Waterline Restoration Based on Condition Assessment – A Case Study

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Introduction

Waterlines comprise well over half of a water utility's built infrastructure. Most of our waterline infrastructure is over forty years old and, with age, leaks and breaks increase, causing concern about water quality, system dependability, and public risk. Yet, waterline restoration must compete for limited dollars within water utility budgets.

Using "break" history criterion to replace waterlines typically results in replacement of some deteriorated waterline segments as well as the replacement of many waterline segments that have substantial remaining useful life. In other words, this single criterion is not cost efficient. More waterlines can be restored within a given budget through the use of a structural condition assessment technology, such as Remote Field Technology (RFT).

This paper describes the City of Calgary's use of RFT to establish an asset management approach to waterline restoration. The approach enables the city to establish priorities that enhance optimum utilization of budgeted funds. The technology is described as it is used in the field. RFT results have been confirmed by visual examination of samples of excavated cast-iron and ductile-iron pipe. The city's use of RFT data to pro-actively restore waterlines is presented, along with an analysis of resulting avoided costs.

Waterline Prioritization

"Break" history, the number of breaks over a given length of line in an established time period, is a common method of prioritizing waterlines for replacement or restoration. This method of line selection is not always cost-effective as it usually results in wholesale replacement of a length of waterline without knowledge as to the remaining useful life of the entire line. Waterline breaks typically can be traced to corrosion, which does not occur consistently, nor can it be predicted over a length of line. Severe corrosion in a few areas of a waterline does not mean that there is corrosion in other areas of the same waterline. Thus, replacement of waterlines based on "break" history results in the replacement of miles of waterline of which the condition is not known. This practice may be considered imprudent when funding is limited and needs are great.

The pro-active waterline distribution manager requires more knowledge as to the condition of the waterlines. Such knowledge may be derived from the collection of data regarding soils characteristics, pipe materials, types and location of service connections, visual inspection of exhumed pipe, and operating conditions. Various combinations of this data combined with "break" history may suggest trends in corrosion rates, allowing the manager to prioritize waterline for replacement in a more effective manner.

However, even with improved prioritization tools, the distribution manager has only gained a better focus as to waterline replacement needs. The additional data still fails to provide detailed knowledge as to the condition of the waterlines. A final step is necessary to complete an accurate condition assessment and, thus, allow for optimization of limited financial resources. RFT is the tool used by the City of Calgary.

Remote Field Technology

Remote Field Technology has been used in oil well field and industrial boiler inspections for decades. Only recently has a tool been developed and patented for use in the water utility industry. For waterline inspection, the RFT circuitry is imbedded in sealed modules that are connected to each other to form a flexible mechanical probe (the RFT tool). The modules, made of stainless steel, are connected to a host computer via a 3,000-foot cable. The modules are connected to each other by U-joints, enabling the entire device to traverse bends and tee paths within the pipe. The tool can be easily inserted into a water pipe at a fire hydrant or other convenient access point. Once inside the pipe, the tool is propelled through the pipe either by water pressure or by pulling the tool through a dry line. Figure 1 is a diagram of the tool.

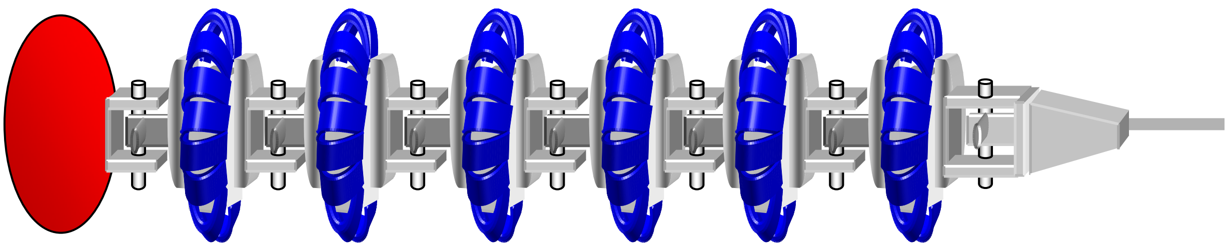


Figure 1- A flexible RFT tool.

