# ASSESSMENT, REHABILITATION AND REPLACEMENT OF THREE LARGE DIAMETER FEEDERMAINS IN THE CITY OF OTTAWA

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## INTRODUCTION

The “A”, “B” and “C” watermains are three of the most important and among the oldest large diameter feedermains in the City of Ottawa’s water distribution system. They are the sole supply pipes conveying water from the Lemieux Island Water Purification Plant and ultimately to 60% of the City`s population. The City of Ottawa’s potable water supply system dates back to 1874 and now includes two large water purification plants and a distribution network comprised of over 2400 km (1200 miles) of pipe supplying a population of over 804,000 people.

The following paper describes the City of Ottawa’s approach to conducting a comprehensive and proactive needs assessment study for these key watermains. The study was initiated and undertaken in recognition of the inherent risks stemming from an uncertainty in the condition and structural integrity of the ageing pipes. In addition, the study stems from a need to provide additional capacity for future growth, to accommodate urban renewal objectives in proximity to the location of the existing pipes and to enhance operational flexibility.

In describing the development and scope of the proposed replacement and rehabilitation program, the paper will highlight the following key aspects:

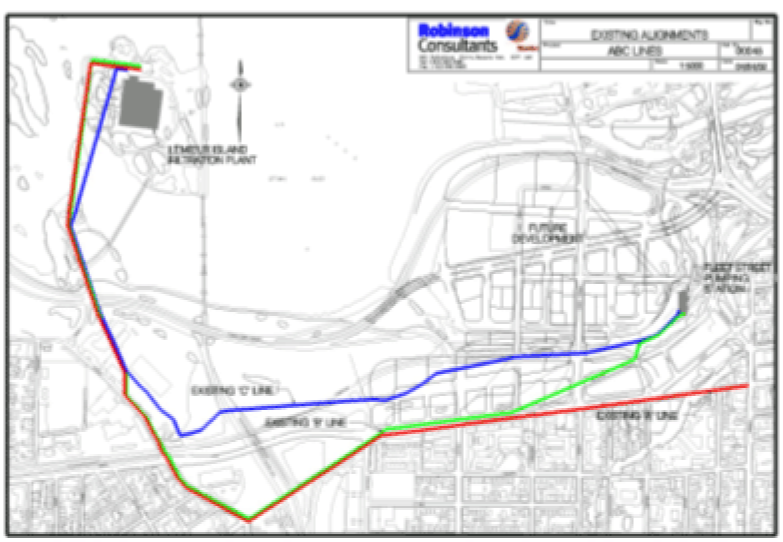
- a description of the constraints and opportunities associated with the unique site setting;
- the application of Value Engineering techniques in the development of a solution and in developing consensus amongst a wide range of stakeholders;
- a summary of the findings of a literature review and in-situ condition assessment of these uncommon types of large diameter pipe; and;
- a discussion on the development of a preferred solution and the selection of appropriate performance, design, construction and materials standards for feedermains of such importance to the overall water supply system.

## SYSTEM HISTORY AND DESCRIPTION OF WATERMAINS

By the beginning of the 20th Century, Ottawa was rapidly out-growing its existing infrastructure. Ottawa faced the new century with its own "Great Fire" in 1900 that was quickly followed by four more major alarms in three years. Not only was the capacity of the water distribution system not adequate to fight fires, the water was also untreated. As a result, records show that typhoid and cholera outbreaks claimed 512 lives over a period of fifteen years (1900 to 1915).

The City needed to improve and extend the intake water from beyond the now polluted Nepean Bay in the Ottawa River as well as construct a new system of feedermains to the existing and growth areas. Onset of the First World War had brought about yet another economic boom in Ottawa. Despite stormy controversy, Lemieux Island at the mouth of Nepean Bay was purchased for the construction of a "High and Low Lift Pumping Station" and sedimentation basins with hypochlorite water treatment. With these improvements, the "A and B Clear Water Conduit Lines" were designed and constructed from 1915 to 1917. The 'C' line was constructed in 1937 to provide additional system capacity.

