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June 26, 2014 RVA 142934

City of London
Environmental and Engineering Service
300 Dufferin Avenue, 8th Flr.
London, ON N6A 4L9

Attention: Matt Feldberg
Water Demand Manager

Dear Mr. Feldberg:

Re: City of London Trunk Water Main Management Plan

We are pleased to submit our final report for the City of London Trunk Water Main Management Plan.

The City recognizes the need to apply a proactive approach to manage its trunk water mains. The accompanying report provides a strategy to manage the risks associated with the trunk water mains. The focus of the strategy is related to conducting condition assessments of the trunk water mains to better understand their probability of failure, plan for their renewal, and establish baseline conditions for comparison to future assessments.

The report also provides a strategy to mitigate the consequences associated with the failure of trunk water mains, including developing Standard Operating Procedures to isolate sections in the event of a failure and eliminating service connections from trunk water mains.

We appreciate the opportunity to assist the City with this strategic undertaking. Please contact the undersigned should you have any questions.

Yours very truly,

R.V. ANDERSON ASSOCIATES LIMITED

Nick Larson, MEPP, P.Eng.
Project Manager

Encls.

CITY OF LONDON

TRUNK WATER MAIN MANAGEMENT PLAN

FINAL REPORT

Prepared for:

City of London

R.V. Anderson Associates Limited
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EXECUTIVE SUMMARY

The City of London has embarked on a multi-year study to develop and implement a plan to improve the management of their trunk water mains. Initiating an ongoing assessment program to inspect all of the trunk water mains on a routine basis is an essential element of the plan. The assessments will be used to:

- Identify the preferred renewal strategy for the water main, such as full/partial replacement or rehabilitation and a timeline for renewal.
- Provide additional information that can be used to refine the probability of failure of the water mains based on the current condition observed through the inspections.
- Establish a baseline for comparison purposes with future inspections so that the deterioration rate for each section can be estimated over time.

The assessment program has been designed to inspect every trunk water main in the City over a period of 20 years. The City owns approximately 200 km of trunk water mains, and therefore approximately 10 km should be inspected every year. The annual cost of the proposed assessment program is estimated to be $750,000 to $1,000,000, excluding costs associated with constructing new chambers or internal City costs.

This report provides a more in-depth 5-year trunk water main assessment program that will result in the inspection of approximately 50 km of trunk water mains. The trunk water mains that are on the first 5 years of the assessment program are in two general categories:

1. Old trunk water mains that have exceeded their expected useful life but have not exhibited any signs of a decrease in the service that they are providing. The assessments of these sections will be used to identify if there is the opportunity to defer the replacement of some portions of the water main based on their current condition.
2. The most critical trunk water mains in the City with the highest consequence of failure. The assessments of these sections will support a proactive approach to risk management of the trunk water mains.

This report also provides recommendations that the City can consider to mitigate the consequences associated with the failure of a trunk water main, such as developing standard operating procedures to isolate sections in the event of a failure and eliminating service connections from trunk water mains.

CITY OF LONDON

TRUNK WATER MAIN MANAGEMENT PLAN

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1.0 INTRODUCTION

The City of London has embarked on a multi-year study to develop and implement a plan to improve the management of their trunk water mains with the goal of minimizing risks. To date, the City has completed a risk assessment for each section of trunk water main. This assessment includes a review of the potential costs arising from their failure, as well as the intervention costs to reduce the risk of their failure.

The next stage of the trunk water main management plan is to complete inspections to collect better information on the current condition of the water mains. The results of the inspections will accomplish the following:

- Identify the preferred renewal strategy for the water mains, such as full/partial replacement or rehabilitation and a timeline for renewal.
- Provide additional information that can be used to refine the probability of failure of the water mains based on the current condition observed through the inspections.
- Establish a baseline for comparison purposes with future inspections so that the deterioration rate for each section can be estimated over time.

To this end, this report will answer three important questions:

1. Which pipelines are the best candidates for inspection?
2. What pipelines should be inspected first?
3. What is an appropriate technology for inspecting each pipeline according to its size and material?

The answers to the questions listed above will be used to develop a 5-year pipeline inspection program that will list the pipelines to inspect each year and the recommended inspection technology that should be used. The inspection program will also review the preparatory work that may be required to inspect some pipelines, such as:

- Coordinating with Operations to take specific facilities (i.e. reservoirs, pumping stations) out of service;
- Coordinating with Operations to isolate a section of a trunk water main;
- Inspection equipment tethering and/or retrieval issues; and
- Installing chambers with vertically oriented gate valves to facilitate the launch of inspection equipment.

2.0 TRUNK WATER MAIN INVENTORY

2.1 Overview of Inventory

The City of London has approximately 205 km of trunk water mains that have a diameter of 450 mm and larger (refer to Table 1 and Figure 1). The trunk water mains range in size from 450 mm diameter to 1,350 mm diameter although two-thirds of the total length of the trunk water mains is in the 450 mm to 600 mm diameter range. It is also apparent from Table 1 that approximately 61% of the trunk water mains are made of concrete pressure pipe.

Table 1 – Trunk Water Main Length by Diameter and Pipe Material

	Length (m)								
Dia. (mm)	**Cast Iron**	**Concrete**	**Ductile Iron**	**PVC**	**Steel**	**Transite**	**Unknown**	**Total**	**% of Total**
450	14,977	4,701	2,822	9,837	172	1,694	4	34,208	16.7%
500	-	2	-	-	-	-	-	2	0.0%
600	-	41,796	63	24,034	17,713	-	-	83,606	40.8%
750	-	7,606	-		21	-	-	7,627	3.7%
900	-	33,425	7	2	3,138	-	-	36,571	17.8%
1050	-	20,940	-		6,487	-	-	27,427	13.4%
1200	-	13,688	-	-	-	-	-	13,688	6.7%
1350	-	2,000	-	-	-	-	-	2,000	1.0%
TOTAL	***14,977***	***124,158***	***2,892***	***33,873***	***27,531***	***1,694***	***4***	***205,129***	***100.0%***
% of TOTAL	***7.3%***	***60.5%***	***1.4%***	***16.5%***	***13.4%***	***0.8%***	***0.0%***	***100.0%***	

2.2 Decade of Construction

Table 2 and Figure 2 summarize the lengths of trunk water mains by the decade of construction. The inventory indicates that there were trunk mains installed in every decade from the 1900s to the 2000s. It is apparent from Table 2 that the largest proportions of the trunk water mains were installed in the 1960s and 1990s. The predominate material, prior to 1950, was cast iron and the predominate materials over the past several decades were concrete and steel. It is also apparent from Table 2 that the City started installing PVC trunk water mains in the 1990s.

It should be noted that cast iron mains that were installed in the early part of the 20th century were typically thicker-walled pit cast. The cast iron water mains constructed after 1950 were typically spun cast and have thinner pipe walls. The thinner pipe wall can result in premature failure caused by external corrosion. This combination of factors can result in newer cast iron pipes having a greater probability of failure than older cast iron pipes.

Table 2 – Trunk Water Main Length by Decade of Construction and Pipe Material

	Length (m)								
Decade	Cast Iron	Concrete	Ductile Iron	PVC	Steel	Transite	Unknown	Total	% of Total
1900s	1,031	-	-	-	-	-	-	1,031	0.5%
1910s	3,784	-	-	-	-	-	-	3,784	1.8%
1920s	4	216	-	-	-	-	-	219	0.1%
1930s	5,491	-	-	-	606	-	-	6,098	3.0%
1940s	450	50	-	-	-	-	-	499	0.2%
1950s	10	16,413	-	-	6,701	1,694	-	24,818	12.1%
1960s	4,208	31,599	-	-	10,012	-	4	45,822	22.3%
1970s	-	4,620	2,617		72	-	-	7,309	3.6%
1980s	-	23,247	192		-	-	-	23,439	11.4%
1990s	-	45,766	37	8,490	9,612	-	-	63,905	31.2%
2000s	-	2,247	47	25,383	527	-	-	28,204	13.7%
TOTAL	***14,977***	***124,158***	***2,892***	***33,873***	***27,531***	***1,694***	***4***	***205,129***	***100.0%***
% of TOTAL	***7.3%***	***60.5%***	***1.4%***	***16.5%***	***13.4%***	***0.8%***	***0.0%***	***100.0%***	

2.3 Water Main Break Records

The City provided an inventory containing 36 records for breaks that have occurred since 1976 on the trunk water mains that are still in service (Table 3). No data was collected prior to 1976. On average the City experiences approximately 1.5 breaks per year on the trunk water mains. Although the City experiences an average of 164 breaks per year in their entire water distribution system, the high consequences from the failure of a trunk water main means that any breaks in the trunk water mains should be avoided[1]. For this reason, it is prudent to have a proactive management program to manage the risk of a trunk water main failure.

[1] City of London Water Main Renewal Plan; RVA (2013).

Table 3 – Trunk Water Main Breaks

Year	Number of Breaks
1976	1
1978	1
1980	1
1981	1
1982	2
1983	1
1985	1
1988	1
1989	2
1991	1
1992	3
1994	1
1995	2
1999	2
2000	1
2001	1
2002	1
2003	1
2004	3
2005	1
2007	1
2009	3
2012	2
2013	2
Total	**36**

Table 4 summarizes the breaks according to the pipe material. Of the 36 breaks, 18 have occurred on cast iron water mains. Cast iron represents 7.5% of the total length of trunk water mains in the City, and therefore this failure rate is disproportionately high.

Table 4 – Trunk Water Main Breaks by Material Type

Material	Number of Occurrences	% of Total
Cast Iron	18	50%
Concrete	4	11%
Ductile Iron	5	14%
PVC	1	3%
Steel	8	22%
Total	**36**	**100%**

The City also records the apparent cause of the water main breaks. It is apparent from Table 5 that the most common cause of the breaks is corrosion and deterioration of the pipeline. This analysis supports the need to complete proactive assessments of the condition of the trunk water mains.

Table 5 – Trunk Water Main Breaks by Apparent Cause

Apparent Cause	Number of Occurrences	% of Total
Contractor	3	8%
Corrosion	9	25%
Deterioration	8	22%
Improper Bedding	1	3%
Settlement	1	3%
Water Hammer	2	6%
N/A	12	33%
Total	**36**	**100%**

3.0 INSPECTION TECHNOLOGIES

The past decade has seen substantial growth and development of non-destructive inspection technologies that are available for assessing pipelines. In general, there are two categories of assessment technologies: leak detection and physical condition assessments.

Leaks in the trunk mains increase the amount of non-revenue water in the City and lowers the overall efficiency of operating the water transmission system. Leaks can also cause damage to adjacent property, accelerate the deterioration of the adjacent road structure, and cause negative impacts to the natural environment by introducing chlorinated water into natural water courses. If a leak persists for an extended period of time then the pipe bedding could deteriorate and result in a catastrophic failure.

The condition of the trunk mains impacts:

- The structural resiliency by impacting the probability of failure from an induced stress;
- The hydraulic capacity of the pipeline which reduces transmission efficiency; and
- The aesthetic quality of the water that is supplied by contributing taste, odour/colour issues to the water and other potential water quality problems.

The following sections provide an overview of the inspection technologies that are commercially available for use on trunk water mains in London, separated into those that find leaks and those that provide information on the physical condition of the water main. For each technology, a brief description of the advantages, limitations, and applicable materials is provided. Table 6 provides a high level summary of the technologies that are described.

3.1 Condition Assessment Technologies

3.1.1 Remote Field Eddy Current Technology

Remote field eddy current (RFEC) technology is a form of electromagnetic inspection that uses a low frequency alternating current field to estimate pipe wall thicknesses in ferrous pipelines and to detect wire breaks in the prestressing wire that wraps around prestressed concrete cylinder pipes (PCCP). The current is emitted from one location and detected at a second location, with the pipe wall/prestressing wire acting as a transmission medium for the electrical current. The variations of both the speed that the current field travels through the pipe wall and the changes to the amplitude of the field as it travels through the pipe wall/prestressing wire are used to estimate the remaining wall thickness/surface area of wall loss or to determine if the pre-stressing wire is broken.

3.1.2 Acoustic Pipe Wall Assessment

Acoustic signals can also be used to estimate the average wall thickness of a section of a pipe. Although an estimate of the average wall thickness for a section of water main is useful, it does not provide any information on the variability of the wall thickness (or more specifically the minimum wall thickness) along a section of water main. This technology cannot detect localized weaknesses or defects.

3.1.3 Magnetic Flux Leakage

Magnetic Flux Leakage (MFL) is another form of electromagnetic inspection that uses large magnets to induce a magnetic field around the pipeline. The distortion in the magnetic field is used to evaluate the integrity of the pipe wall. The MFL tool is required to be in close contact with the pipe wall, and therefore is only applicable to clean, unlined cast/ductile iron or steel pipes.

3.1.4 Impact Echo (Sounding)

Impact echo testing quantifies the echo that is produced when a sound is induced by striking the interior surface of a pipeline. Its use in the assessment of trunk water mains is limited to assessing the extent of the delamination of the concrete core of PCCP. This type of testing requires man-entry into the pipeline.

3.1.5 Seismic Pulse Echo

Seismic pulse echo uses the same theory of the impact echo test coupled with an analysis of the velocity of the sound wave to assess the integrity of the concrete core of PCCP. The technology is only applicable for out of service mains that are at least 1,200 mm in diameter because it requires man-entry into the pipeline. The advantage of this test is that it is less expensive than RFEC wire break scans and can provide additional information about the overall structural integrity of the PCCP beyond inferred conclusions that are made based on the number of prestressing wires that are broken.

3.1.6 External Visual Assessments

The exterior wall of trunk mains can be visually assessed if they are exposed. This can provide information on the depth and degree of pitting in cast/ductile iron pipes or the integrity of the concrete coating on PCCP. The obvious limitation to this technique is that it can only be assessed on exposed sections of the pipeline and in these cases the water main would also have to be taken out of service (i.e. depressurized). However, if proper coordination occurs it is possible to collect data in connection with other planned works.

3.1.7 Internal Visual Assessments

The interior of trunk mains can be visually assessed using standard CCTV inspection technologies or by man-entry if the pipeline is 1,200 mm or larger. Visual observations can be effective to assess the interior surface of the pipe, but can only be used to infer the condition of the pipeline. This technique is applicable to pipe material types that exhibit internal signs of failure, such as PCCP that will begin to crack and delaminate as the steel wires break. The best application of an internal visual assessment is to be completed together with an assessment technology such as electromagnetic inspection.

3.1.8 Internal Laser Profiling

The interior of trunk mains can be profiled using a laser that traverses the pipe. This provides information on surface defects, most notably internal pitting caused by corrosion. This process requires a clean pipe interior to produce accurate results. Furthermore, galvanic corrosion is often more prevalent on the exterior of the pipe, and therefore an understanding of the internal corrosion is of limited use.

3.1.9 Discrete Ultrasonic Measurement

Discrete ultrasonic measurement is used to determine the thickness of a pipe wall at a specific location. The technology measures the speed at which an ultrasonic wave passes through an object. The disadvantage of this technology is that it requires physical contact with the pipe wall to be tested, and therefore requires man-entry into the pipeline or for the exterior surface to be exposed.

3.2 Leak Detection

All commercially available leak detection technologies rely on identifying the acoustic signature of an active leak. Echologics has a new technology called *Echo Wave* that uses advanced filters to focus in on the low frequency sounds of the leaks and a hydrophone that is installed so that it is in contact with the water in the main. This technology improves the ability to detect leaks in large diameter mains. The advantage of this technology is that it has only minimal contact with potable water as the hydrophone can be inserted through an existing small tap on the main.

Pure Technologies has both the *Smart Ball* and *Sahara* tools that are used for detecting leaks. The *Smart Ball* is a free swimming tool that travels with the flow of water in a pipeline. The Sahara tool is a tethered tool that is pulled through a water main. Both tools listen for the acoustic signatures of leaks. Recent City experience suggests that using a free swimming tool requires a secure capture plan.

Global Asset Management Engineering also has a leak detection tool for large diameter water mains called the LDS1000™. It is a tethered tool that can be launched through existing pressure fittings greater than 50 mm diameter. The primary advantage of this tool is that it is also equipped with a camera that can be used to perform a visual assessment of the interior surface of the water main.

3.3 Recommended Assessment Technologies by Pipe Material

3.3.1 Pre-stressed Concrete Pressure Pipe

The predominant failure mechanism of PCCP is a burst section caused when the tensile strength of the pipeline is exceeded. The tensile strength decreases when the pre-stressing wires that wrap around the interior cylinder of the pipe fail. The failure of pre-stressing wire is caused when the concrete coating of the pipelines deteriorates and the pre-stressing wire corrodes. A greater number of wire breaks increases the probability of failure of a section of PCCP. Pure Technologies uses the RFEC technology to determine if the pre-stressing wires of

PCCP have failed. The technology is used on a number of platforms for use on a pressurized pipeline, depressurized or partially drained pipelines, or a fully drained pipeline.

An additional consequence of the failure of the prestressing wires is delamination of the interior cement lining from the steel core. When this occurs there is often visual evidence of longitudinal cracks in the cement lining. There is also a change in the sound that is produced when the cement lining is struck with a hammer because there is a gap between the cement lining and the steel core. For these reasons, visual and sounding assessments from inside the pipeline can also provide corroborating evidence that the pre-stressing wires have failed. Pure Technologies would also perform visual and sounding assessments if the assessments are completed in a water main that is 1,200 mm in diameter or larger and has been taken out of service.

NDT Corporation provides seismic pulse echo testing for PCCP. Although not widely used in the Canadian water industry, the technology is more cost effective and provides additional information about the structural integrity of the pipe sections. The difference in this technology is that it measures whether the pipe's concrete core and external prestressing wire are acting as one structural unit. The tool can determine whether there is sufficient stress on the wires to put the concrete core in sufficient compression. As mentioned in Section 3.2, this can be considered a better indicator of the structural stability of a concrete pressure pipe beyond an understanding of the number of wire breaks.