Waterline inspection by Remote Field Technology results in the ability to locate and measure areas of corrosion and other defects. RFT measures the wall thickness of a pipe by passing an electromagnetic signal through the pipe wall. Changes in the signal are analyzed, resulting in identification of pipe defects. By passing a low frequency current through an exciter coil, the coil is able to generate and emit electromagnetic fields. The electromagnetic field attenuates or weakens with distance and shifts in phase as it travels away from the exciter coil. Two distinct coupling paths exist between the exciter and the detector coils: the direct path, which is down the inside of the pipe; and the indirect path, through the pipe wall near the exciter, down the outside of the pipe, and then back through the pipe wall near the detector. The RFT technique is centered on the electromagnetic field that follows the indirect path. Figure 2 is a diagram of the RFT technology.

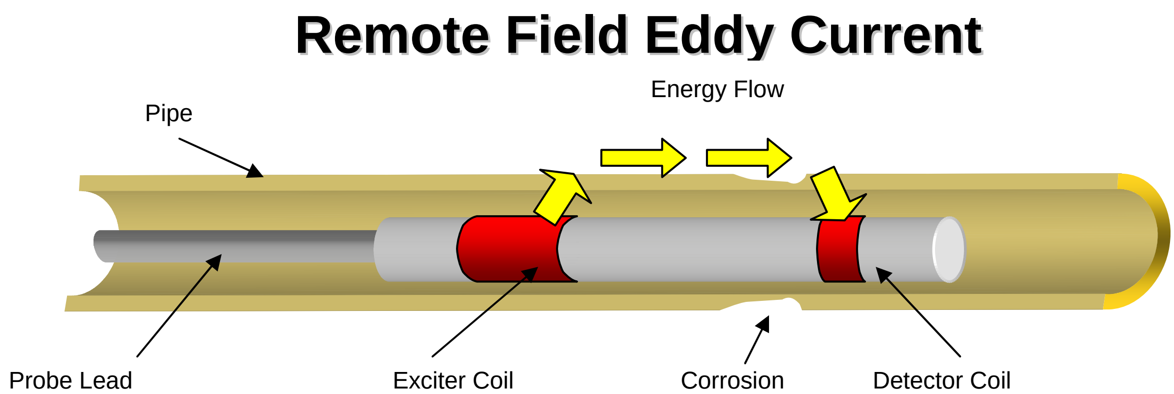


Figure 2 – RFT method

By the time the field reaches the detector coil, the field from the indirect route is greater than that from the direct one, thus dominating the remote field. The attenuation and phase delay of the electromagnetic signal that follows the indirect path is sensitive to changes in wall thickness, allowing corrosion pits and wall thinning to be detected.

The tool records data only when moving. The tool is designed to take two readings of the same stretch of pipe: the first, when the tool is initially propelled through the pipe; and the second, when the tool is being retrieved. Readings are amplified, filtered and digitized for transmission to the above ground computer. One data set is obtained every 1.5 mm of travel. The computer then gathers, processes, and stores data for analysis. The data analysis results in a condition assessment report, detailing the condition of each pipe segment.