The location of the 'A', 'B' and 'C' mains is shown on **Figure 1**. Two of the pipes (the low pressure 'B' and 'C lines) currently convey water from the Lemieux Island Water Purification Plant to the Fleet Street Pumping Station and the third (the high pressure 'A' line) is connected directly to the distribution network. The 1296 mm (51") diameter 'A' and 'B' watermains are made of "lock-bar" steel pipe (an old construction method consisting of two cast half pipe steel sections joined longitudinally with a locking metal bar). In some sections, the pipe is constructed as a double wall riveted steel pipe. The 'C' line is a 1200 mm (48") diameter reinforced concrete cylinder pipe. Each of the three pipes is approximately 2.4 to 2.8 km (1.4 to 1.7 mi) long. Key details of the 'A', 'B' and 'C' mains are summarized in **Table 1.**



## FIGURE 1: EXISTING WATERMAINS

The study area shown on **Figure 1** is commonly known as LeBreton Flats. The LeBreton Flats area has a long history of urban renewal and was previously occupied by industries, railway lands, landfills, automotive service stations, and warehousing. The residential developments that previously existed on Lebreton Flats were demolished in the 1950's. The buildings were removed and much of the rubble, ash and charred wood from the removal of the buildings remain on site within areas converted to landfill.

The pipes are now located within and adjacent to an area of historical significance as well as within an area where past land uses have resulted in a site where the soils are known to be contaminated with highly corrosive materials.

**TABLE 1: DESCRIPTION OF 'A', 'B' and 'C' FEEDERMAINS**

<table>
<tr><th>Line</th><th>Dimensions</th><th>Material</th><th>Age</th><th>Function</th></tr>
<tr><td>A</td><td>51 inch diam.<br>2.8 km long</td><td>Cement-lined lock bar (thin-walled steel)</td><td>87 yrs</td><td>Supplies water at high pressure from Lemieux Island to the distribution system.</td></tr>
<tr><td>B</td><td>51 inch diam.<br>2.8 km long</td><td>Cement-lined lock bar and double wall steel riveted (thin-walled steel)</td><td>87 yrs</td><td rowspan="2">Together, these two pipes supply water at low pressure from Lemieux Island to the Fleet Street Pumping Station, and from there to the distribution system.</td></tr>
<tr><td>C</td><td>48 inch diam.<br>2.4 km long</td><td>Reinforced concrete</td><td>65 yrs</td></tr>
</table>

## NEED FOR ASSESSMENT AND PROJECT OBJECTIVES

The 'A, 'B' and 'C' Lines currently provide water to over 400,000 customers. The needs assessment stems from the requirement to determine the condition of the existing mains and to ensure that the water distribution system maintains appropriate supply capacity and reliability in both the near and long terms. The main issues with respect to these lines include:

**Pipe Condition** - These pipes are some of the oldest and largest in the City. Condition assessment data available at the time of the study did not indicate that pipe failure was imminent; however, there were signs that the pipes had been subjected to corrosion and were showing signs of degradation due to age;

**Rapid Community Growth** - Higher rate of population growth than predicted in the 1997 Official Plan and continued population growth for the areas served by the Lemieux Island Water Purification Plant led to a re-evaluation of the timing of capacity upgrades. The conclusion was that upgrades would be required within a 10 year timeframe;

**Increasing Water Demands** – Higher than initially projected water demands are observed given that previously recommended water efficiency strategies have not been implemented. The capacity of the pipes must thus be increased to meet these future water demands;

**Urban Renewal** - Relocation of a major portion of line 'C' and part of line 'B' will be required, in the next 5 to 10 years, to accommodate the LeBreton Flats redevelopment and the realignment of a major Transit bus corridor (West Transitway). A proposed sewer rehabilitation project on Bayview Road will also require the relocation of segments of the 'A' and 'B' lines within the next 5 years;

**Water Quality Standards** – There is a requirement to maintain existing water quality standards and potentially the need to meet higher future standards. Upgrades to the watermains will ensure that the integrity of the system is maintained and protected.