The following recommendations are made for the inspection of PCCP:

- The City should complete electromagnetic inspections to determine the number of prestressed wires that have broken for trunk water mains under 1,200 mm in diameter.
- The City should also complete a visual/sounding assessment of the interior concrete core of the pipeline for trunk water mains 1,200 mm in diameter or greater.
- The City should complete a pilot project to conduct seismic pulse echo testing of a section of trunk water main that is 1,200 mm in diameter or greater.

3.3.2 Cast Iron, Ductile Iron and Steel Pipe

Cast iron, ductile iron and steel turn to graphite when they corrode. This process is referred to as galvanic corrosion. Water mains that are severely corroded may still be able to withstand normal operating pressure despite the reduction in pipe wall thickness. For this reason, the failure of ferrous water mains is more often attributed to circumferential breaks caused by external loads as opposed to “through holes” caused by corrosion. It should be noted that galvanic corrosion is more prevalent on the exterior of water mains, and therefore it is difficult to assess in buried water mains. It should be noted that large diameter cast iron and ductile iron water mains also have thicker walls than small diameter water mains. This increases the time that it takes for the corrosion to cause a through hole in large diameter mains.

The external loads that cause the failure of ferrous water mains are typically attributed to two factors:

- Movements in the surrounding soil structure caused by frost action.
- Degradation of the pipe bedding caused by a leak in the pipeline.

PICA Corporation uses the RFEC technology to measure pipe wall thickness and corrosion defects in any ferrous material. The measurement is done by traversing a tool through the interior of a water main. Their application of the RFEC technology results in high resolution information on the remaining wall thickness of a water main. The analysis will specify the average remaining wall thickness for each pipe section, the minimum remaining wall thickness in the pipe section, and the specific location of the minimum thickness reading (distance along the section and clock reading) to a resolution of approximately 15 to 25 mm.

The primary disadvantage of PICA’s application of the RFEC technology is that the pipe does have to be swabbed to remove tubercles prior to the inspection to ensure proper travel of the tool. This process could impact water supply to the customers serviced from the section of pipe that is being tested. In addition, PICA’s inspection tool cannot traverse through a butterfly valve.

PURE Technologies also uses the RFEC technology to measure pipe wall thickness and corrosion defects in ductile iron or steel pipelines. Their application of the RFEC technology results in medium resolution information on the remaining wall thickness of a water main. The analysis will specify the average remaining wall thickness for each pipe section, the minimum remaining wall thickness in the pipe section, and the specific location of the minimum thickness reading (distance along the section and clock reading) to a resolution of approximately 250 mm. The primary disadvantage of the application of this technology on ferrous pipelines is that resolution is not high enough to detect individual pits or through-holes.

As described in Section 3.1, Echologics uses acoustics to determine the average remaining wall thickness of a water main. However, the technology is limited to providing the average wall thickness on a segment of water main that is between two appurtenances (i.e. between two valves). This limits the usefulness of the information for making renewal decisions for a specific section of trunk water main because the corrosion of ferrous water mains can often be localized based on specific soil and groundwater conditions.

The following recommendations are made for the inspection of ferrous trunk water mains:

- The City should complete a pilot project to conduct high resolution wall thickness assessments of a section of cast iron, ductile iron or steel trunk water main.
- The City should complete medium resolution wall thickness assessments of sections of ductile iron or steel trunk water mains that are adjacent to PCCP that will also be subjected to RFEC inspections to determine the number of wire breaks that have occurred.
- The City should review the results of both the high resolution and medium resolution pipe wall thickness tests and determine if there is a net benefit to the use of either technology. The determination of net benefit should be based on the cost of each technology and whether the increased resolution of information provides more confidence to determine if a pipe should be replaced.

3.3.3 PVC Pipe

The City has approximately 34 km of PVC trunk water mains. There are no current commercialized technologies to test the structural integrity of PVC water mains. The City should keep abreast of the latest developments in the non-destructive testing industry and look for opportunities to pilot a technology that may provide information on the structural integrity of PVC water mains.

Table 6 – Summary of Trunk Water Main Technologies for Assessing Structural Integrity of Pipelines

Technology	Applicable Pipe Materials	Pipe Size Range	Man Entry Required	Exposed Exterior Required	Pipeline to be Drained	Type of Condition Information Collected	Comments
RFEC	PCCP, DI, CI, Steel	>= 450 mm diameter	No	No	No	DI/CI/Steel – pipe wall thickness (resolution varies by specific application of technology) PCCP – prestressed wire breaks	RFEC can also be applied to external surface of pipeline
Acoustic	DI, CI, Steel	Any	No	No	No	Average pipe wall thickness	
MFL	Steel	>= 200 mm diameter	No	No	No	Wall integrity	Requires close contact with interior surface of pipe
Sounding	PCCP	>=1,200 mm diameter	Yes	No	Yes	Delamination of internal concrete core	
Seismic Pulse Echo	PCCP	>=1,200 mm diameter	Yes	No	Yes	Integrity of internal concrete core	
External Visual Assessment	Any	Any	No	Yes	No	PCCP - Deterioration of external mortar coating DI/CI/Steel – Extent of external corrosion/pitting	
Internal Visual	Any	Any	No	No	No	PCCP – Deterioration of internal concrete core DI/CI/Steel – Extent of internal corrosion/pitting	Use of CCTV robot required to prevent man entry and draining of pipeline
Internal Laser Profiling	Any	Any	No	No	Yes	Internal defects, most notably internal corrosion/pitting	Requires the internal surface to be cleaned to provide accurate results
Discrete Ultrasonic Measurements	DI, CI, Steel	Any	Yes	Yes	Yes	Thickness of pipe wall at specific locations	Requires direct contact with pipe wall

4.0 INSPECTION PROGRAM

4.1 Past Inspection Experience

Over the past 8 years the City has conducted structural assessments (i.e. electromagnetic inspections) of approximately 10 km of trunk water mains and leak detection on a further 19 km of trunk mains. At this rate, the City will take approximately 160 years to structurally assess all of their trunk water mains once.

Starting in 2013 the City instituted an annual budget for the inspection program of all water mains. The annual amount budgeted for the program is $620,000 per year until 2023 and then $320,000 per year from 2024 and beyond. This program will allow the City to accelerate the assessment rate of the trunk water mains.

4.2 What pipes should be inspected?

The trunk water mains are one of the most critical assets to support the City's provision of safe and reliable water to its customers. Understanding and managing the risk of failure of the trunk water mains is an essential element of the City's overall asset management program. The City should establish a program to inspect every trunk water main in the system on a routine basis to support the asset management program.

The inspection program will provide information to help the City minimize the risk of a trunk water main failure. Trunk water main failures can result in significant catastrophic consequences, such as causing sinkholes which result in direct costs (emergency repairs and road restoration) and indirect costs (disruptions to business, traffic, etc.). The City has estimated that a recent failure of the Lake Huron trunk water main cost approximately $1.3 million. A large GTA municipality estimated that the failure of a large diameter trunk water main in 2009 resulted in a total cost in excess of $15 million.

The City program should be designed to inspect every trunk water main on a maximum of a 20-year interval. This will result in the City inspecting an average of 10 km every year based on the current inventory of trunk water mains. The cost of inspection of trunk water mains ranges from approximately $40 to $100 per m depending on the technology that is used. Using these estimates, inspecting all of the trunk water mains in the City will cost approximately $15 to $20 million. This would require an annual expenditure of approximately $750,000 to $1,000,000 (in 2014 dollars). This represents a 15% to 50% increase in the current program budget of $650,000 per year for the next 10 years.

The trunk water mains in the City have a renewal cost of approximately $646 million (Table 7). Therefore an expenditure of $20 million over 20 years (or approximately 3% of the value) represents a relatively small amount of money to manage the risks associated with the failure of trunk water mains.

Table 7 – Replacement Cost of Trunk Water Mains

Dia. (mm)	Length (m)	Unit Renewal Cost ($/m)	Total Renewal Cost ($ millions)
450	34,208	2,500	85.5
600	83,606	3,000	250.8
750	7,627	3,000	22.9
900	36,571	3,500	128.0
1,050	27,427	3,500	96.0
1,200	13,688	4,000	54.8
1,350	2,000	4,000	8.0
TOTAL	***205,129***		**646.0**

4.3 What pipes should be inspected first?

The inspection program that is outlined in this report has been designed to determine which pipelines are the best candidates for inspection. The assessment information can be used to accomplish two goals:

1. Deferral of capital
2. Managing Risk/Prioritizing Renewal of Trunk WMs

4.3.1 Deferral of Capital

The deferral of capital is one goal that can be accomplished from completing the assessments of the trunk water mains. This concept is based on using the results of the assessments to only replace the portions of the trunk water main that are found to be in poor condition and deferring the replacement of the remaining portion of the trunk water main to a future date.

Four assumptions need to be made when considering whether spending money to inspect the trunk water mains for the purposes of deferring capital expenditures is warranted:

1. The renewal timeline for the pipeline is in the near term.
2. The entire length of pipeline that will be assessed is being planned for renewal.
3. The size of the water main does not need to be increased to accommodate growth in the City.
4. The results of the assessment will be used to replace only those sections that are found to be in a condition that is poor enough to warrant replacement and the replacement of the sections that are found to be in good condition will be deferred until a later date.

With respect to the fourth assumption, there are no strict guidelines that can be followed to determine the number of wire breaks or the minimum wall thickness that triggers a replacement. Some of the companies that provide the assessment technologies are reticent to provide recommendations for the renewal strategies based on the results of the inspections.

If the four assumptions stated previously are satisfied then an economic analysis can be considered to determine when the cost of the assessment is warranted. For example, replacing a 1 km section of 600 mm diameter trunk water main can cost approximately $3 million. If an inspection is completed at a cost of $50,000 and 50% of the capital cost of the water main can be deferred for 10 years, then the present value of replacing 50% of the water main now, performing the inspection, and replacing the remaining 50% of the water main in 10 years is approximately $2.5 million (assuming a discount rate of 5%). In this example, deferring the capital replacement of 50% of the trunk water main for 10 years will save the City approximately $500,000. This example is summarized in Table 8.

Table 8 – Present Value of Performing Inspection, Replacing 50% of the Water Main Now and Replacing 50% of the Water Main in 10 Years

Length (m)	1,000
Diameter (mm)	600
Unit Replacement Cost ($/m)	$3,000
Inspection Cost (A)	$50,000
Capital Cost to Construct 50% of Water Main in 2014 (B)	$1,500,000
Capital Cost to Construct 50% of Water Main in 2024	$1,800,000
Present Value of 2024 Capital Cost (C)	$920,870
Total Present Value to Replace Entire Water Main and Perform Inspection (A + B +C)	**$2,470,870**
Cost to Replace Entire Water Main Now	$3,000,000
Savings incurred by deferring replacement of 50% of the water main	**$528,130**

One factor that needs to be considered before using the results of the inspection to defer capital is the constructability of replacing only some sections of a trunk water main. For example, it will be feasible to replace the first half of a pipeline and not the second half. However, it will not be feasible to replace every-other pipe section. Somewhere between these two extremes there is a point where the additional costs to replace multiple small sections of a pipeline will stop becoming cost effective due to the following cost factors:

- Contractor mobilization costs;
- Additional closure pieces;
- Additional costs associated with testing and commissioning multiple sections of new pipe; and
- Restoration costs.

If the additional cost factors described above cause the construction cost of the current and future construction activities to increase by 20%, then the present value of replacing 50% of the water main now, performing the inspection, and replacing the remaining 50% of the water main in 10 years is approximately $3 million (assuming a discount rate of 5%). In this case, there would not be any financial advantage to completing the inspections and deferring the capital expenditure. This example is summarized in Table 9.

Table 9 – Present Value of Performing Inspection, Replacing 50% of the Water Main Now and Replacing 50% of the Water Main in 10 Years with Construction Cost Increased by 20%

Length (m)	1,000
Diameter (mm)	600
Unit Replacement Cost ($/m)	$3,600
Inspection Cost (A)	$50,000
Capital Cost to Construct 50% of Water Main in 2014 (B)	$1,800,000
Capital Cost to Construct 50% of Water Main in 2024	$1,800,000
Present Value of 2024 Capital Cost (C)	$1,105,044
Total Present Value of to Replace Entire Water Main and Perform Inspection (A + B +C)	**$2,955,044**
Cost to Replace Entire Water Main Now	$3,000,000
Savings incurred by deferring replacement of 50% of the water main	**$44,946**

The City will need to be prepared to interpret the inspection results and make a decision about which sections of the pipe line need to be renewed (i.e. replaced or rehabilitated). This is one of the strongest arguments for conducting baseline inspections on pipelines that are relatively new. The baseline inspections are compared to the next inspection in the future, and will provide the necessary comparative testing to better determine the deterioration rate of the infrastructure. This information will provide valuable information for making a decision regarding the renewal strategy and timelines.

The examples described above are for illustrative purposes; however, the principles should be considered as the City proceeds with an approach to use the results of the condition assessments to defer capital expenditures or undertake “surgical” replacement of short sections of trunk water main. The City should track these costs closely and review the strategy at the end of the 5-year time period to determine the degree to which the unit replacement costs for smaller sections of the trunk water main are greater than the costs to replace the entire pipe length.

4.3.2 Risk Management Plan – Proactively Managing Probability of Failure

Within the context of managing the risk associated with the trunk water main network, the City uses an approach that is based on estimating the probability and consequence of a trunk water main failing. The risk ranking for each trunk water main is shown in Figure 3. The current approach to estimating the probability of failure of a trunk water main is based on several inferred factors, such as pipe material, pipe age, operating pressure, and historical failure history.

The failure of trunk water mains represents a much greater consequence, and therefore, the management needs to be proactive. The assessment information can be used to better estimate the probability of failure of each trunk water main that is inspected. The results can also be used to adjust the probability of failure for similar pipe materials/vintages that are not directly assessed. This approach will help the City to better understand the risk of failure of each trunk water main and to further prioritize the renewal of the existing infrastructure.

A proactive risk management approach supported through a comprehensive understanding of the condition of the trunk water mains is also a strong argument for completing baseline inspections on newer pipelines. The baseline inspections are then used for comparison purposes when subsequent assessments are completed in the future.

4.3.3 Risk Management Plan – Managing Consequence of Failure

The City's approach to estimate the consequence of failure is based on a review of the impacts associated with a failure of the trunk water main. The consequence of failure is based on the pipe size, traffic impacts, flow rate in the pipe, adjacent property type, and impacts to other utilities or the natural environment. The consequence of failure score for each trunk water main is shown in Figure 4.

In order to manage the consequence of failure the City should prepare Standard Operating Procedures (SOPs) for each trunk water main in the system. The SOPs should:

- Describe how to take each major section of trunk water main out of service, such as indicating which valves should be opened and/or closed;
- Review the impacts to the surrounding customers and establish a plan to maintain water service confirmed through hydraulic modeling of the system;

- Ensure that there is the ability to launch pipeline inspection equipment inside the pipeline (i.e. sufficient appurtenances and space in the chambers);
- Document available valves and field-confirm their operability;
- Show connections to other pipes in the water main network; and
- Include the historical construction information, record drawings, previous assessment results, etc. to make them the single source of information on each of the major pipe sections.

The SOPs will accomplish 2 important goals:

1. Make sure that the City is prepared for a failure on every trunk water main in the City by having a strategy to minimize the consequences of a failure.
2. Provide the necessary plan to take the water mains out-of-service for the routine inspection program that is recommended in this report.

4.4 Recommended Inspection Program

The recommended inspection program is based on the City completing approximately 10 km of inspections each year. This will result in the City assessing all of the trunk water mains over a 20 year period.

4.4.1 Deferring Capital Expenditures

The City should pilot the use of an assessment technology in coordination with an approach to defer capital where feasible. The best water main candidates for this approach will be the sections with the highest priority for replacement, such as:

- Trunk water mains in the system that are on the City’s 10-year capital renewal plan.
- Trunk water mains in the system where other water mains or sewers in the same right-of-way are on the City’s 10-year capital renewal plan.
- Trunk water mains in the system that are expected to be in the worst condition based on age or failure history.

If the City is able to successfully defer the replacement of a portion of the trunk water main that is inspected without increasing the capital cost to replace the remaining portions then the City should consider routinely assessing all trunk water mains prior to replacing them.

The trunk water mains that are highest priority for replacement in the City are the 450 mm cast iron water mains that were constructed in the 1910s. These pipes are beyond their expected service life. However, their failure history does not suggest that the level of service that they provide has declined. The City should assess the structural integrity of these old trunk water mains to determine if their renewal timing should be adjusted based on an understanding of their current condition.

Figure 5 and Table 10 summarize the proposed assessment program for inspecting old cast iron trunk water mains. There is a total of approximately 14.9 km of cast iron trunk water mains that are between 80- and 110-years old. These water mains should be subjected to high resolution wall thickness assessments to better estimate their current condition. The results of the assessments will be used to adjust their probability of failure and determine/revise a renewal plan to make sure the trunk water mains will continue to provide a high level of service over the next several decades.

Table 10 also identifies when the trunk water main or adjacent sewer is being planned for renewal according to the City's latest 10-year capital plan. It would be prudent for the City to prioritize the assessment of the sections of trunk water main in the locations where the road right-of-way will be disturbed in the near future. This will ensure that the City has a better understanding of the condition of the trunk water main before the construction activities begin on the adjacent infrastructure. It would also be prudent for the City to align the capital improvements that may be required to complete the assessments of the trunk water mains (i.e. chamber installations/modifications) with the other planned right-of-way construction activities.

Appendix A contains individual maps for each location of the inspection program summarized in Table 8.