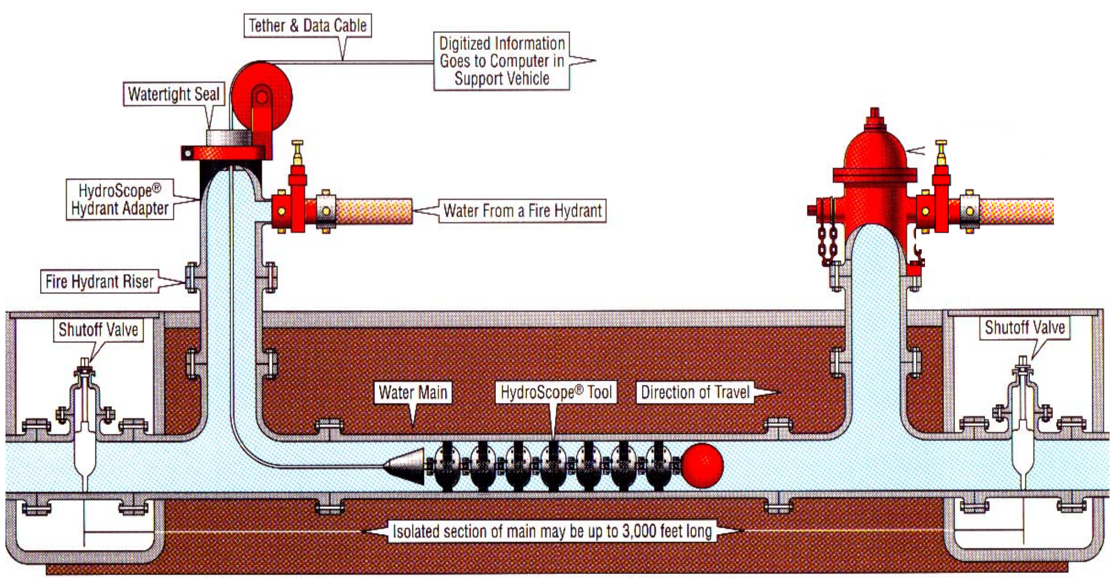


Figure 3 – The RFT tool is inserted through a fire hydrant and propelled by water flow down the waterline.

Figure 3 is a depiction of the tool being routed through a waterline, accessed through a fire hydrant. The top works of the hydrant are removed and a Hydrant Adapter is installed. The pipeline section to be inspected is isolated from the system, and the tool is inserted. The Adapter is closed and water from another hydrant is used to propel the tool through the waterline. The tool is retrieved by the tether, and the line is disinfected and returned to service.

City of Calgary Approach

Validating RFT

During a seven-year period (1993-1997), the City of Calgary undertook an aggressive study to examine the physical condition of water mains and identify the factors that affect the corrosion process. The city contracted with Hydroscope Canada the developer of a proprietary RFT tool for waterline condition assessment. The accuracy of the Hydroscope readings was verified via comparison to actual pit depths measured on sample pipes that were later exhumed and replaced. Results of this work were presented at length at the AWWA Infrastructure Conference in 2001 [Kozhushner, 2001] and will be summarized below.

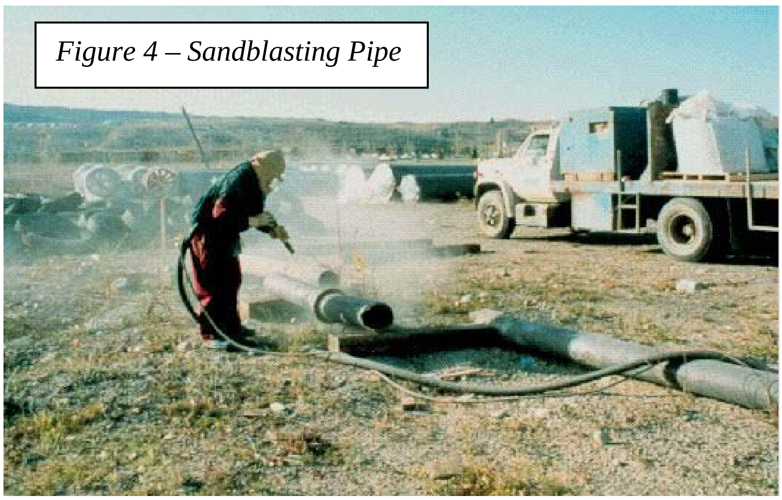


Figure 4 – Sandblasting Pipe

A few mains condition-assessed by Hydroscope were selected for accuracy verification. This included mains that had either high failure records or were practically without failure. These were condition-assessed (Hydroscoped) and samples recovered for examination, to verify Hydroscope accuracy on a full spectrum of pipes; the total research included every pipe material in all conditions, from the worst to the best.

The pipe recovery sample size for a given job was generally just over 100m; several samples were performed each year for a total of nearly 2000m of pipe. A great deal of data about these pipe sections and the soil in which they were bedded was collected. For Hydroscope accuracy verification, the pipe sections were laid out in a field in duplication of their original order, and sandblasted (see Figure 4) to reveal all of the corrosion pits and holes normally filled with graphite plugs.

The pits were all recorded as part of the research effort to connect corrosion with other factors such as soil chlorides, sulphates and redox potentials; and correlated to Hydroscope data: the three deepest pits on any given pipe-length of main.