Due to the combination of factors mentioned above, it was determined that there was an immediate need to assess the condition of the mains and study alternatives for the rehabilitation and/or replacement of these key components of the overall network.

## CONDITION ASSESSMENT OF THE 'A', 'B' AND 'C' LINES

### General Approach

There have been a number of recent developments in non-destructive evaluation (NDE) for the inspection of watermains in recent years. These techniques have generally been developed to inspect gray cast iron, ductile iron, PVC and pre-stressed concrete pipes. Many of the techniques are also limited to small diameter (<450mm) pipes.

To define the most appropriate condition assessment approach the National Research Council's Institute for Research in Construction (IRC) completed a comprehensive literature search to review the history of similar pipe and to determine condition assessment approaches applied by other water authorities. The IRC also completed a survey of North American municipalities to determine which jurisdictions currently have lock bar pipe in their systems and their experience with this type of pipe.

**History of Lock-bar Pipe**

Lock-bar steel pipe is made by rolling steel plate into a cylinder then joining the two edges of the curved plate together (Refer to **Figure 2**). The joint is made by placing a long thick strip of metal, with an H-shaped cross-section, over the two edges. The strip is then hammered to close and seal the pipe. Lock bar pipe-to-pipe joints are typically fastened together by rivets, although some pipe was welded together during rehabilitation.

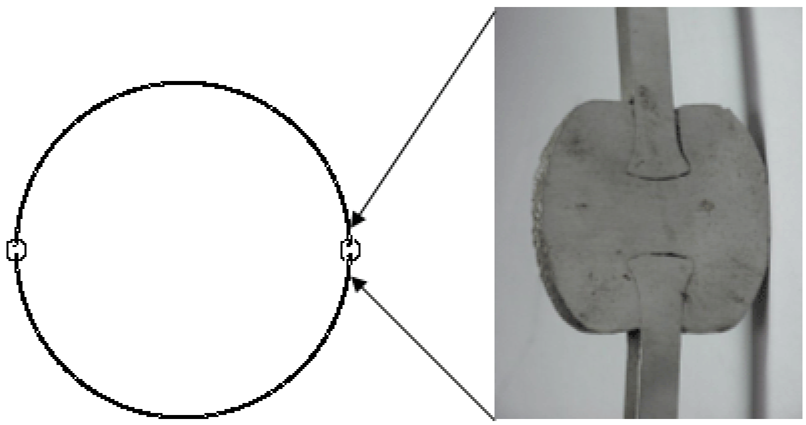


**FIGURE 2 – LOCK BAR PIPE**

The technique for constructing lock bar pipe was developed in Australia in 1896. The lock bar pipe was designed to be a light pipe to transport to remote areas without the capabilities to cast large diameter pipes. The pipe was first used for water distribution applications in 1897 with the start of the 915 mm diameter, 557 km long Coolgardie line in Australia. External pitting was first noted in the Coolgardie line (Engineering News, Anonymous 1911) in 1905, or approximately 7 seven years after construction had begun and only two years after the line was fully operational. In the following three years, over 150 leaks were detected. These leaks were all attributable to external corrosion. Investigations indicated that the line was also subject to internal corrosion, where serious tuberculation was detected. Ruptures due to lock bar failures were also being tracked, but found to be insignificant with only two failures by 1910.

**Experience with Lock-bar Pipe in Other Areas**

The use of lock-bar in North America was not as widespread as in other parts of the world. This was due to the availability of large diameter cast iron pipe as an alternative. However, our research did locate several municipalities with lock-bar in their water distribution system. These municipalities, including one authority in

Australia, were subsequently contacted for information on their experiences with this type of pipe.

