minimum hoop thickness to calculate the segment's remaining service life.

All remaining service life calculations take safety factors into consideration as detailed in Table C.3-1: Asbestos Cement EchoLife® Assumptions below. Therefore, segments showing 0 year RSL may not necessarily have imminent failure.

After the ePulse® remaining thickness is measured, the remaining life of the pipe can be estimated using the Schlick Failure Criterion (Combined Loading):

$$\left(\frac{P}{P_c}\right) + \left(\frac{W}{W_c}\right)^2 > 1$$

Equation C.3-1: Combined loading

Where P is the design pressure, P_c is the critical failure pressure in the absence of external loading, W is the external load, and W_c is the critical failure load in the absence of internal pressure.

The critical pressure and critical load can be written in terms of the remaining hoop thickness as:

$$\sigma_h = \frac{P_c \cdot D_i}{2 \cdot t_c}$$

Equation C.3-2: Hoop Stress

$$\sigma_R = 0.0795 \frac{Fm \cdot W_c \cdot (D_i + t_c)}{t_c^2}$$

Equation C.3-3: Three-Edge Bearing Load to cause Failure

Where F_m is the soil bedding factor and t_c is the critical failure thickness.
The critical thickness occurs when the pipe can no longer withstand the loading conditions. The critical thickness of the pipe is estimated using Equation C.3-2: Hoop Stress and Equation C.3-3: Three-Edge Bearing Load to cause Failure. The loss rate is estimated linearly using the

installation date of the pipe and the measured residual thickness. The loss rate is then used to determine the remaining life of the pipe.

The operating pressure, design thickness, diameter, pipe depth of cover, bedding and soil conditions are required to determine the critical thickness. Assumptions were made for information that is unattainable or unknown. All assumptions are conservative and listed in C.3-1 below.

Table C.3-1: Asbestos Cement EchoLife® Assumptions

Pipe Information	Estimate or Assumption	Source
Soil Density	120 lbs/ft^3 (conservative)	Construction Guide for Soils & Foundations. Richard G. Ahlvin, Vernon Allen Smoots. Page 76, Section 12.3: Dry Density
Bedding Type	Class C: Granular - lightly compacted bedding (conservative). Load Factor = 1.5	Annual Book of ASTM Standards 2003. Section 4: Construction. Author: American Society for Testing & Materials. Page 8
Pipe Depth	1 feet to 6 feet	Measured on site
Surge Pressure	50 psi	Assumed based on Echologics' experience
Safety Factor on Pressure	2.5	Pumping Station Design: Revised 3rd Edition. Garr M. Jones, Robert L. Banks. Section 4-6, Asbestos Cement Pipes; Available Sizes & Thicknesses. Page 4.24
Safety Factor on External load	2	Buried Pipe Design Third Edition. A. P. Moser & Steven Folkman. Table 5.3, Page 252
Rupture modulus of AC	5000-6000 psi. 5000 psi is most conservative and has been used	Buried Pipe Design Third Edition. A. P. Moser & Steven Folkman. Table 5.1, Page 248
Tensile strength of AC	3000-4000 psi. 3000 psi is most conservative and has been used	Buried Pipe Design Third Edition. A. P. Moser & Steven Folkman. Table 5.1, Page 248

Appendix D Abbreviations

AC	Asbestos Cement: Pipe wall construction consisting of asbestos cement.
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.
GIS	Geographic Information System: A system designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data.
GPS	Global Positioning System: a global system of satellites used to provide precise positional data and global time synchronization.
IB	In-Bracket. Please refer to the technical glossary.
MLCS	Mortar Lined and Coated Steel Pipe
OOB	Out-of-Bracket. Please refer to the technical glossary.
POI	Point of Interest. Please refer to the technical glossary.

Appendix E Glossary of Technical Terms

Acoustic Wave Speed	Also known as: wave speed, wave velocity, velocity. The speed at which a coupled-mode pressure wave travels along a pipe.
Blue/White Station	A piece of equipment where a sensor is connected to transmit the data to a central location. Typically stations are colour coded blue or white.
Coherence	Measure of similar vibration frequency between two channels (Blue and White stations or a node pair).
Correlation	The process of comparing two acoustic signals for similarity in the time domain. Echologics technologies use correlation to judge the time delay between two signals. This allows for determination of the location of leaks along a pipeline.
In-Bracket	A noise source that is within the span of pipe between two Stations or Nodes.
Leak Discovered	A point along a pipe that is likely loosing water to the surrounding soil and environment. For a leak to be classified as discovered, a field technician must acquire at least three pieces of unique evidence that suggest existence and location.
No Leak Discovered	No evidence of leakage was discovered or a POI was under investigate and it was determined that it was not a leak.
Node	A piece of equipment where a sensor is connected to transmit the data to a central location. Typically nodes are paired with other nodes as part of a large array installed on a pipeline or in an area.
Out-of-Bracket	A noise source that is outside the span of pipe between two Stations or Nodes.
Point of Interest	Evidence of some form of noise or energy on the pipe. There is not enough evidence to classify a point of interest as a leak.
Segment	A section of pipe surveyed in one measurement. The length of the segment is the distance between two sensors.
Sensor	A device used to measure physical or chemical properties of a system. In the context of this report this term will be typically used as a reference to a vibration sensor.
Site	A neighborhood or area within which a segment of pipe exists.