A system for categorizing the Hydroscope pit-depth findings versus the visual measurement was developed. A set of four "bins" was selected, matching the interests of the engineer evaluating the pipe:

1. Through-holes and pits leaving under 20% wall remaining thickness (W.R.T.)
2. Pits leaving between 20% & 40% W.R.T.
3. Pits leaving between 40% & 65% W.R.T.
4. Pits leaving over 65% W.R.T.

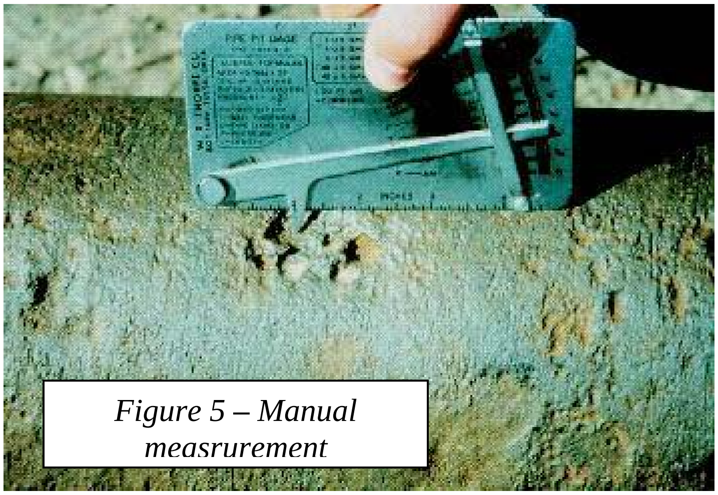
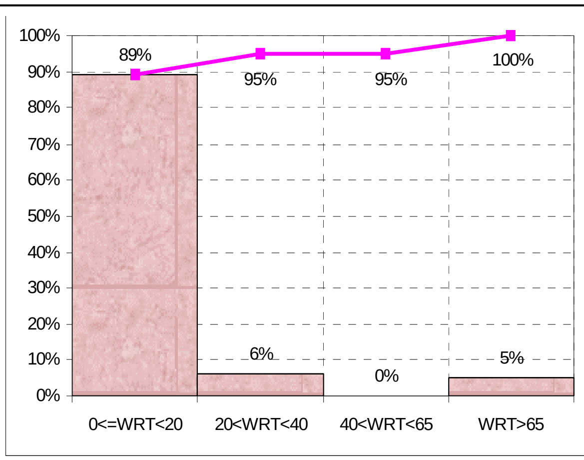


Figure 5 – Manual measrurement

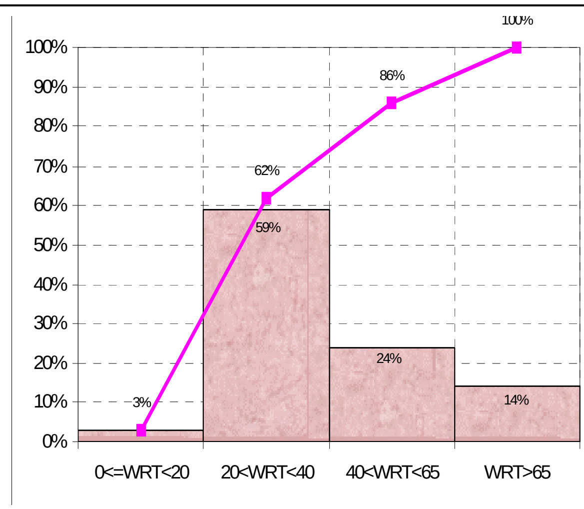
Each Hydroscope pit datum was compared to the appropriate pit in the actual pipe. Results of the comparison of visual measurement to Hydroscope findings are summarized in the graphs below (Figure 6). All graphs are for the data collected in 1999, which showed higher accuracy from the Hydroscope process than 1998, indicating dramatic improvement in the data interpretation - partly due to collaboration between Calgary and Hydroscope.

It must be noted that visual measurement data can vary from Hydroscope condition assessment data due to various factors. One such factor is the reliability of the Hydroscope technology, which is the purpose of the analysis. However, variance can also be the result of tight clustering of pits that are measured by Hydroscope as a single defect, the existence of graphitization that may not have been removed by sandblasting, and interior wall defects. Each of these variance factors can distort the comparison efforts. In all of these cases, the volume of metal missing at any location is actually detected better by the Hydroscope than by pit-depth measurement. Therefore, the results of the comparisons could only be favorably enhanced if these conditions were known.