It was found that most water authorities have experienced significant leakage problems with lock bar pipe including one water authority that has completed over 3000 spot repairs on a 19 km section of such pipe. As a result, several water authorities have implemented corrosion prevention measures including cement mortar lining, impressed current systems, cathodic protection and even moving the pipe above ground to mitigate external corrosion.

Based on the experience of these other jurisdictions, three different corrosion based failure modes were identified for lock bar pipe:

- Internal corrosion producing pits that have eventually penetrated the pipe wall and caused leaks,
- External corrosion producing pits that have eventually penetrated the pipe wall and caused leaks, and,
- Less frequent occurrences of pipe rupture have been reported when corrosion has preferentially attacked either the lock bar or the rivets along the joints. This type of corrosion likely occurs due to the differences between metals of the pipe components.

**Approach to Condition Assessment**

Four distinct groups of condition assessment methods were initially considered for the 'A', 'B' and 'C' lines. These were:

1) *Assessment of the overall condition of the pipe by leak testing;*
2) *Mechanical testing and failure analysis of a pipe sample;*
3) *Assessment of the external condition of the pipe using vacuum excavation equipment. Select locations to examine based soil chemistry, half cell potential measurements of current corrosion activity, soil type, water table elevation, land use (previous and present); and;*
4) *Assessment of the interior condition of the pipe by CCTV Investigation.*

A phased approach to the condition assessment was implemented and, ultimately, only a preliminary investigation was undertaken before a conclusion on the pipe condition was reached. The results are discussed below:

*1) Leakage Test*

Leakage testing was completed on line 'B' (Lines 'A' and 'C' could not be taken out of service for testing). The purpose of the test was to determine the amount of leakage from the mains at a known pressure. The testing was completed by isolating sections of the line 'B' and by measuring the amount of water added to the mains to maintain the test pressure. The test pressure varied from 20 psi to 35 psi. The measured leakage rate was found to vary from approximately 4 to 1500 times greater than the expected leakage rate based on Ministry of Environment criteria for a new pipe (results were extrapolated to reflect the lower test pressures).

*2) Pipe Sample Testing*

A section of ‘A’ line was salvaged as part of a previous contract that required a connection to this line. The sample is shown in **Figure 3** and was located in non-contaminated and well drained soils which is not the case for a significant portion of the ‘A’, ‘B’ and ‘C’ Lines. Given that the trench conditions from where the sample was removed are considered to have a low corrosion potential, a much higher level of corrosion is expected to have occurred at other locations along the main. The pipe sample was therefore considered to represent a best case scenario for the overall condition of the pipe. A visual inspection of the pipe sample was completed and the results are generally described as follows:

- The pipe appeared to have been originally wrapped in a bituminous impregnated burlap coating. Most of the coating was no longer present on the pipe sample;
- The exterior pipe wall had many corrosion pits including pits that appeared to be at least 50 % through the pipe wall;
- A number of the rivets showed corrosion damage;
- The cement lining was thinnest over the lock bar and the bar inside the pipe was significantly corroded. There appeared to be a tendency for the formation of longitudinal cracks in the lining on either side of the lock bar. This may have exposed the lock bar to corrosion;
- Some of the cement mortar lining was very soft and red in colour. This mortar appears to have been penetrated by corrosion products from the pipe. It is likely that this damage occurred while the pipe was in service; and;
- The exterior lock bar also showed signs of serious corrosion damage.

**FIGURE 3: ‘A’ LINE SAMPLE AT BRONSON AVENUE**

*3) Assessment of External Corrosion Potential*

The exterior of the pipe was not examined as part of the study due to the cost and the potential for damaging the pipes. A Limited Phase I Environmental Site Assessment was, however, completed to identify the sites that could contribute to the exterior corrosion of the existing pipes. The sites were rated as having a potential corrosion level of high, medium or low based on the following criteria:

| | |
|---|---|
| High | corrosive environment strongly suspected |
| Medium | corrosive environment likely |
| Low | corrosive environment not likely |

A total of fifty-six (56) sites of concern were identified in the Limited Phase 1 ESA. Seventeen (17) sites were classified as having "high" corrosion potential with another nine (9) identified as having "medium" corrosion potential. A summary for each main is provided in Table 2.