4.4.2 Proactive Risk Management

The City should perform condition assessment for the purposes of a proactive approach to risk management on the trunk water main with the highest consequence of failure. This will provide information to adjust the probability of failure information. This information will also be used as a baseline for future assessments.

Figure 6 and Table 11 summarize the proposed testing program for the trunk water mains to support the City's proactive approach to risk management. There are approximately 32.9 km of trunk water mains that are between 20 and 60 years old. The predominant material for these trunk water mains is PCCP. The City should investigate the structural integrity of these pipelines to provide baseline information for comparing to future assessments and to determine if their renewal plan should be adjusted. Appendix B contains individual maps for each location of the inspection program summarized in Table 11.

Table 11 also identifies when the adjacent sewer or adjacent small diameter distribution main is being planned for renewal according to the City's latest 10-year capital plan. It would be prudent for the City to align the capital improvements that may be required to complete the assessments of the trunk water mains (i.e. chamber installations/modifications) with the other planned right-of-way construction activities.

Table 10 – Assessment Program for Deferring Capital Expenditures

Location Number	Street	From	To	Decade of Installation	Material	Diameter (mm)	Length (km)	Inspection Technology	Year to Complete Inspection	Number of New Chambers Required*	Number of Chambers to be Modified*	Estimated Cost of New/Modified Chambers*	Estimated Cost of Inspection	Estimated Total Cost of Project	Year that Trunk Water Main or Adjacent Sewer is Planned for Renewal in the Current 10 year Capital Plan
1	York Street	Stanley St	Waterloo St	1900s	Cast Iron	450	1.3	High Resolution Wall Thickness Assessments	2015	0	1	$20,000	$70,000	$90,000	2024 to 2026
2	Wellington Street	York St	Central Ave	1900s	Cast Iron	450	1.0	High Resolution Wall Thickness Assessments	2015	0	1	$20,000	$50,000	$70,000	2025 to 2026
3	Central Avenue	Wellington Street	Maitland St	1910s	Cast Iron	450	0.7	High Resolution Wall Thickness Assessments	2015	0	0	$0	$40,000	$40,000	2014 and 2026
4	William Street	Central Avenue	Simcoe St	1910s	Cast Iron	450	1.4	High Resolution Wall Thickness Assessments	2015	0	1	$20,000	$70,000	$90,000	2017 and 2020
5	Dundas Street	Highbury Ave N	Veterans Memorial Pkwy	1960s	Cast Iron	450	4.2	High Resolution Wall Thickness Assessments	2015	0	2	$40,000	$210,000	$250,000	2018
6	Adelaide Street North	Windemere Rd	Governers Rd and Williams St (On Governers Rd)	1930s	Cast Iron	450	2.4	High Resolution Wall Thickness Assessments	2016	0	2	$40,000	$120,000	$160,000	2018
7	Horton Street East	85 North of Thames St	Richmond St	1910s	Cast Iron	450	0.7	High Resolution Wall Thickness Assessments	2016	0	2	$40,000	$30,000	$70,000	Not on 10 year capital Plan
8	Springbank Drive	Westmount Dr	Wonderland Rd S	1930s	Cast Iron	450	3.2	High Resolution Wall Thickness Assessments	2016	1	1	$80,000	$160,000	$240,000	Not on 10 year capital Plan
						Total	**14.9**					**$260,000**	**$750,000**	**$1,010,000**	

*Note: Number of New Chambers Required, Number of Chambers to be Modified and Estimated Cost of New/Modified Chambers are preliminary estimates.

Table 11 – Assessment Program for Proactive Risk Management

Location Number	Street	From	To	Decade of Installation	Material	Diameter (mm)	Length (km)	Inspection Technology	Year to Complete Inspection	Number of New Chambers Required*	Number of Chambers to be Modified*	Estimated Cost of New/Modified Chambers*	Estimated Cost of Inspection	Estimated Total Cost of Project	Year that Trunk Water Main or Adjacent Sewer is Planned for Renewal in the Current 10 year Capital Plan
1	Sunningdale Rd E	Uplands Dr	Highbury Ave N	1990s	PCCP	1200	4.3	Structural Integrity	2016	0	2	$40,000	$300,000	$340,000	Not on 10 year capital Plan
2	Highbury Ave N	Sunningdale Rd E	Fanshawe Park Rd E	1990s	PCCP	1200	1.4	Structural Integrity	2017	0	1	$20,000	$90,000	$110,000	Not on 10 year capital Plan
3	Fanshawe Park Rd E	Highbury Ave N	Clarke Rd	1950s/1990s	PCCP	1200	2.4	Structural Integrity	2017	0	1	$20,000	$170,000	$190,000	Not on 10 year capital Plan
4	Clarke Rd	670m North of Fanshawe Park Rd E	Oxford St E	1990s	PCCP	450, 1050-1200	4.9	Structural Integrity	2017	0	1	$20,000	$340,000	$360,000	2021
5	Commissioners Rd E	Wharncliffe Rd S	1km East of Jackson Rd	1960s	PCCP	600 - 900	8.8	Structural Integrity	2018	0	2	$40,000	$610,000	$650,000	Not on 10 year capital Plan
6	Commissioners Rd W	Crestwood Dr	Wharncliffe Rd S	1960s	PCCP	600 - 900	4.2	Structural Integrity	2019	0	1	$40,000	$300,000	$340,000	2015
7	Wharncliffe Rd	Commissioners Rd E	White Oak Rd	1950s/1960s	PCCP	600	2.2	Structural Integrity	2019	0	1	$40,000	$150,000	$190,000	Not on 10 year capital Plan
8	White Oak Rd	Southdale Rd E	West of Hwy 402	1950s	PCCP	600 - 750	4.7	Structural Integrity	2019	0	1	$40,000	$330,000	$370,000	Not on 10 year capital Plan
						Total	**32.9**					**$260,000**	**$2,290,000**	**$2,550,000**	

*Note: Number of New Chambers Required, Number of Chambers to be Modified and Estimated Cost of New/Modified Chambers are preliminary estimates.

4.5 Discussion of Issues Related to Inspection Program

The following sections provide a discussion on some of the key issues related to undertaking the proposed inspection program.

4.5.1 Taking Trunk Water Mains Out of Service Temporarily

The best approach for conducting assessments of trunk water mains is to take them out of service temporarily. This will reduce the coordination efforts that are required in the City's Operations department. Taking the trunk water mains out of service will also reduce the risk associated with preparing the pipeline for assessments (i.e. swabbing) and delays in the assessment activities.

It is recognized that the City has some trunk water mains that act as large "distribution" pipes. These sections of trunk water mains have a large number of service connections that will be impacted if the pipeline is taken out of service. The City will have to carefully plan to ensure the continued provision of water service to its customers while the trunk water mains are taken out of service. The City should also develop a strategy to construct parallel smaller diameter distribution water mains in the locations where the trunk water mains have service connections. This will reduce the consequences of a trunk water main failure and improve the ability to take the trunk water mains out of service.

If there are situations where the trunk water main cannot be taken out of service, then the City should consider conducting assessments using technologies that can be used on active trunk water mains. This will require careful coordination with the Operations group to make sure that the flow rate in the trunk water main is controlled through closing valves or adjusting the operation of some facilities.

4.5.2 Constructing New Chambers to Allow Access for Inspection Equipment

The inspection equipment is likely to require the installation of chambers with appropriately designed valves to introduce and retrieve the equipment from the pipeline. This will include appurtenances such as vertically-oriented tees with gate valves/blind flanges or wyes with gate valves/blind flanges. As part of the SOPs for each trunk water main, the City should review the current chamber and valve arrangement to support inspection equipment and develop a plan to install new chambers with the necessary appurtenances. This process will also provide the opportunity for the City to replace some of their remaining butterfly valves with gate valves or rehabilitate existing valve chambers.

It is also recommended that the work associated with constructing new chambers be undertaken in a separate contract. The companies that offer inspection services do not have staff who can complete this type of work, and therefore would have to sub-contract the service to a third party. This increases the risks that the inspection company takes on, and would therefore result in a higher unit cost for inspection.

4.5.3 Internal City Costs for Undertaking Pipelines Inspections

It should be recognized that the City incurs considerable internal costs to complete pipeline inspections for work associated with planning/coordinating the inspection activities and preparing the pipelines for the inspections. Some of the factors that influence the City's internal costs are:

- Overtime wages paid to staff
- Union compliance with the necessary activities to undertake the inspections
- Purchase of equipment and materials to prepare the pipelines (i.e. swabs)
- Deferral of staff time and City resources away from other maintenance activities that are required in the system.

Over the past several years the City has been collecting better information that can be used to quantify these internal costs; however, at the current time it is not feasible to assign a dollar value to these costs.

4.5.4 Limited Number of Qualified Bidders

For many of the pipeline inspection services there are often a limited number of qualified companies who will bid on a contract. In some cases, there may only be one firm that is in a position to respond. The City should consider the following strategies to increase the number of qualified bidders that responded to inspection contracts:

- Complete the installation of chambers and appurtenances in a separate contract. Section 4.5.2 discusses this strategy in more detail.

- Work with industry partners to pilot the use of new technologies in the Ontario water sector. This will help companies that offer technologies that have not been proven in the Ontario or Canadian market to overcome some of the barriers that are currently limiting the number of qualified bidders.
- Increase the volume of work that is included in each individual contract. This could include bundling all of the inspections that will be completed each year into one contract, or issuing a single contract for a multi-year inspection program. A larger contract may draw the interest of more companies because there is a larger reward available for an upfront investment that would be similar for a smaller contract.
- Developing terms of reference for the inspection services that ask for outcome-oriented deliverables as opposed to the application of specific technologies. For example, the terms of reference could be written to ask for the assessment to provide the structural integrity of each pipe section based on completing inspections. This would allow the application of any technology that can be used to assess the structural integrity of a pipe. For example, either PURE's technology to count wire breaks or NDT Corporations technology to assess structural integrity using the speed of sound could be utilized to determine the current structural integrity of the pipeline.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The City of London has embarked on a multi-year study to develop a plan to improve the management of their trunk water mains. Initiating an ongoing assessment program to inspect all of the trunk water mains on a routine basis is an essential element to the plan. The assessments will be used to:

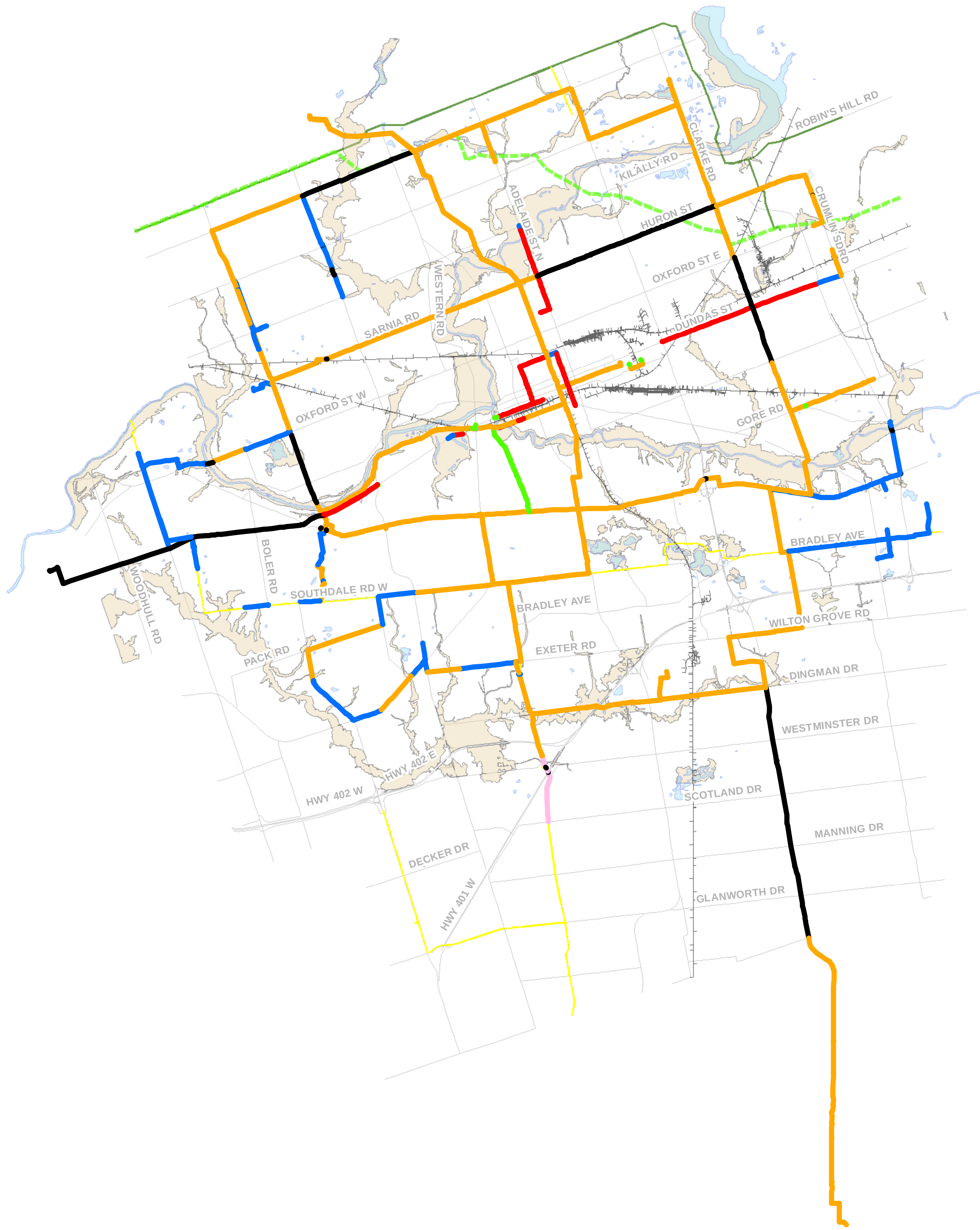
- Identify the preferred renewal strategy for the water main, such as full/partial replacement or rehabilitation and a timeline for renewal.
- Provide additional information that can be used to adjust the probability of failure of the water mains based on the current condition observed through the inspections.
- Establish a baseline for comparison purposes with future inspections so that the deterioration for each section can be estimated over time.

The following recommendations should be considered by the City as they initiate their assessment program:

1. The assessment program should inspect every trunk water main in the City on a 20-year cycle. This will result in assessing approximately 10 km of water mains every year. The annual cost to inspect the trunk water mains is estimated to be between $750,000 and $1,000,000. This represents a 15% to 50% increase in the current program budget of $650,000 per year for the next 10 years.
2. The City should prepare Standard Operating Procedures (SOPs) for each trunk water main in the system. The SOPs will make sure that the City is prepared for a failure on every trunk water main in the City and provide a strategy to minimize the consequences of a failure. The SOPs will also provide the necessary plan to take the water mains out-of-service for routine inspections.
3. Through the development of the SOPs for each trunk water main, the City should review the current number and locations of valves to facilitate the operation and inspection of the pipelines. The City should install new chambers and associated appurtenances on trunk water mains that do not have a sufficient number of valves or locations where testing equipment can be inserted/retrieved into the pipelines.
4. Through the development of the SOPs for each trunk water main, the City should investigate which sections of trunk water have service connections. The City should develop a plan to construct parallel, small diameter distribution water mains in these

locations and transfer the service connections from the trunk main to the distribution main.

5. The City should perform condition assessments for the purposes of deferring capital expenditures on the trunk water mains that are past their theoretical useful life. The 5-year program recommends that the City assess approximately 13.9 km of trunk water mains for this purpose at an estimated cost of approximately $1 million.
6. The condition assessments should be prioritized based on the City's 10-year capital plan. Trunk water mains that are planned for renewal in the short term, or in locations where the adjacent distribution water main or sewer in the same right-of-way are being planned for renewal in the short term, should be assessed before the design work for the proposed capital improvements are initiated.
7. The City should perform condition assessments for the purposes of a proactive approach to risk management on the trunk water main with the highest consequence of failure. This will provide information to adjust the probability of failure information and provide a baseline condition for future assessments. The 5-year program recommends that the City assess approximately 32.9 km of trunk water mains for this purpose at an estimated cost of approximately $2.6 million.
8. The current technology that should be used to assess the condition of metallic pipelines is high resolution wall thickness measurements. The current technology that should be used to assess the condition of PCCP is structural integrity supported by wire breaks, seismic pulse echo, or other forms of sounding.
9. The City should work with industry partners to pilot the use of new technologies to assess the structural integrity of their trunk water mains. For example, PURE is developing the capability to put their RFEC technology on their *SmartBall* platform. This could reduce the cost of inspecting the trunk water mains.