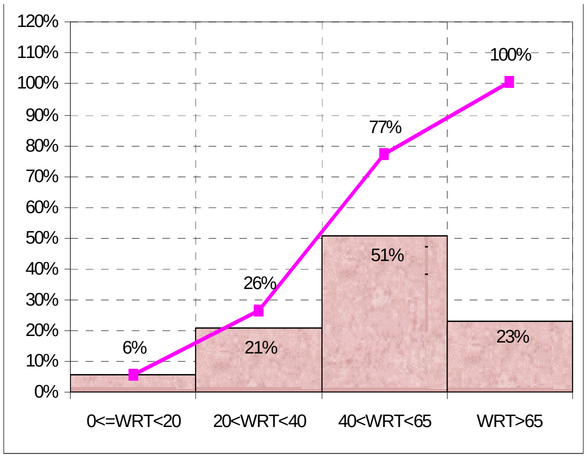
Figure 6– Measured Value of Pipe Defects
Relative Frequency Distribution and Cumulative Frequency
Pink Bars indicate percentage of sample in respective WRT range. Line is cumulative.



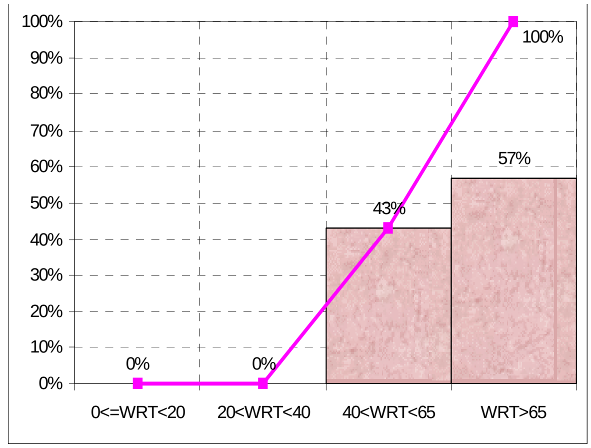
For Hydroscope calls of less than 20% WRT



For calls between 20% to 40% WRT



For calls between 40% and 65% WRT



For calls over 65% WRT

In summary of the comparative analysis, the City of Calgary found:

- The Hydroscope pit depth data are within 20% W.R.T. of the visually measured pit 95% of the time.
- The accuracy on the most important data for the evaluator - through holes and very deep pits - is extremely high, with nearly 90% of through-holes and deep pits being correct calls.
- With the variances that can be expected between Hydroscope analysis and visual measurement, the accuracy and reliability of Hydroscoping is considered highly acceptable.

<u>Practical Use of RFT</u>

Based on Calgary's analysis, Hydroscope evaluations of cast iron mains are used with confidence, not only to make replace/defer decisions on main replacement, but on decisions to replace only short segments of main. Calgary has reduced main replacements from 300m to 80m and even 60m, based on Hydroscope assessments that showed only 60m of the main to have severe pitting.