**TABLE 2: CONTAMINATED SITES IN PROXIMITY TO THE 'A', 'B' AND 'C' LINES**

| Watermain | Medium Corrosion Potential | High Corrosion Potential |
|---|---|---|
| 'A' Line | 1 | 5 |
| 'B' Line | 4 | 6 |
| 'C' Line | 2 | 3 |

*4) Assessment of Internal Corrosion*

An inspection of the interior of the pipes was not completed as part of this project for the following reasons:

- Access points were too far apart to permit internal CCTV investigation
- Dewatering the pipes for inspection could have compromised the pipes' structural integrity and prevented recommissioning
- The pipes could not be effectively isolated to provide safe access
- Manned entry was considered too dangerous due to the age of the pipes and the valves.

Sections of 'A' and 'B' lines near the Lemieux Island water treatment plant site were replaced in the early 1990's as part of a previous upgrade contract. An inspection of the pipe interiors was completed at that time and confirmed that the in-situ applied cement mortar lining was missing in certain areas and that the exposed steel had corroded.

**Condition Assessment Conclusions**
In summary, the condition assessment program revealed the following:

- Line 'B' is leaking. Given that Line 'A' was installed adjacent to and at the same time as Line 'B', it is also assumed to be leaking.
- An inspection of a sample of Line 'A' showed signs of lining delamination, interior corrosion, exterior corrosion pitting, corrosion of the rivets and serious corrosion of the lock bar.
- An investigation of the past land uses identified many sites along the existing watermain alignments with medium to high corrosion potential.
- A previous inspection of the pipe interior confirmed that the pipe was corroded where the in-situ applied cement mortar lining was missing.

This data indicated that the pipe had been subjected to interior and exterior corrosion. It was also confirmed that the lock bar was subjected to corrosion and that failure of the lock bar could lead to a rupture of the pipe.

In consideration of the above results combined with the factors listed in the problem definition section of this paper, it was clear that rehabilitation and/or replacement of the pipes was necessary. It was therefore concluded that no further condition assessment investigations were necessary and that alternatives for their upgrade needed to be investigated.

## APPLICATION OF VALUE ENGINEERING TO THE PROJECT

The 'A', 'B' and 'C' lines assessment project was recognized as having an impact on a number of stakeholders. It also presented a number of issues and challenges that required input, expertise and consensus from a wide variety of individuals representing a range of disciplines. A Value Engineering (VE) Team consisting of members from the project consultants, the City of Ottawa and affected agencies was formed.

The project team recognized that Value Engineering can be used as an effective tool to define a project and if conducted at an early stage in the life of the project, the greatest benefits in terms of overall life-cycle cost savings could be achieved. This is primarily because the project definition itself and the selection of appropriate criteria have the biggest impact on the development of the preferred solution. The process not only provided an effective forum for building consensus amongst the project team, it also provided a formalized process that lead to a focus on the critical project objectives, criteria and feasible solutions and provided a clear direction on the steps for the project. In the experience of the City of Ottawa and its consultants, the process also proved itself to be a great team-building exercise.

## RESULTS OF THE VALUE ENGINEERING PROCESS

The key objectives and goals of the three (3) day VE Session were to:

- Confirm the functional objectives of the 'A', 'B' and 'C' lines within the water distribution system;
- Develop 2-4 feasible alternatives to be assessed in more detail following the VE Session; and;
- Determine criteria and weightings for evaluation of the alternatives.

During the VE Session, the VE Team evaluated many ideas with respect to their potential for adding value to the project and for addressing the objectives of the study. Based on the identified functional objectives related to system capacity, operational flexibility and system reliability, the conclusion of the VE team was that the system requirements were for the three existing pipes (Lines 'A', 'B' and 'C') to be replaced with two new pipes.