N

Figure 1 Trunk Water Main Material

- Cast Iron
- Concrete
- Ductile Iron
- PVC
- Steel
- Transite
- Unknown
- Imperial Oil Pipeline
- Railway
- Union Gas Pipeline
- Water Body
- Hazard Area
- Sun Oil Pipeline
- Arterial Roads

0 1,000 2,000 4,000
Meters

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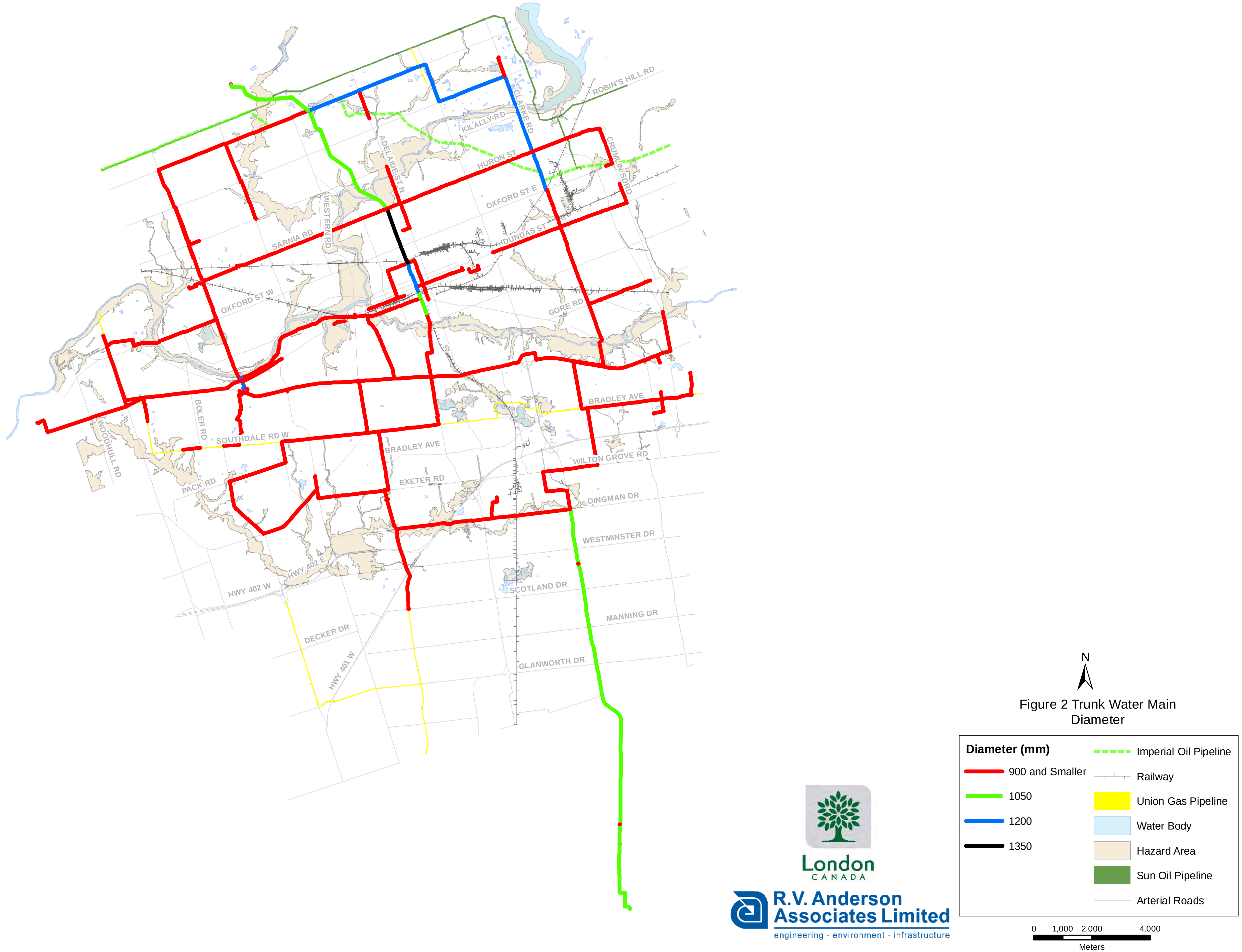

Figure 2 Trunk Water Main Diameter

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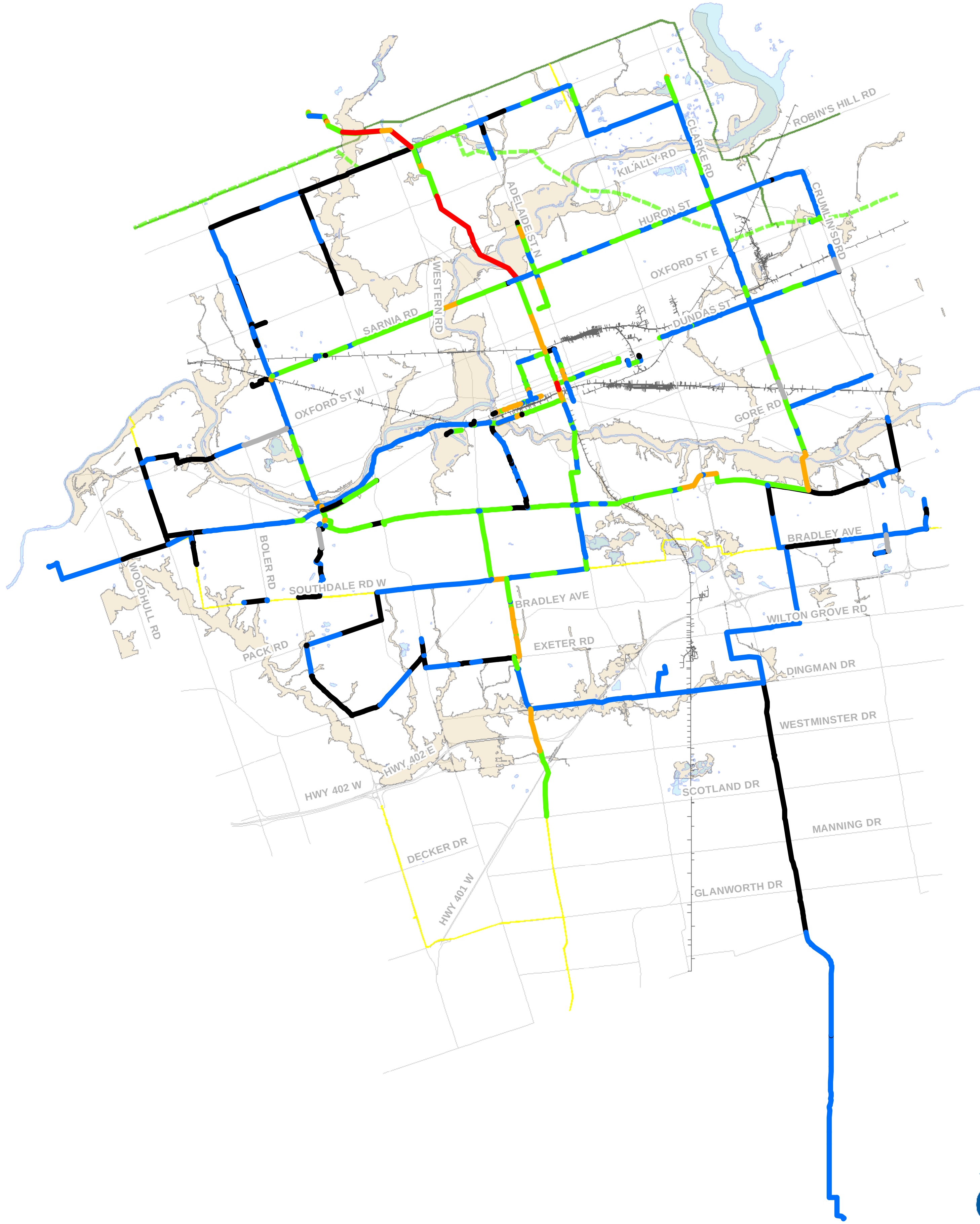

N

Figure 3 Trunk Water Main
Risk of Failure

Risk Score	
0=Low, 100=High	Imperial Oil Pipeline
Unknown	Railway
0 - 12.5	Union Gas Pipeline
12.5 - 25	Water Body
25 - 37.5	Hazard Area
37.5 - 50	Sun Oil Pipeline
50 - 60	Arterial Roads

0 1,000 2,000 4,000
Meters

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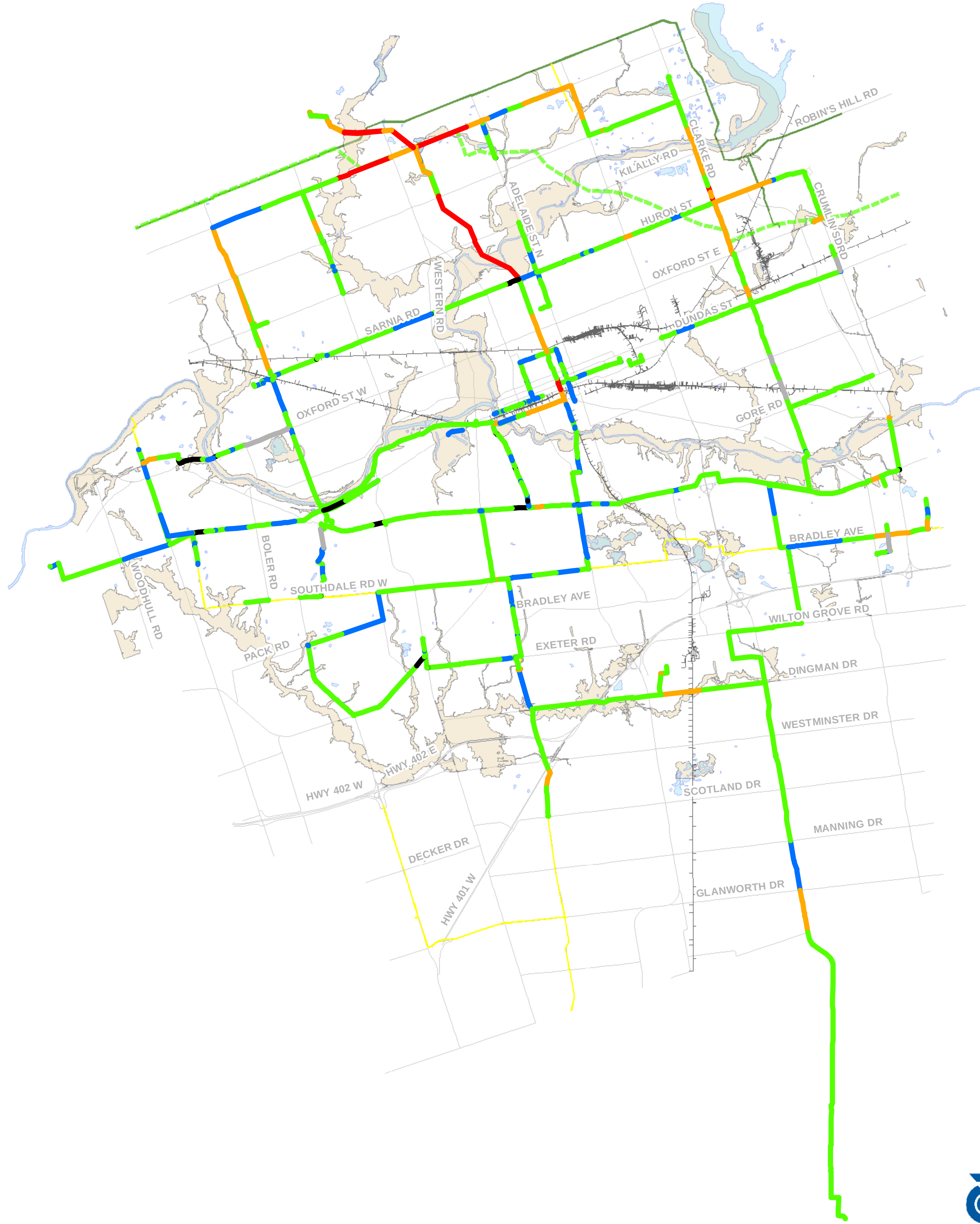

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Figure 4 Trunk Water Main
Consequence of Failure

Consequence Score

0=Low, 100=High

- Unknown
- Less than 20%
- 20% - 40%
- 40% - 60%
- 60% - 80%
- Greater than 80%
- Imperial Oil Pipeline
- Railway
- Union Gas Pipeline
- Water Body
- Hazard Area
- Sun Oil Pipeline
- Arterial Roads

0 1,000 2,000 4,000
Meters

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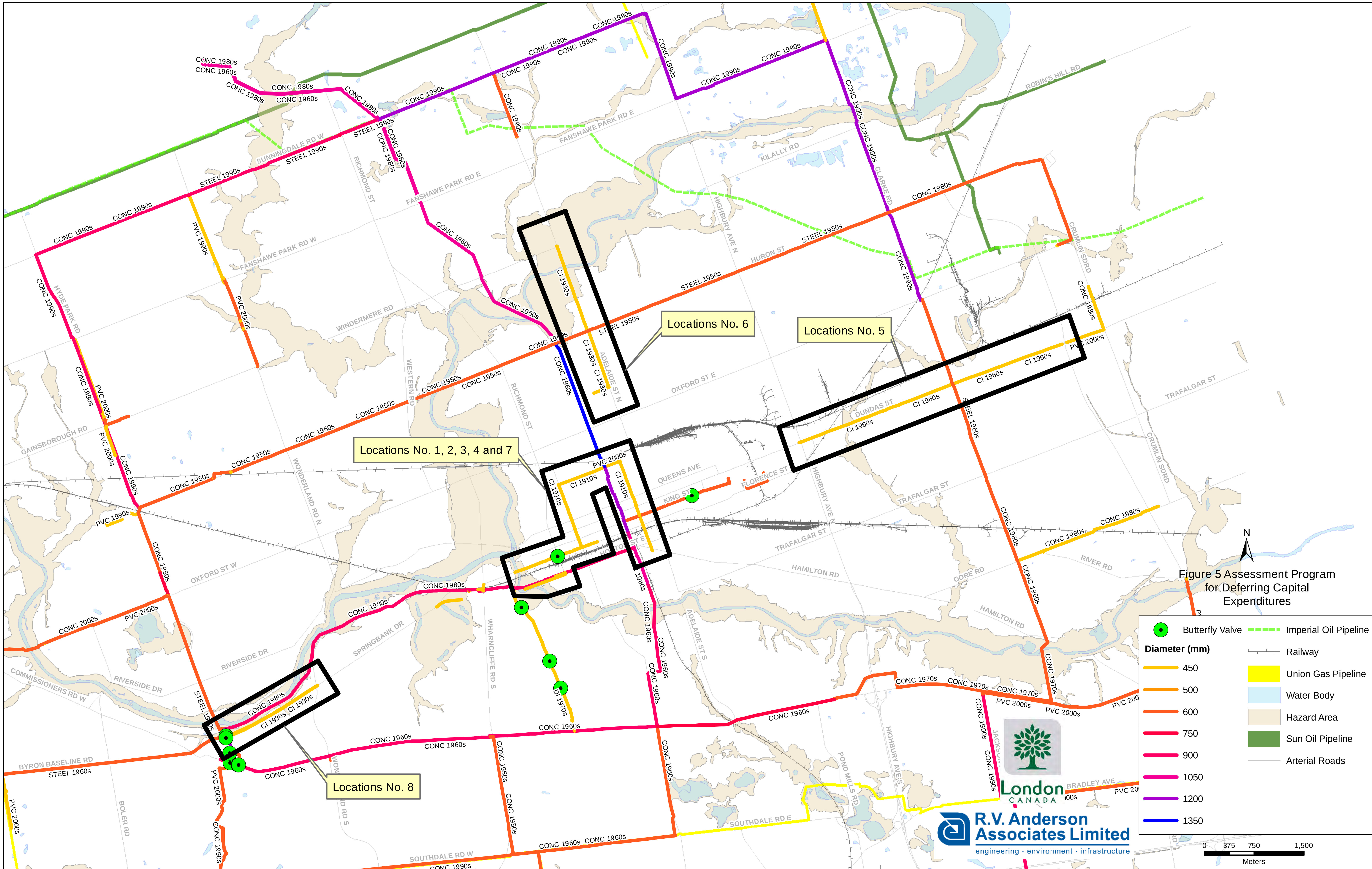

Figure 5 Assessment Program for Deferring Capital Expenditures
Locations No. 1, 2, 3, 4 and 7
Locations No. 5
Locations No. 6
Locations No. 8
Butterfly Valve
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
Arterial Roads
N
0 375 750 1,500
Meters
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SUNNINGDALE RD W
FANSHAWE PARK RD E
FANSHAWE PARK RD W
WINDERMERE RD
GAINSBOROUGH RD
HYDE PARK RD
WONDERLAND RD N
WESTERN RD
RICHMOND ST
ADELAIDE ST N
HIGHBURY AVE N
CLARKE RD
CRUMLIN SDRD
ROBIN'S HILL RD
KILALLY RD
HURON ST
OXFORD ST E
OXFORD ST W
DUNDAS ST
QUEENS AVE
KING ST
FLORENCE ST
TRAFALGAR ST
HAMILTON RD
GORE RD
RIVER RD
SPRINGBANK DR
RIVERSIDE DR
COMMISSIONERS RD W
BYRON BASELINE RD
WHARNCLIFFE RD S
ADELAIDE ST S
POND MILLS RD
BRADLEY AVE
SOUTHDALE RD E
SOUTHDALE RD W
BOLER RD