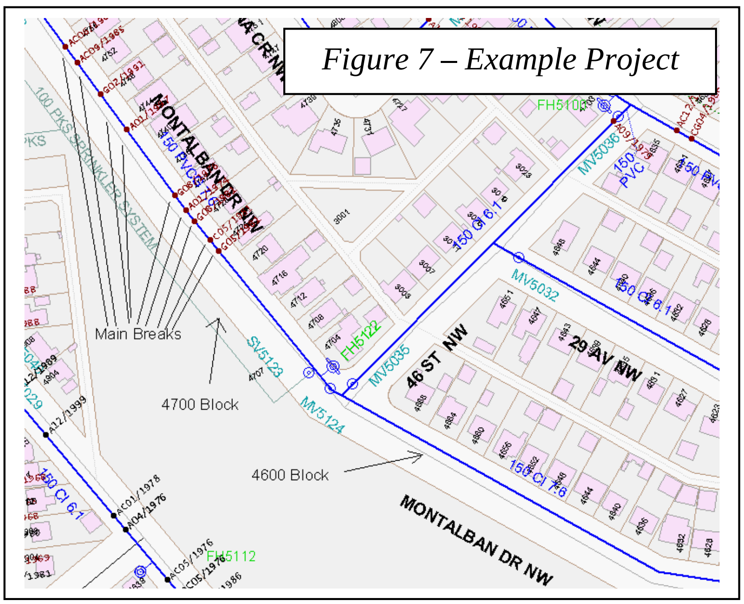


Figure 7 – Example Project

The map presented as Figure 7 provides an excellent overview and dramatic example of a water utility's ability to control main replacement costs with RFT. The project considered by the City of Calgary was the replacement of the waterline on the 4600 and 4700 blocks of Montalban Drive NW. The water utility had recorded nine main breaks on the 4700 block, while the 4600 block had no breaks. The typical main-replacement program would have called for the replacement of the waterline on both blocks, due to the assumption that both had the same pipe characteristics (circa 1960, CI 6”) and the same soil characteristics and resistivity. With such common characteristics, it might be assumed that the 4600 block waterline would have similar corrosion pits and a high probability of failure in the future.

However, Hydroscope data showed, unmistakably, that this was not the case. The absence of failures on the 4600 block was not due to soil pressure delaying the “popping” of holes, but to the lack of through-holes at all. One-third of the waterline that would have been replaced was not replaced at all, thus saving the City nearly one-third of the project cost.

Calgary uses the “Hydroscope depth” for every pit to make critical planning decisions. To that end, all Hydroscope data are entered into the utility's GIS database so that the corrosion profile for any Hydroscoped main can be brought up as part of the map, or on a special "Infrastructure Viewer" Java applet. This viewer shows Hydroscope data as a graph with distance along the main as the x-axis and wall thickness as the y-axis, and each pit shown as a “mine shaft”, a black vertical line from the top of the graph (outer wall) toward the bottom of the graph (inner wall).