The requirements were thus identified as:

- Providing a new low-pressure pipe, in a new alignment, from Lemieux Island WPP to the Fleet Street Pumping Station that also has the ability to connect directly to the distribution network and having the ability to serve as a high pressure back-up discharge line from Lemieux Island WPP; and;
- Providing a high-pressure pipe, within the existing 'A' Line alignment, from Lemieux Island WPP to a direct connection to the distribution network at Bronson at Laurier.

The VE Session also provided direction for further analysis of specific pipe alignment and rehabilitation/upgrade alternatives that are discussed in the following sections of the paper.

## ASSESSMENT OF PIPE ALIGNMENTS AND FUNCTIONAL DESIGN

### Hydraulic Assessment and Pipe Sizing

A calibrated hydraulic model of the City's water distribution system was developed and applied in determining the sizing requirements for the proposed pipes as well as to confirm operational pressures along the pipes for the various alignment alternatives. Based on the modeling results, which also considered future system growth and capacity requirements, the pipe diameters were determined to be 1675 mm and 1980 mm for the low and high pressure mains respectively. The final piping arrangement will also make use of a section of the existing 'A' line piping which links two key distribution mains. This section of main will be rehabilitated to a minimum diameter of 1050 mm using a trenchless technology.

### Evaluation of Pipe Alignment Alternatives

The ‘A’, ‘B’ and ‘C’ Lines study was conducted following the guidelines set out in the Municipal Engineer’s Association’s (MEA) Class Environmental Assessment (Class EA) Process for Municipal Water Projects. Since the proposed modifications also had the potential to impact federally (i.e. National Capital Commission) owned lands, the requirements of the Canadian Environmental Assessment Act were also incorporated into the assessment. Alternatives were evaluated on the basis of their technical feasibility, their impacts on the natural and social environment, construction issues and overall costs. The key constraints common to all alternative alignments included the contaminants present from past land uses, the proposed redevelopment plans for the study area, as well as construction staging and safety. The preferred pipe alignments are shown on **Figure 4**.

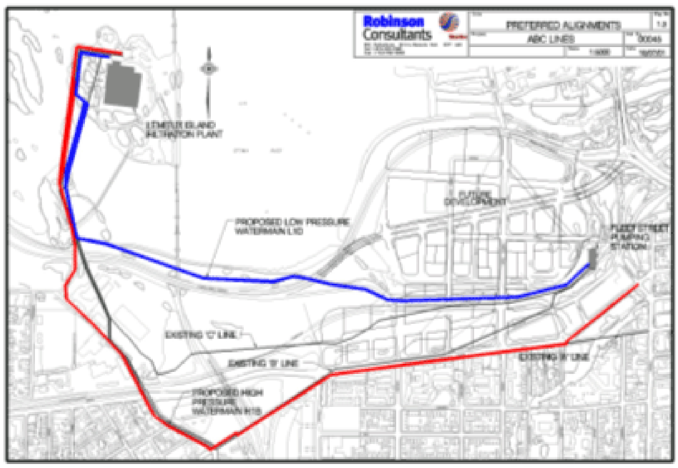



**FIGURE 4: PREFERRED PIPE ALIGNMENTS**

*Challenges Related to Contaminated Soils*

The proposed replacement watermains generally traverse through, or adjacent to, an area known as LeBreton Flats. As previously discussed, this area poses a number of challenges related to the site’s previous land uses. The preferred alignments were selected with consideration for the cost of disposing of the contaminated soils, the cost of treating the contaminated groundwater, the safety considerations and risks of working with contaminated materials, and the potential long-term impacts of the contaminants on the proposed watermain materials.

*Challenges Related to Groundwater Control*

LeBreton Flats is bordered to the north by the Ottawa River. Geotechnical investigations revealed that due to the highly porous nature of the landfill material and the hydraulic connectivity with the Ottawa River, excavations below the groundwater table will require a method of limiting the groundwater flow into the construction excavation. Due to the hydraulic conductivity of the landfill areas, the potential also exists for the dewatering operations to impact the hydraulic gradient and the subsequent movement of contaminated groundwater.