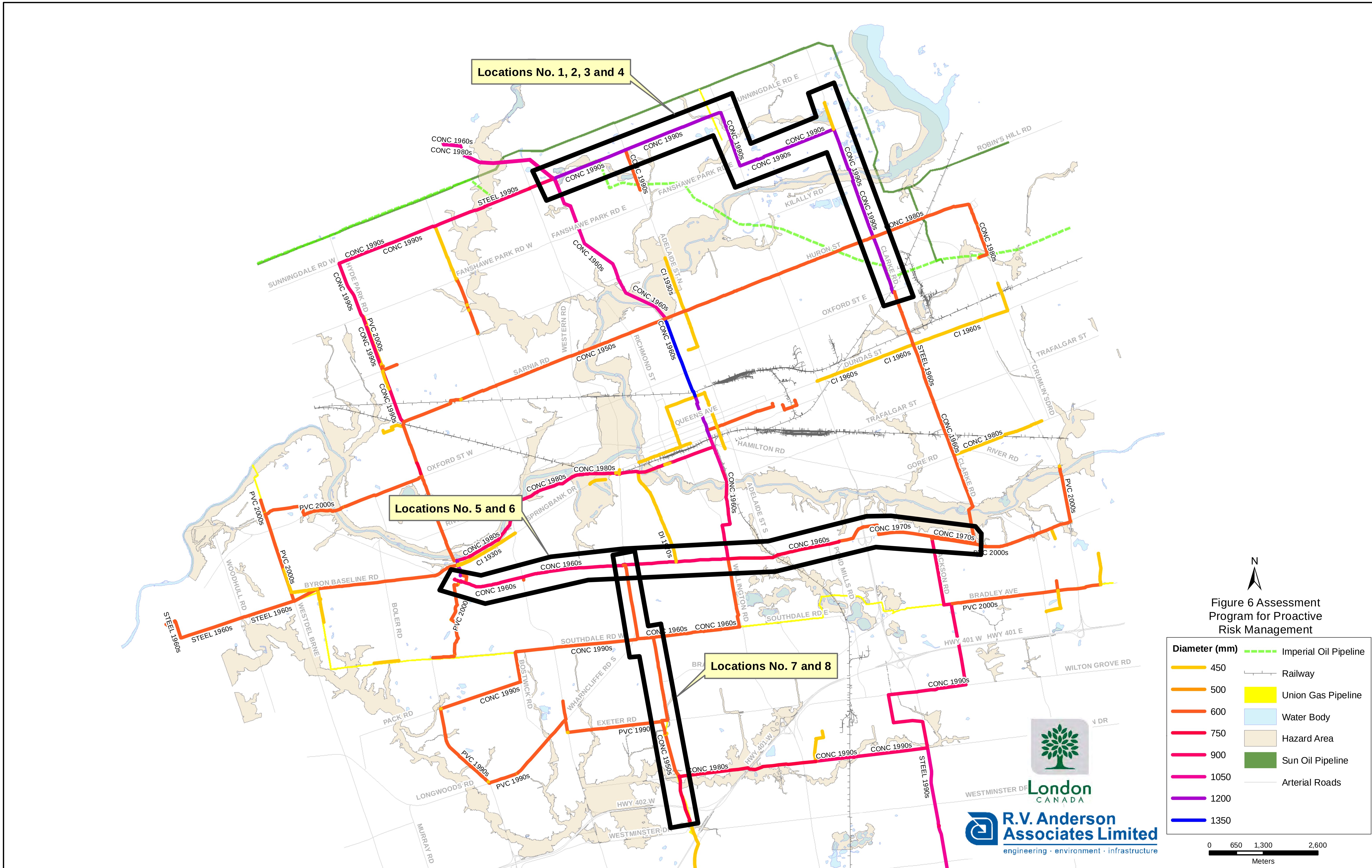
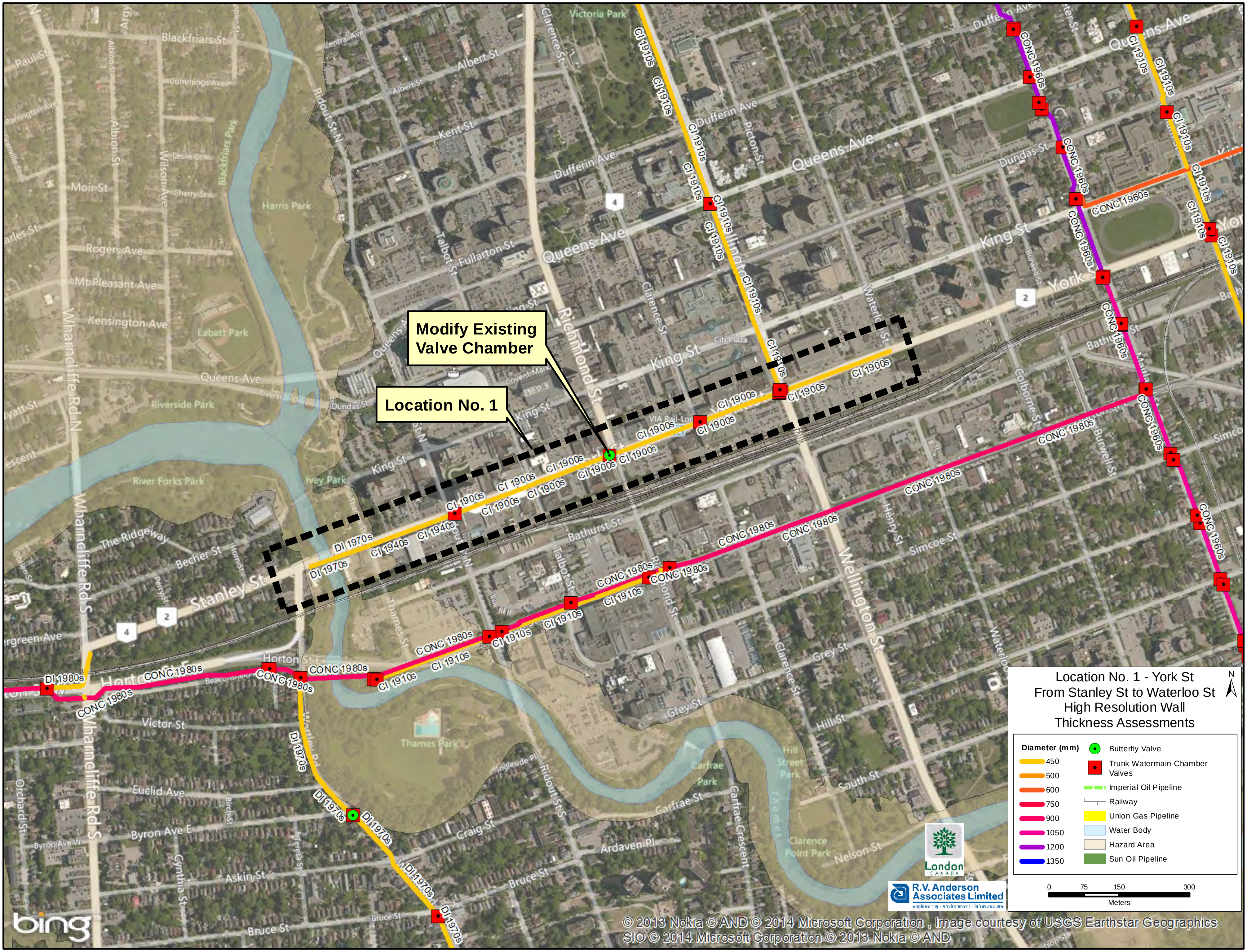


Figure 6 Assessment Program for Proactive Risk Management


Modify Existing Valve Chamber
Location No. 1
Location No. 1 - York St
From Stanley St to Waterloo St
High Resolution Wall
Thickness Assessments
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0 75 150 300
Meters
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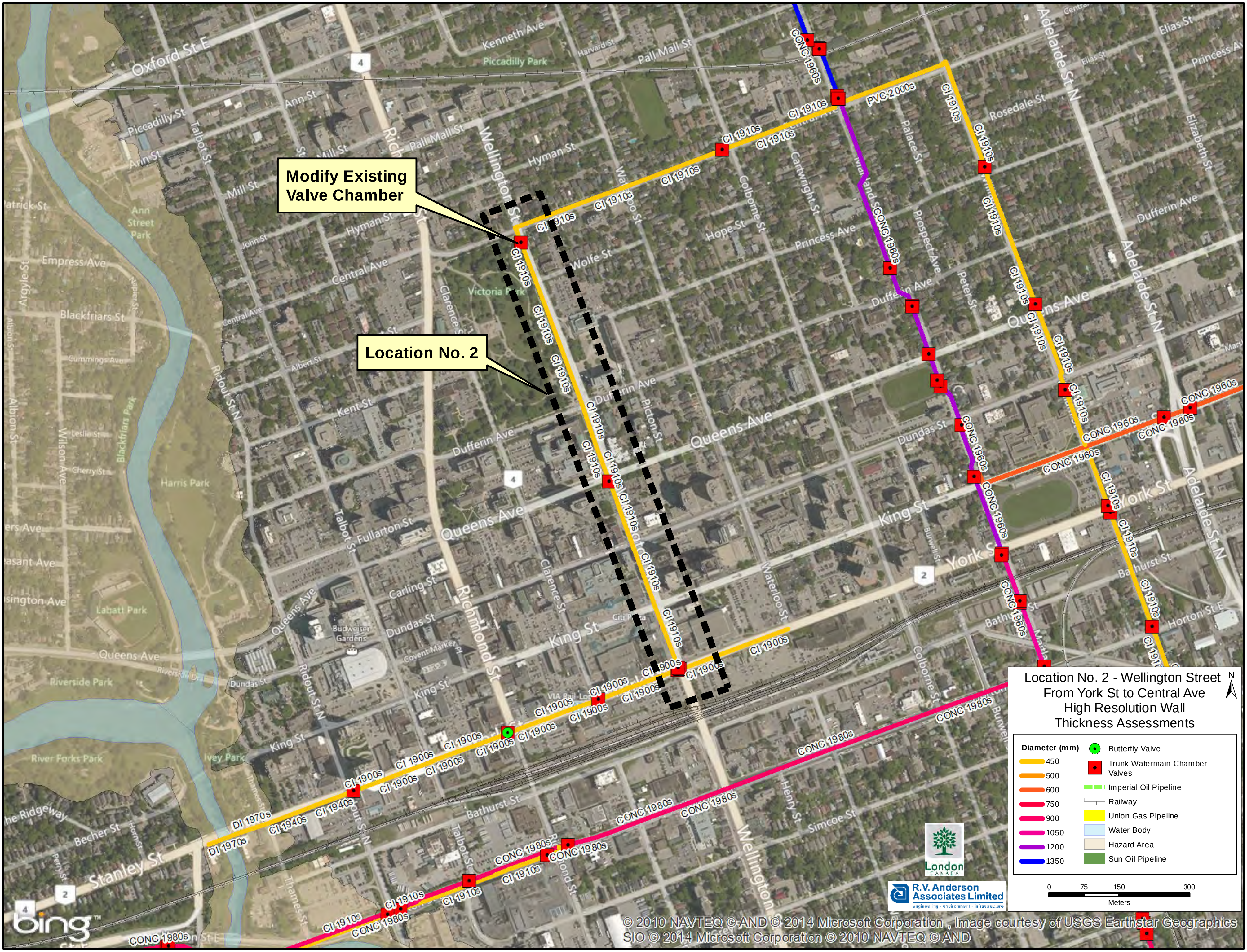
Modify Existing Valve Chamber
Location No. 2
Location No. 2 - Wellington Street From York St to Central Ave High Resolution Wall Thickness Assessments
N
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0 75 150 300
Meters
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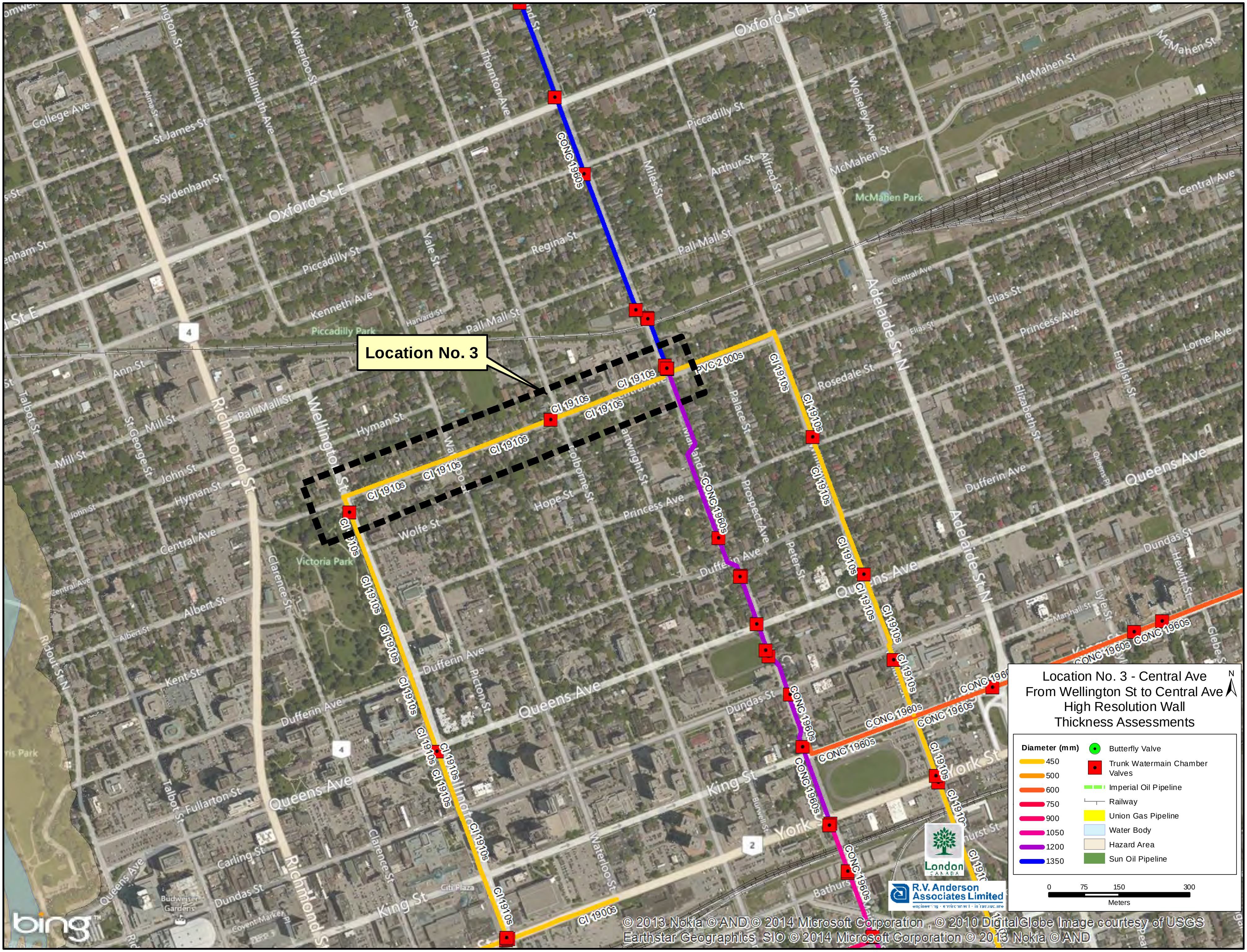
bing
Wellington St
Richmond St
Queens Ave
King St
York St
Dundas St
Dufferin Ave
Central Ave
Oxford St E
Adelaide St N
Waterloo St
Colborne St
Victoria Park
CI 1910s
CI 1900s
CONC 1960s
CONC 1980s
PVC 2000s
DI 1970s
CI 1940s



Location No. 3 - Central Ave
From Wellington St to Central Ave
High Resolution Wall
Thickness Assessments
Location No. 3
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0 75 150 300
Meters
N
London CANADA
R.V. Anderson Associates Limited
CI 1910s
CONC 1960s
PVC 2000s
CI 1900s
Oxford St E
Central Ave
Queens Ave
Dufferin Ave
Princess Ave
Piccadilly St
Pall Mall St
Wellington St
Richmond St
Adelaide St N
Waterloo St
Colborne St
King St
York St
Dundas St
Victoria Park
Piccadilly Park
McMahen Park
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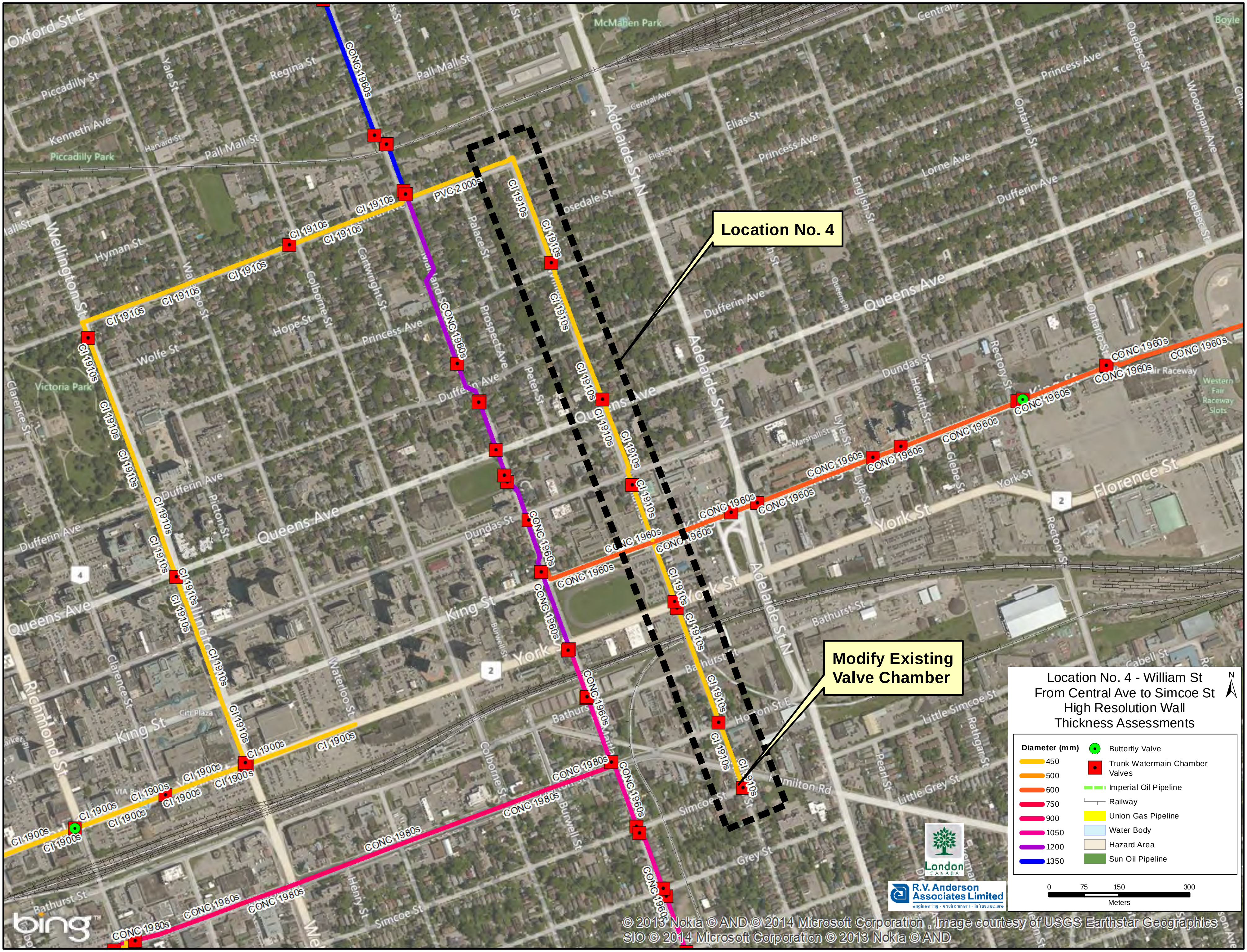