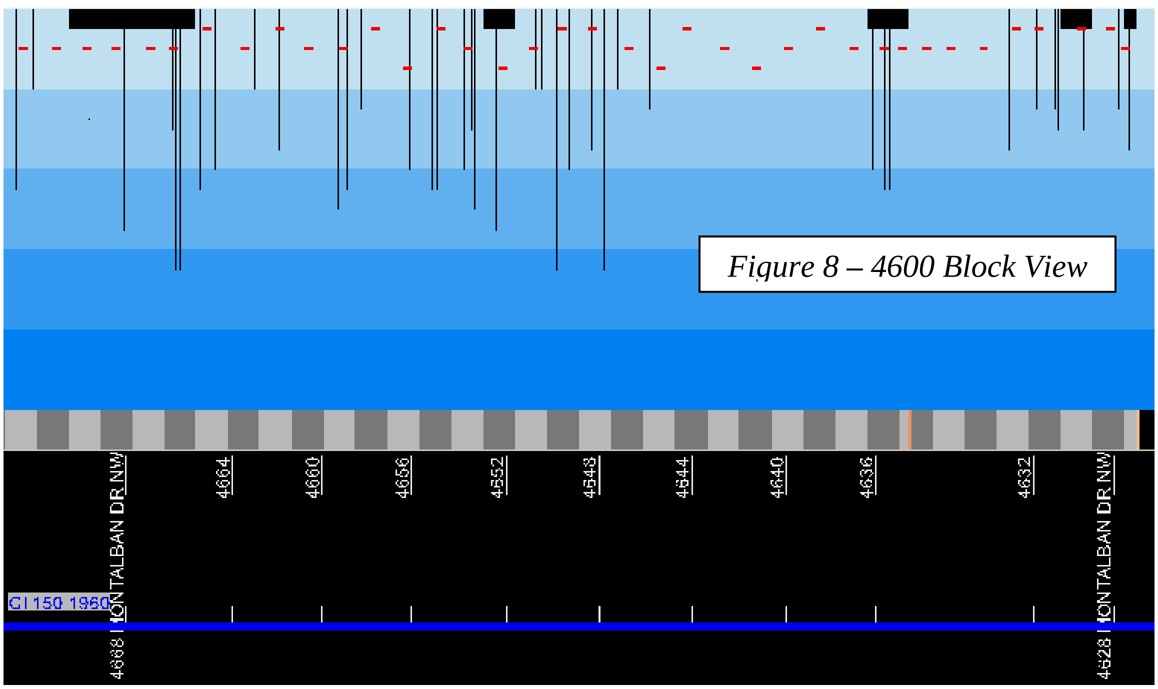


Figure 8 – 4600 Block View

Five shades of blue are used in the background as a visual reference to indicate the points of 100%, 80%, 60%, 40%, 20%, and 0% wall remaining. The above graphic (Figure 8) is a view of the 4600 block of Montalban NW. It indicates only four pits that have less than 40% wall remaining, being the result of some 40 years of corrosion. Some 35 remaining years of useful life may be expected before the break-rate becomes intolerable. The results for the 4700 block (Figure 9) were sharply different. The profile shows a large number of through-holes waiting to "pop", in addition to the nine breaks already sustained. An equally large number of deep pits (20% wall remaining) would follow in a few years. Note that the

Infrastructure Viewer now shows the main at that location to be "PVC 150 2000", the CI having been immediately replaced in the following construction season.

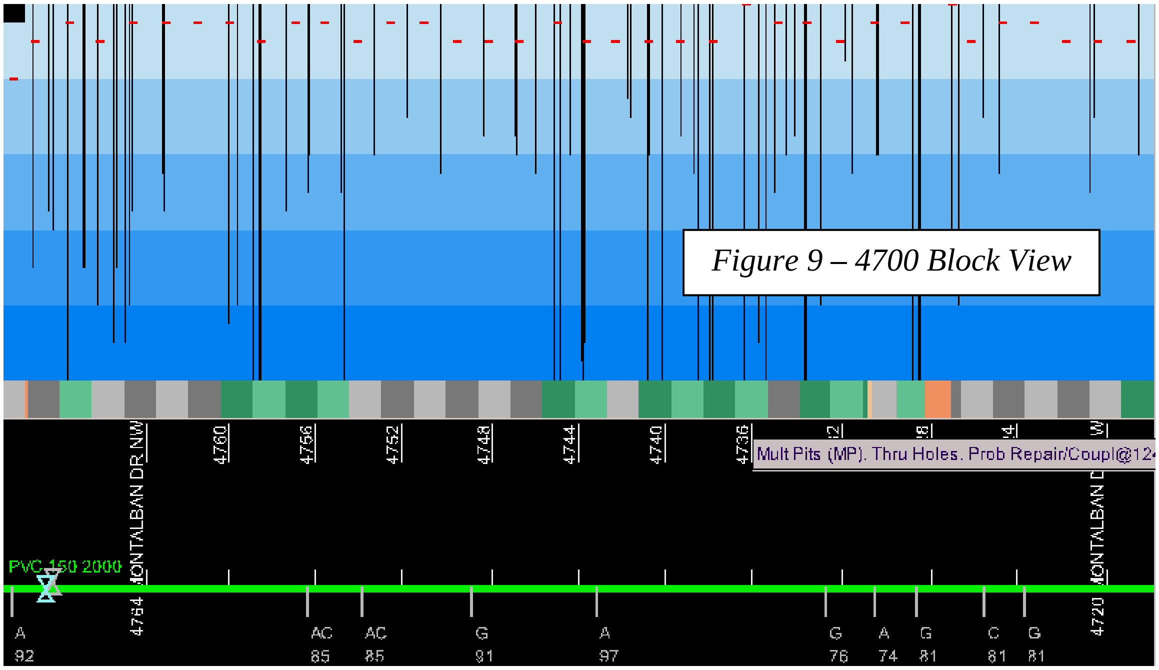


Figure 9 – 4700 Block View

In this example, at least 300m of replacement were deferred at a savings in excess of roughly $200,000 Cdn.

Using Hydroscope and RFT in Progressive Program

Calgary's approach to ongoing use of Hydroscope and RFT targets four critical uses for the technology:

1. Providing certainty in decision-making for "controversial cases", such as mains with little prior history of failure that would indicate need for replacement, but which have a "golden opportunity" available at the time. An example is a major downtown street with construction of a large convention center that required a street closure and repairs to the Centre Street Bridge. This project closed the traffic bottleneck of Centre Street itself for the first time in 30 years. Before the availability of Hydroscope, both mains in the street would have been routinely replaced since "that opportunity won't come by for decades". However after Hydroscoping both mains, it was determined that replacement would not be necessary for several decades. Thus, the city saved substantial replacement costs.