A band of non-contaminated rock fill along the Ottawa River shoreline was ultimately selected as the preferred corridor for the low pressure watermain. Due to the potential impacts of the groundwater flow on construction and contaminant movement, the final watermain alignment was selected to position the watermain above the water table where possible. Careful consideration was also given to the watermain profile to ensure that the hydraulic grade line was maintained safely above the top of the pipe and groundwater level to avoid a loss of pressure that could permit groundwater inflow into the pipe.

*Challenges Related to Future Development Plans*
Current land use planning for the LeBreton Flats area proposes the redevelopment of the site with mixed residential, business and public uses. A major public transportation link will also bisect the site. The watermain alignments were evaluated with consideration for their impact on these redevelopment plans and in consultation with the National Capital Commission, the site's owner, to ensure that their redevelopment needs were addressed. The preferred alignments for the watermains are outside of the proposed development boundaries or are in public right-of-ways.

*Challenges Related to Valving and Construction Staging*
Another key consideration in the selection of a preferred alternative was a recognition that the construction would have to be conducted and staged in a manner that had minimal impact on the operation of the water distribution system. Decommissioning and isolation of various segments of the system is difficult due a lack of reliable valves on these old and very large feedermains.

The preferred solution allows for the staged construction of the low pressure line without any impact on the system other than for connections to the Water Purification Plant and to the Fleet Street Pumping Station. The existing Line 'A' will provide the required water supply to the distribution system while the connections are made.

Once the new low-pressure line is constructed and operational, the existing 'A' Line can be decommissioned and the new high pressure line can be constructed.

## SUMMARY

The condition assessment and future needs study for three of the largest watermains in the City of Ottawa's water distribution system presented a number of unique challenges. Foremost amongst these challenges was the fact that the ageing pipes are critical components of the overall distribution system and were constructed at the turn of the 20$^{th}$ Century using an uncommon pipe construction method consisting of thin-walled steel pipe sections. Experiences in other jurisdictions having this “lock-bar” pipe show that they are prone to corrosion that can eventually lead to severe leakage and ultimately structural failure.

Being that the pipes are located in areas where the soils and groundwater are known to be contaminated, the risks were considered high enough to merit a proactive approach to rehabilitation of the mains. Furthermore, the condition of the in-line valves is now such that it does not permit full operational flexibility and the ability to isolate the individual pipes for a direct condition assessment or repairs if necessary.

Considering these issues as well as the need to upgrade the pipes to provide additional capacity for future growth and relocate significant segments to accommodate urban renewal objectives in proximity to the location of the existing pipes, it was concluded that the three existing pipes would be replaced by two new large diameter watermains (1675 mm and 1980 mm). An assessment of various pipe alignment alternatives was conducted in accordance with the requirements of the Municipal Class Environmental Assessment Process. The preferred solution was ultimately to construct one of the pipes (low-pressure pipe) in a completely new alignment which would then allow for the decommissioning of the existing mains and the construction of the new high-pressure pipe within the same alignment as one of the existing pipes. The proposed solution also addressed future growth requirements and urban renewal objectives adjacent to the existing pipes.

**ACKNOWLEDGEMENTS**

The authors of the paper wish to acknowledge the significant participation of other project team members whose work is reflected in this paper:

Jon Makar, Ph.D., P.Eng. and Dr. Jack Zhao, Ph.D., P.Eng, Institute for Research in Construction, National Research Council of Canada

Pierre Maheux, M.Sc., P.Geo. and Fred Griffiths, Ph. D., P.Eng., Jacques Whitford and Associates Ltd.

Ian Doherty, P.Eng., Trenchless Design Engineering Ltd.

Steve Taylor, P.Eng., National Capital Engineering

Kim Howie, P.Eng., Robinson Consultants Inc.

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