Location No. 4
Modify Existing Valve Chamber
Location No. 4 - William St
From Central Ave to Simcoe St
High Resolution Wall
Thickness Assessments
N
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0
75
150
300
Meters
London CANADA
R.V. Anderson Associates Limited
bing
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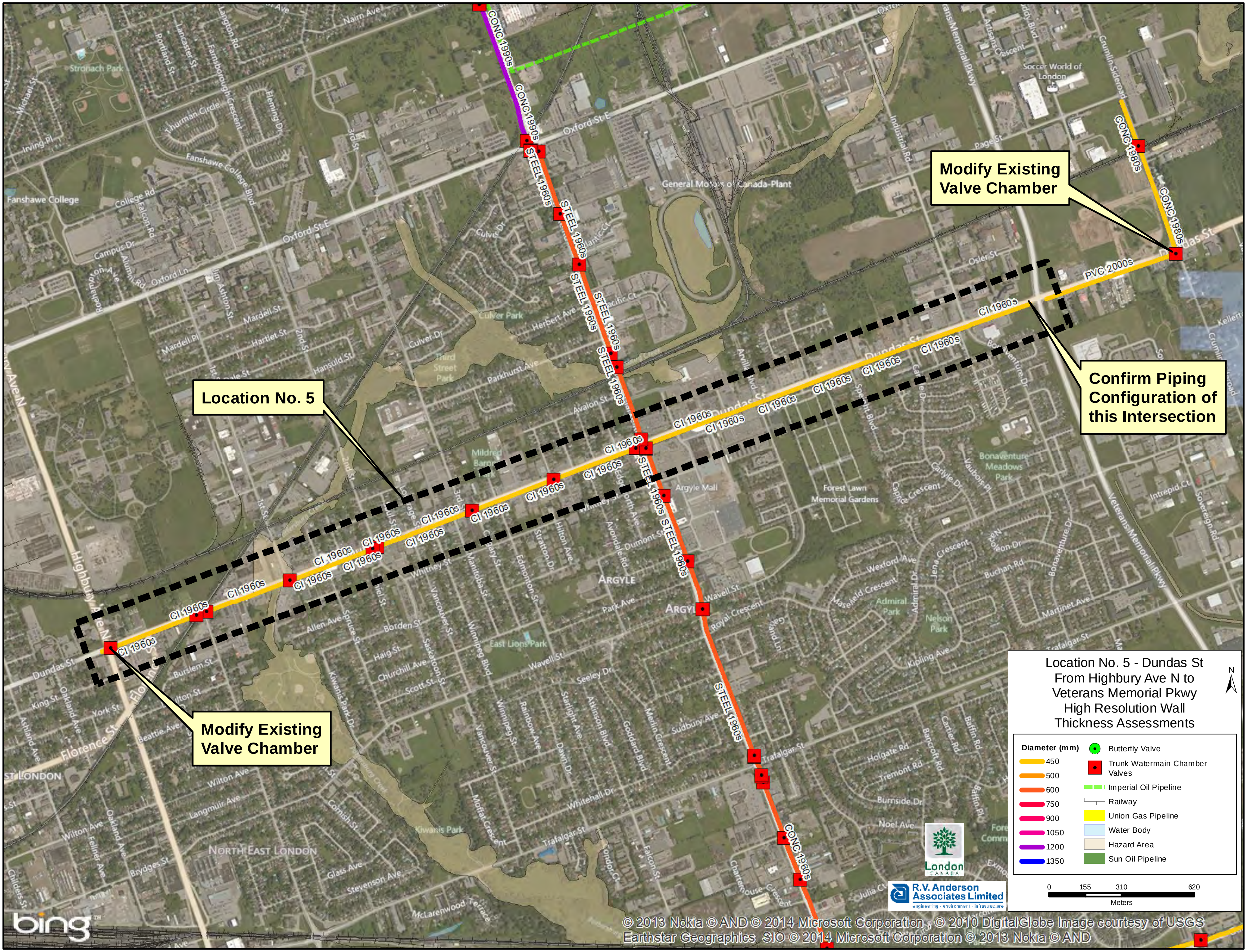
SIO © 2014 Microsoft Corporation © 2013 Nokia © AND
CONC 1960s
CI 1910s
CI 1900s
CONC 1980s
PVC 2000s
Oxford St E
Queens Ave
Dufferin Ave
King St
York St
Adelaide St N
Wellington St
Richmond St
Victoria Park
Florence St
Hamilton Rd
Simcoe St


Modify Existing Valve Chamber
Confirm Piping Configuration of this Intersection
Location No. 5
Modify Existing Valve Chamber
Location No. 5 - Dundas St From Highbury Ave N to Veterans Memorial Pkwy High Resolution Wall Thickness Assessments
N
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0 155 310 620
Meters
London CANADA
R.V. Anderson Associates Limited
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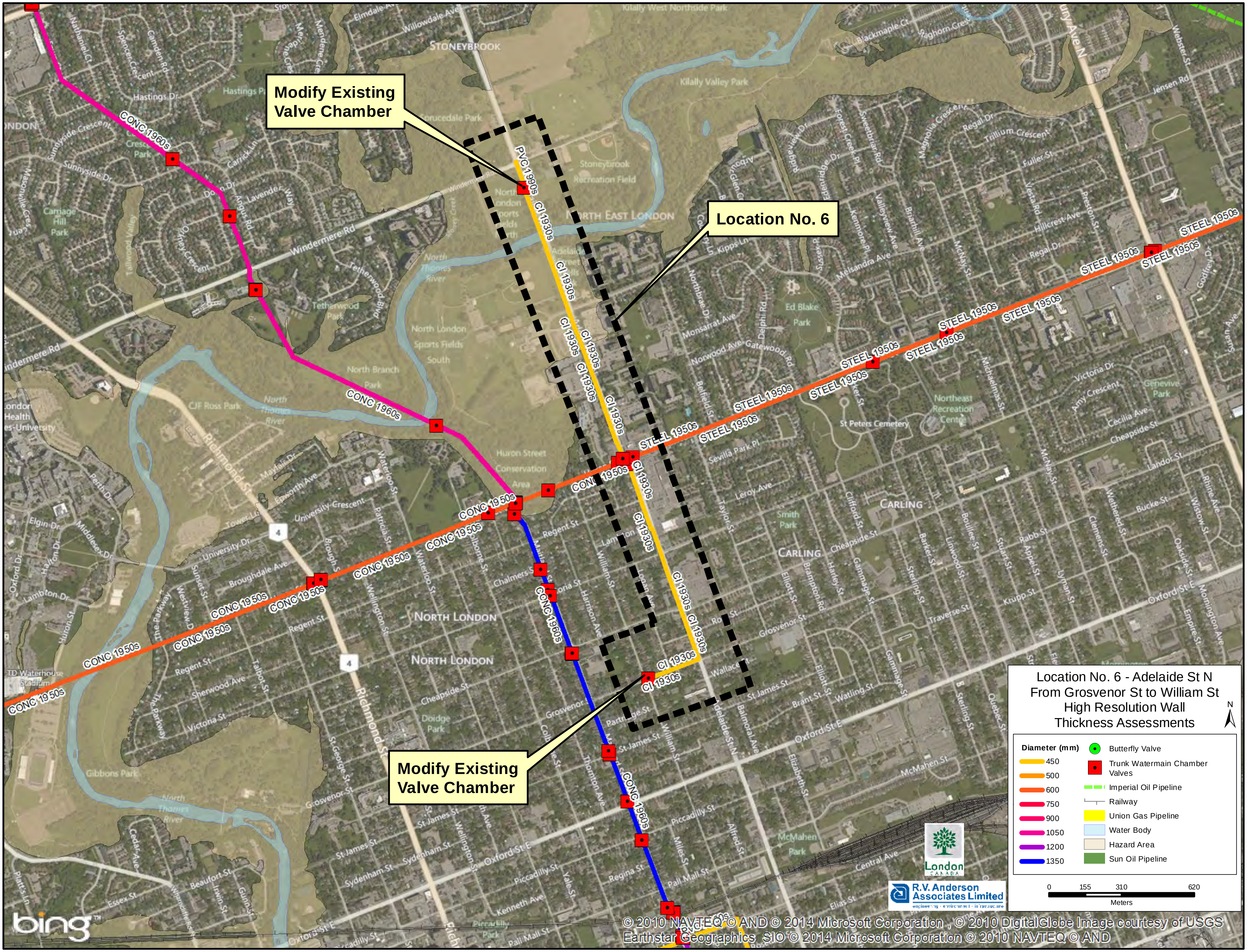
Modify Existing Valve Chamber
Location No. 6
Modify Existing Valve Chamber
Location No. 6 - Adelaide St N
From Grosvenor St to William St
High Resolution Wall
Thickness Assessments
N
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0
155
310
620
Meters
London CANADA
R.V. Anderson Associates Limited
PVC 1990s
CI 1930s
STEEL 1950s
CONC 1950s
CONC 1960s
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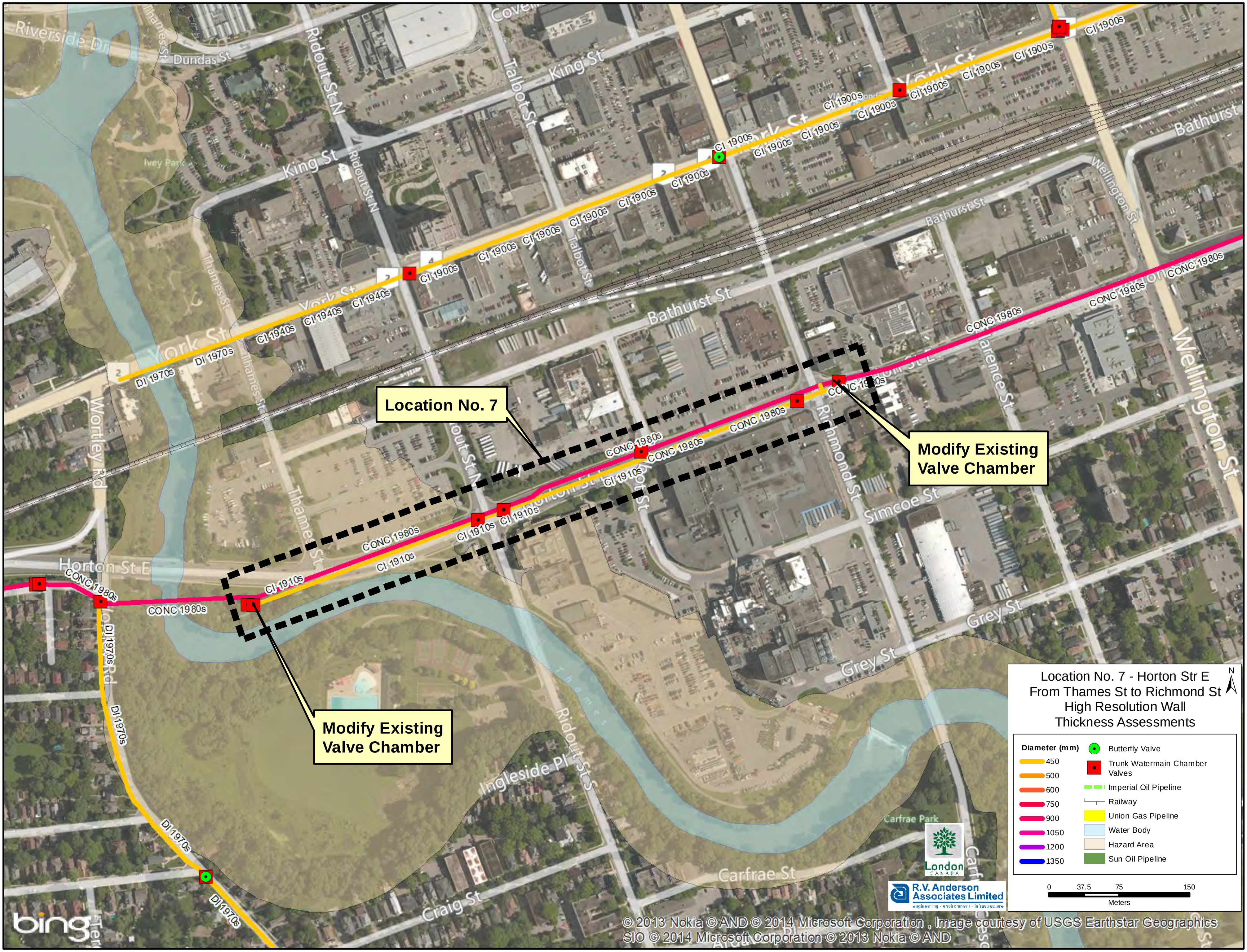
Location No. 7
Modify Existing Valve Chamber
Modify Existing Valve Chamber
Location No. 7 - Horton Str E
From Thames St to Richmond St
High Resolution Wall
Thickness Assessments
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0 37.5 75 150
Meters
London CANADA
R.V. Anderson Associates Limited
York St
King St
Dundas St
Riverside Dr
Ridout St N
Talbot St
Richmond St
Wellington St
Bathurst St
Horton St E
Thames St
Simcoe St
Grey St
Wortley Rd
Ingleside Pl
Carfrae St
Craig St
Ivey Park
Carfrae Park
CI 1900s
CI 1940s
CI 1910s
DI 1970s
CONC 1980s
bing
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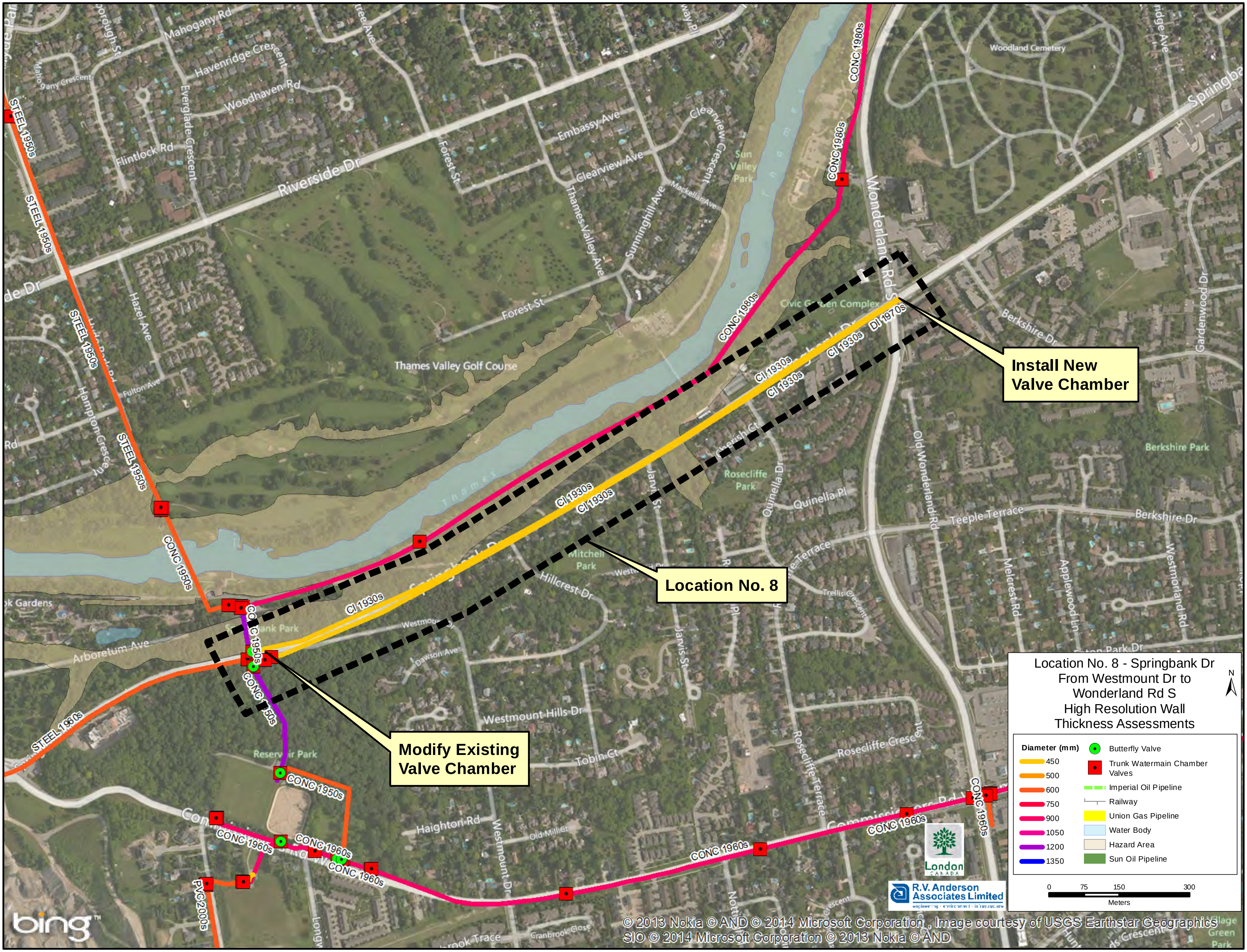
Location No. 8 - Springbank Dr
From Westmount Dr to
Wonderland Rd S
High Resolution Wall
Thickness Assessments
Install New
Valve Chamber
Location No. 8
Modify Existing
Valve Chamber
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0
75
150
300
Meters
N
London
CANADA
R.V. Anderson Associates Limited
DI 1970s
CI 1930s
CONC 1980s
CONC 1950s
CONC 1960s
STEEL 1950s
STEEL 1960s
PVC 2000s
Riverside Dr
Wonderland Rd S
Springbank Dr
Thames Valley Golf Course
Woodland Cemetery
Civic Garden Complex
Rosecliffe Park
Mitchell Park
Reservoir Park
Berkshire Park
Berkshire Dr
Teeple Terrace
Hillcrest Dr
Westmount Hills Dr
Haighton Rd
Arboretum Ave
Commissioners Rd W
Old Wonderland Rd
Forest St
Mahogany Rd
Havenridge Crescent
Woodhaven Rd
Flintlock Rd
Embassy Ave
Clearview Ave
Hazel Ave
Jarvis St
Quinella Dr
Quinella Pl
Rosecliffe Terrace
Rosecliffe Crescent
Westmount Dr
Tobin Ct
Melcrest Rd
Applewood Ln
Westmorland Rd
Gardenwood Dr
bing
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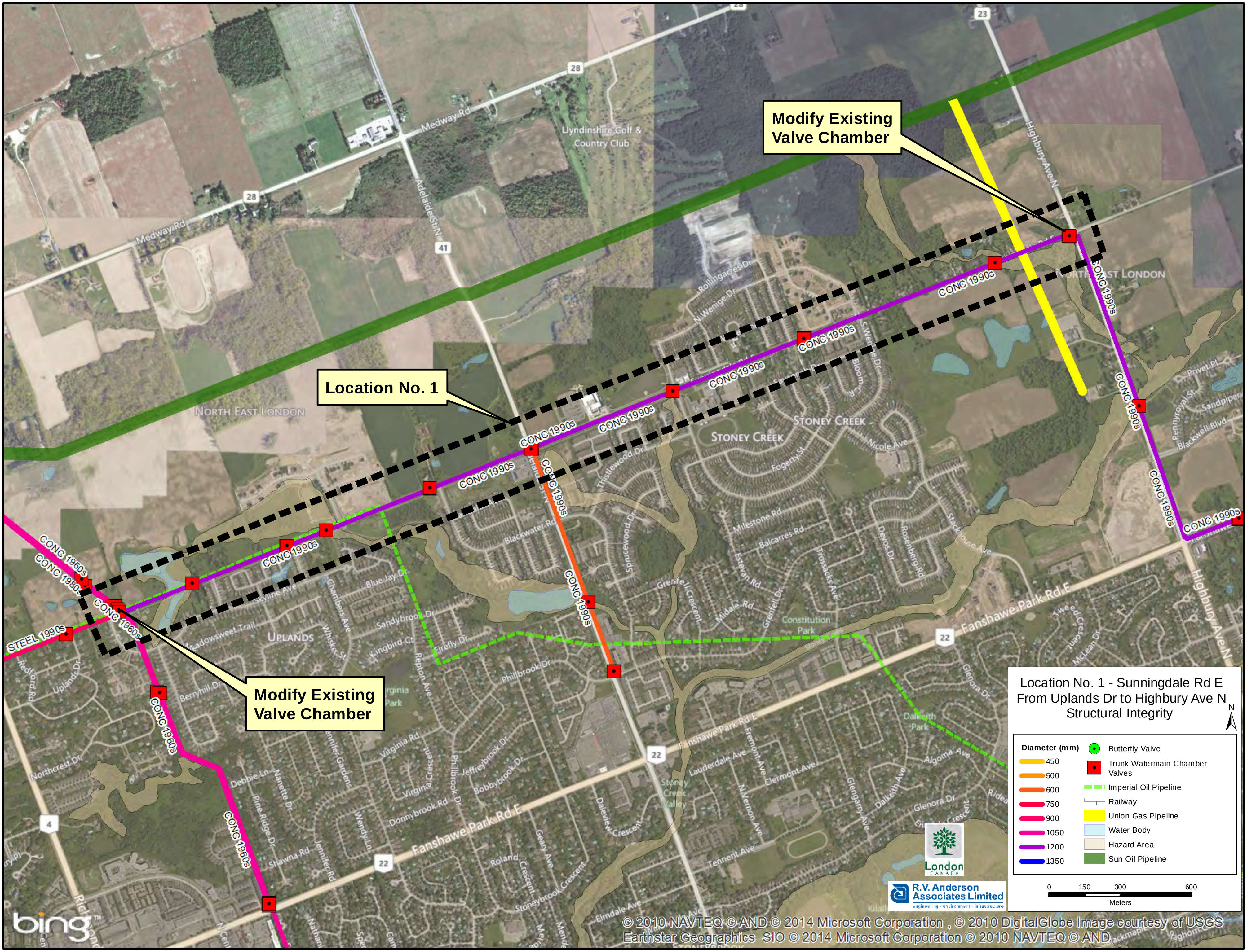