2. Additional decision-information for immediate replacement decisions, which is the bulk of Calgary's Hydroscope program. About half of Calgary's replacement program each year consists of mains that the city opts to replace based solely upon failure records. The remainder of the program is subjected to Hydroscope condition assessment. This allows selection of certain mains from a prioritized candidate pool. Using Hydroscope, the city makes spot restoration or replacement decisions by identifying the location and extent of existing through-holes or deep pits, and avoids wholesale waterline replacement.

3. "Benchmarking" of the thick-wall cast iron system. Previous research, including the first Hydroscope experiments, shows that the consistency of deterioration from one block of pipe to the next increases with wall thickness. The thickest-walled pipe in the system, the pit-cast iron pipe installed prior to 1955, is very consistent in condition in adjacent blocks of similar soil type and install date. A portion of the city's Hydroscope project from 1999 to 2002 established a benchmark for mains of specific vintage and soil type. The city Hydroscoped approximately 10% of the 500km inventory of thick-wall cast iron mains with the intent of predicting the lifecycle of the remaining 90%, using the "benchmark" mains as a prioritization model.

4. Rehabilitation and life extension decision-making. The term "replacement" has been used throughout this paper, as it is the most expensive waterline asset management option. Waterline rehabilitation or restoration is, most often, a more cost-effective solution. One such rehabilitation technique used by Calgary is with cathodic protection anodes, rather than total replacement. Again, the Hydroscope is of definitive value in this program, as anode retrofit is only appropriate to ductile iron mains that have significant but not yet "fatal" corrosion levels -preferably almost no pits of less than 50% W.R.T. A decision to use anode retrofit for a main rather than replacement avoids about 75% of the construction cost.

While easy to calculate for one job, the savings resulting from use of the Hydroscope are more difficult to assess for the overall program. Merely counting up all the cases where the Hydroscope data deferred a replacement is simplistic, since Hydroscope data also have *caused* replacements to be selected that would have been missed without it - yet obviously it would be wrong to regard those cases as a "cost" incurred from Hydroscoping. Those cases, too, are an asset to the utility, since repairs and bad service to customers are avoided by the replacement.

On the balance, the Calgary engineers regard the Hydroscope RFT as a tool that increases the accuracy of the city's main replacement/rehabilitation selections from an 80% efficiency rate to over 90%, better than halving the error rate. For corrosion-related replacement decisions, the main selection accuracy is now, effectively, 100%. Since few utilities check the accuracy of their existing selection techniques by a sustained program of pipe recovery and sandblasting, it is possible for them to presume every replacement job a success. However, the early returns from Calgary's pipe recovery work in the mid-1990's showed that about one main in five then selected did not have to be replaced. From a main replacement program of some $10 million Cdn. per annum, about $2 million were being wasted. That waste is now confined to mains that are selected without benefit of Hydroscoping.

It is estimated that the City of Calgary has experienced an approximate 100% payback on Hydroscope condition assessment fees. The city estimates over $1 million in replacement savings annually from the use of RFT, while the annual cost of condition assessment is approximately $600,000. The current $10 million annual budget for main replacement in Calgary represents a significant reduction from the early 1990's, when it peaked at $17 million. It had been expected that the budget would have to rise again as the rate base grew to permit it. Partly because of Hydroscope technology, however, it is now expected that the budget can remain level and, indeed, be further reduced in the future, as the cumulative effects of the more-accurate replacement program are felt.

Conclusion

In order to reliably provide high quality water, waterline asset managers must collect reliable data about the condition and external influencers of waterlines. Although "break" history combined with external data (such as soils characteristics) may be used to prioritize waterlines for replacement or restoration, knowing the actual condition of the waterline is critical to achieving optimum success with limited budgets. Using RFT technology for waterline condition assessment enables selective replacement and renewal.

The City of Calgary, working in collaboration with Hydroscope, has gained significant cost-effectiveness in its waterline asset management program. Using RFT to determine actual waterline condition, the City of Calgary has created efficiencies that eliminate the use of scarce funding on unnecessary waterline replacement. Further, the technology has resulted in the prescription of repairs in instances where waterlines were thought to be in good useful condition. The City of Calgary has demonstrated that the application of RFT technology significantly improves efficiency in waterline asset management.