Modify Existing
Valve Chamber
Location No. 1
Modify Existing
Valve Chamber
Location No. 1 - Sunningdale Rd E
From Uplands Dr to Highbury Ave N
Structural Integrity
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0
150
300
600
Meters
N
CONC 1990s
CONC 1960s
CONC 1980s
STEEL 1990s
North East London
Stoney Creek
Uplands
Medway Rd
Adelaide St N
Highbury Ave N
Fanshawe Park Rd E
Llyndinshire Golf & Country Club
London
CANADA
R.V. Anderson Associates Limited
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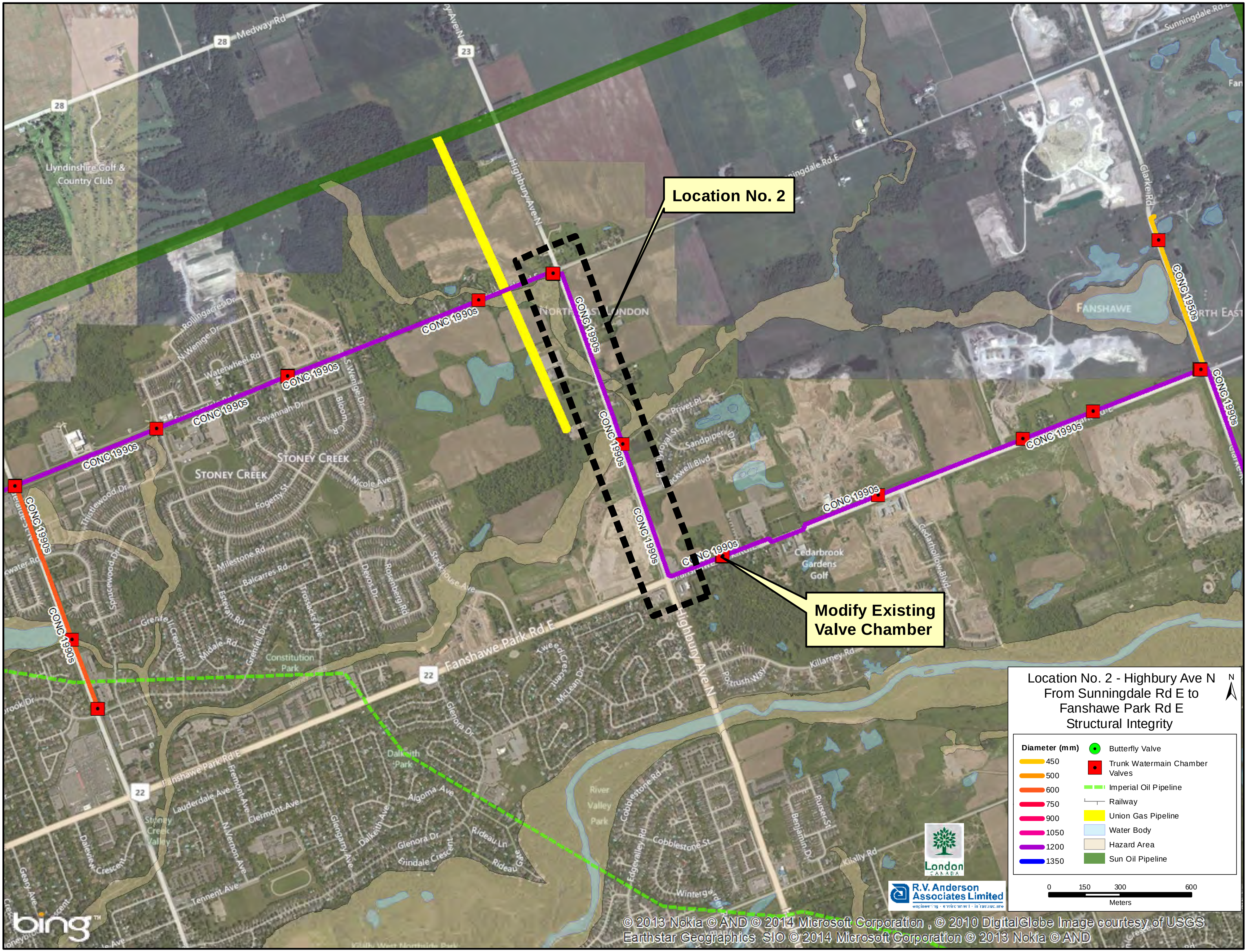

Location No. 2
Modify Existing Valve Chamber
CONC 1990s
CONC 1950s
Location No. 2 - Highbury Ave N
From Sunningdale Rd E to
Fanshawe Park Rd E
Structural Integrity
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0 150 300 600
Meters
London CANADA
R.V. Anderson Associates Limited
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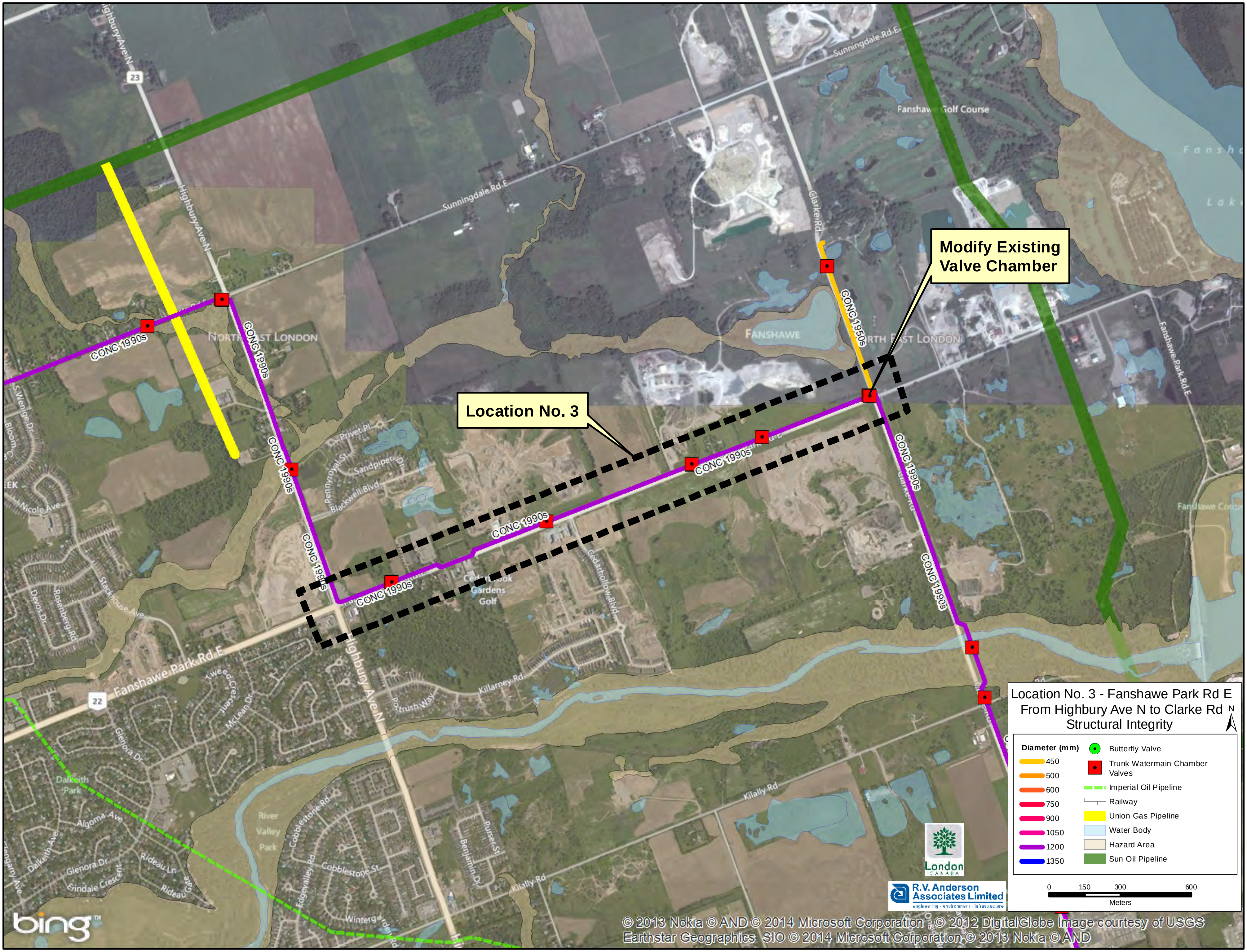

Location No. 3 - Fanshawe Park Rd E
From Highbury Ave N to Clarke Rd
Structural Integrity
Modify Existing Valve Chamber
Location No. 3
CONC 1990s
CONC 1950s
Sunningdale Rd E
Highbury Ave N
Clarke Rd
Fanshawe Park Rd E
Fanshawe Golf Course
North East London
Fanshawe
Kilally Rd
Killarney Rd
Cedarbrook Gardens Golf
River Valley Park
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0 150 300 600
Meters
London CANADA
R.V. Anderson Associates Limited
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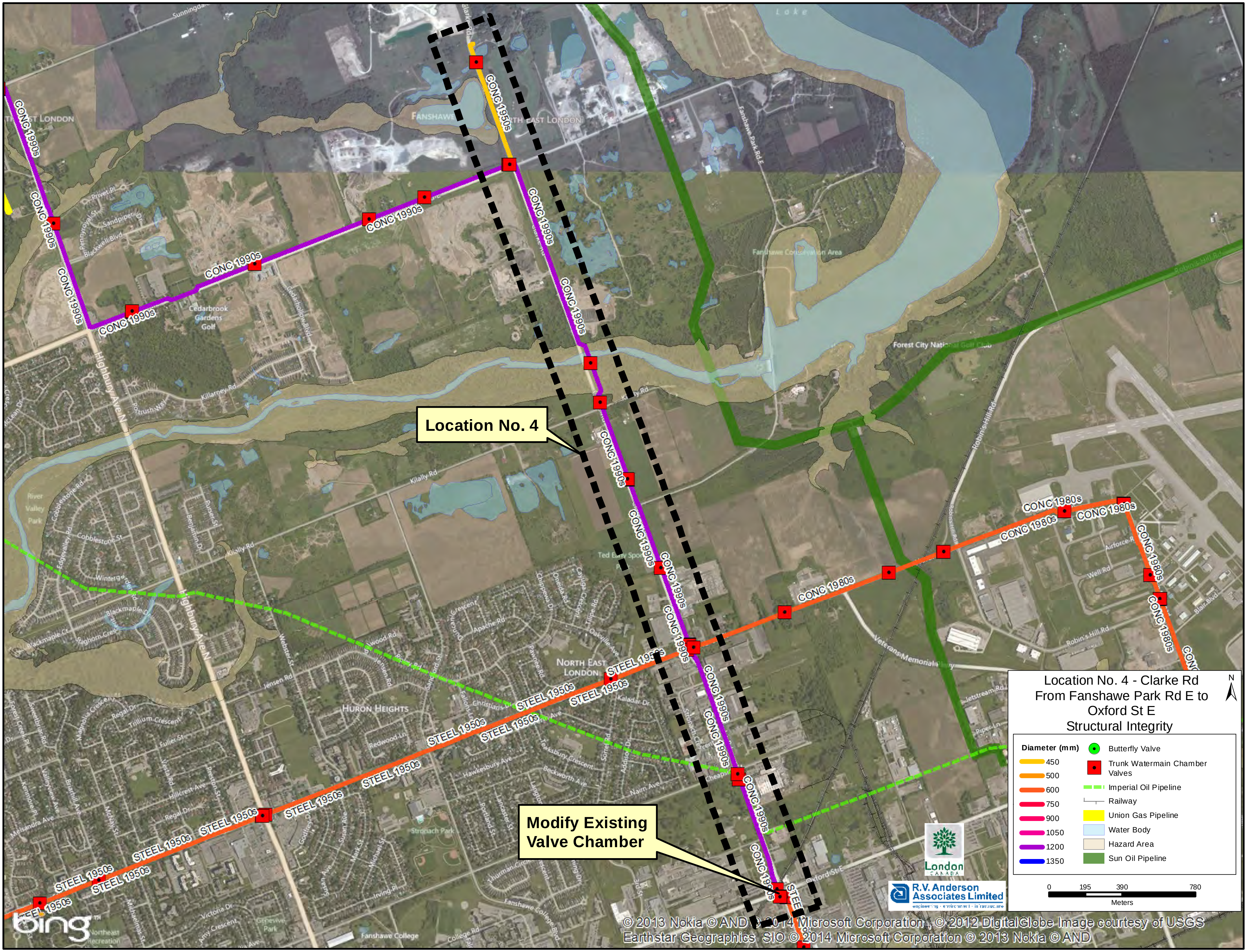
Location No. 4
Modify Existing Valve Chamber
Location No. 4 - Clarke Rd
From Fanshawe Park Rd E to
Oxford St E
Structural Integrity
N
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0
195
390
780
Meters
London
CANADA
R.V. Anderson Associates Limited
CONC 1950s
CONC 1990s
CONC 1980s
STEEL 1950s
North East London
Huron Heights
Highbury Ave N
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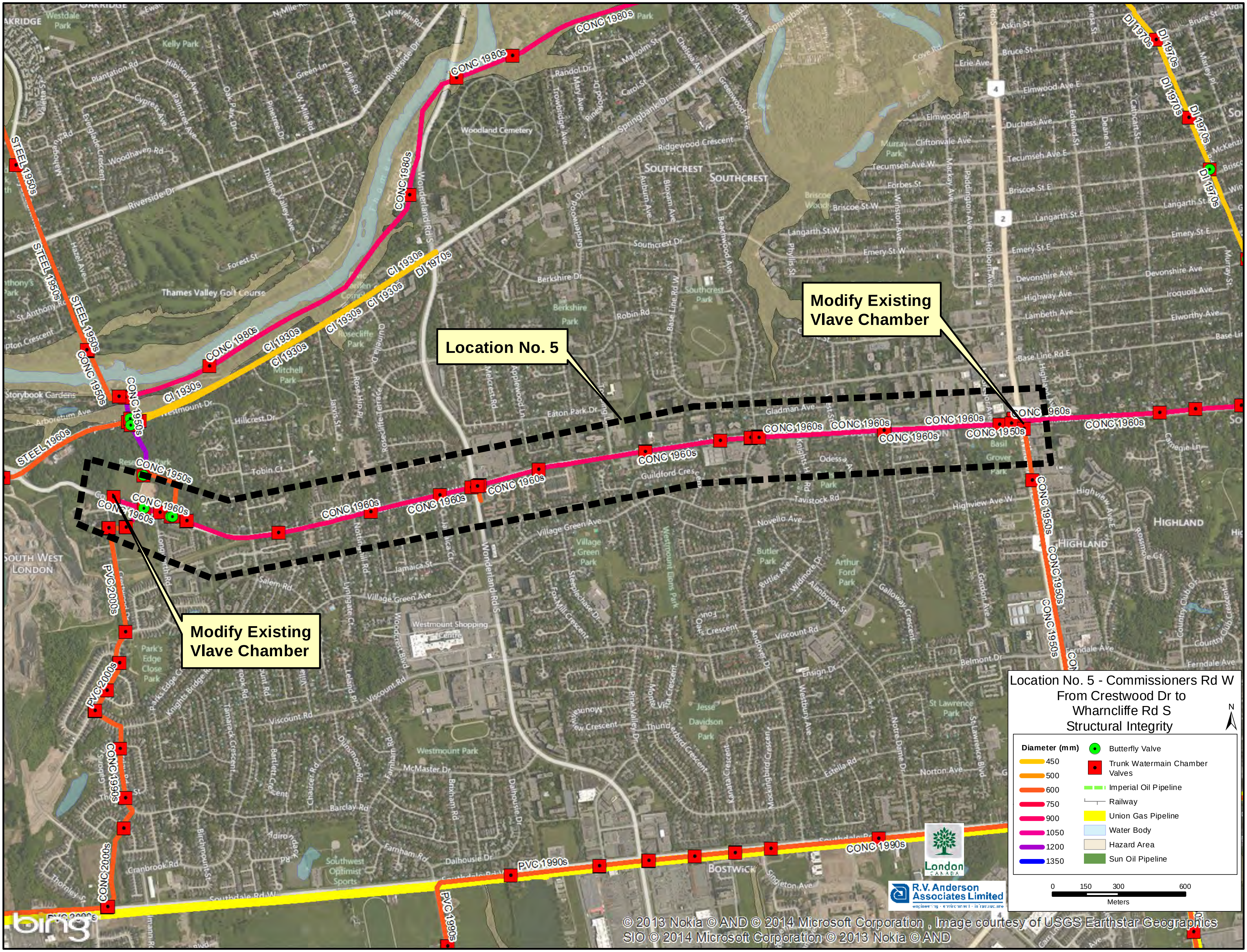

Location No. 5
Modify Existing Vlave Chamber
Modify Existing Vlave Chamber
Location No. 5 - Commissioners Rd W From Crestwood Dr to Wharncliffe Rd S Structural Integrity
N
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0 150 300 600
Meters
London CANADA
R.V. Anderson Associates Limited
CONC 1960s
CONC 1950s
CONC 1980s
CI 1930s
DI 1970s
STEEL 1950s
STEEL 1960s
PVC 2000s
CONC 1990s
PVC 1990s
CONC 2000s
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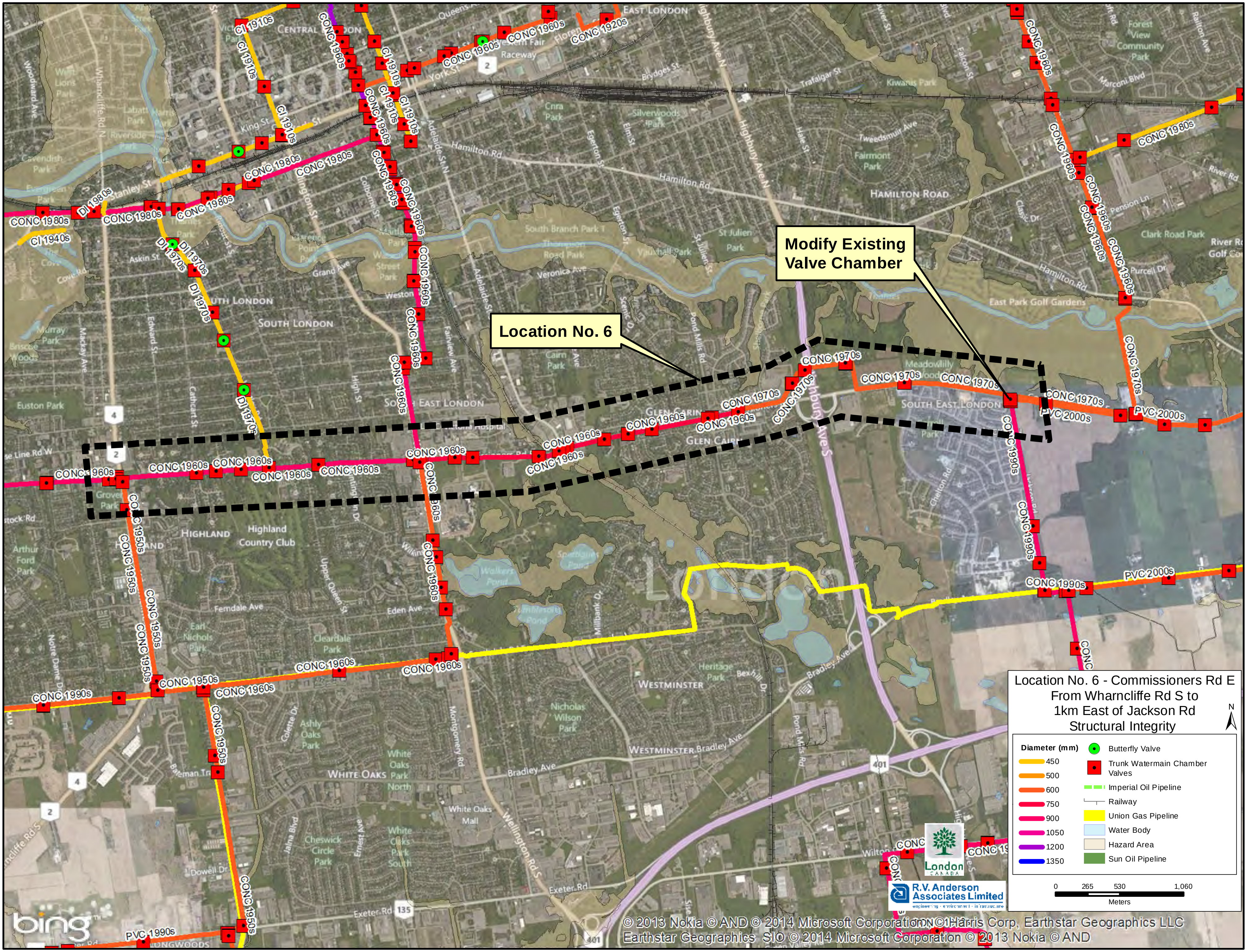
Location No. 6
Modify Existing Valve Chamber
Location No. 6 - Commissioners Rd E
From Wharncliffe Rd S to
1km East of Jackson Rd
Structural Integrity
N
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0
265
530
1,060
Meters
London CANADA
R.V. Anderson Associates Limited
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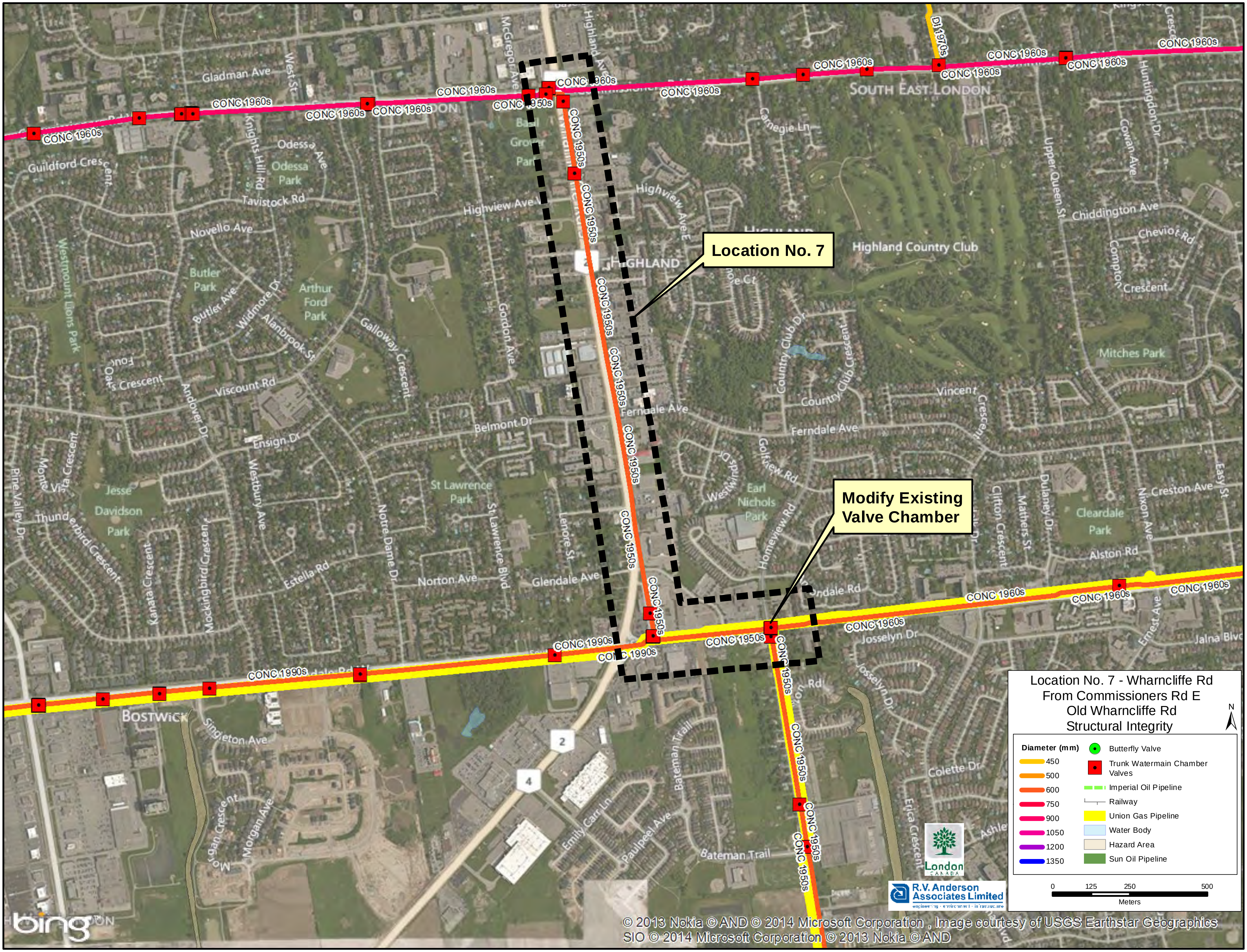
CONC 1970s
CONC 1960s
CONC 1990s
CONC 1950s
CONC 1980s
CONC 1920s
CI 1910s
CI 1940s
DI 1970s
DI 1980s
PVC 2000s
PVC 1990s
SOUTH LONDON
SOUTH EAST LONDON
GLEN CAIRN
HIGHLAND
WESTMINSTER
WHITE OAKS
HAMILTON ROAD
CENTRAL LONDON
EAST LONDON


Location No. 7
Modify Existing Valve Chamber
Location No. 7 - Wharncliffe Rd
From Commissioners Rd E
Old Wharncliffe Rd
Structural Integrity
N
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0
125
250
500
Meters
London CANADA
R.V. Anderson Associates Limited
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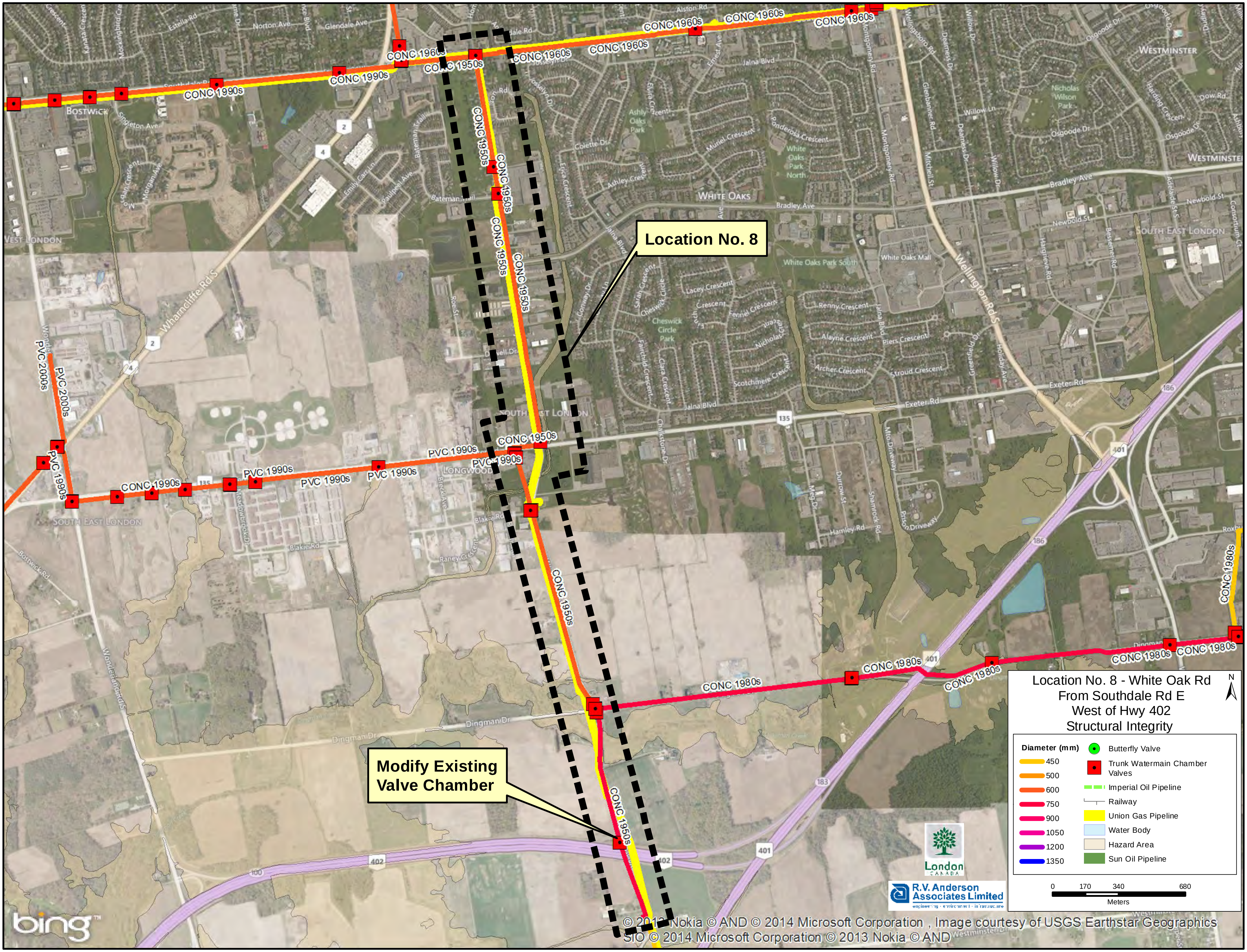
bing
CONC 1960s
CONC 1950s
CONC 1990s
DI 1970s
South East London
Highland Country Club
Highland
Bostwick
Ferndale Ave
Highview Ave
Glendale Ave
Belmont Dr
Mitches Park
Cleardale Park
Earl Nichols Park
St Lawrence Park
Jesse Davidson Park
Arthur Ford Park
Butler Park
Odessa Park



Location No. 8
Modify Existing Valve Chamber
CONC 1960s
CONC 1950s
CONC 1990s
PVC 1990s
PVC 2000s
CONC 1980s
Location No. 8 - White Oak Rd
From Southdale Rd E
West of Hwy 402
Structural Integrity
Diameter (mm)
450
500
600
750
900
1050
1200
1350
Butterfly Valve
Trunk Watermain Chamber Valves
Imperial Oil Pipeline
Railway
Union Gas Pipeline
Water Body
Hazard Area
Sun Oil Pipeline
0 170 340 680
Meters
N
London CANADA
R.V. Anderson Associates Limited
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bing