EXPERIENCES WITH WATERMAIN CORROSION

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Introduction

The cost of rehabilitating the 38,000 km of water distribution piping in Ontario, currently valued at $21.2 billion ($2,725 per capita) [1] has become a major focus of attention. Not only is it estimated that 15% of the water supplied is unaccounted for but the average annual breaks per 100 km is an astounding 25 resulting in annual emergency repair costs estimated at $65 million.[2]

The Ministry of Environment report of January 1987 entitled "The Need for a Rehabilitation Program for Water Distribution Systems in Ontario" further estimated that the annual cost for replacing Ontario's water system would be $50 million assuming only 50% required reconstruction over the next 50 years.[3] There is a major concern as to who will pay the cost of this rehabilitation since most current water rate charges are insufficient to provide replacement funding. Despite appeals for funding to all levels of government by the Ontario Sewer and Watermain Contractors Association, it is apparent that there is substantial resistance to these requests. Yet as the appeals for special funding echo through our industry, municipalities continue to repair about 9500 breaks annually with the expectation that this number will continue to grow. The Environment Ministry estimates however that if the break frequency could be reduced to 10 breaks per 100 km, then an annual savings of $15 million would be realized.[4]

The question then arises as to whether or not the "break" rate can be practicably reduced. Numerous studies [5,6] have identified corrosion to be the primary cause of both grey cast iron and ductile iron watermain failures. Accordingly, if the corrosion activity can be reduced then the service life can be proprotionately extended and the "break" rate reduced.

Material Composition Matrix for Typical Water Distribution System

Corrosion activity is not uniform from one distribution system to another, or even within the same distribution network. There is however a consistent emerging picture of the typical water distribution system with respect to its corrosion activity. As a result of some recent observations gleaned from participation in several "needs" studies, from conclusions of various studies reported in the literature and from observations made during previous watermain corrosion investigations, a relatively consistent picture can be presented as in Figure 1.

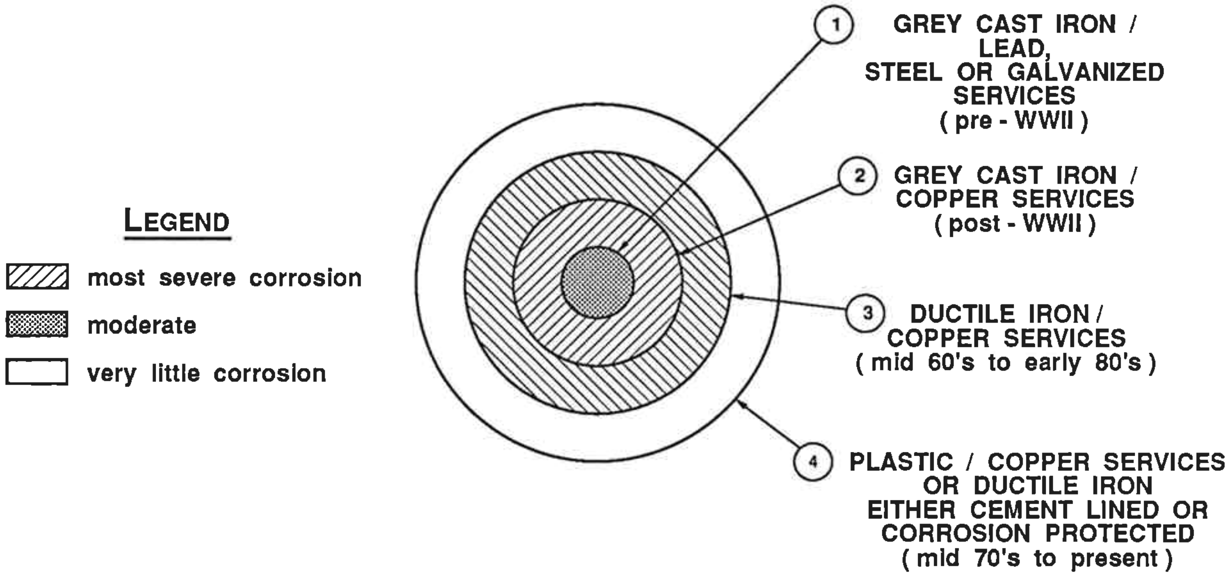

FIGURE 1

The typical water distribution system has a core piping system (Zone 1) composed of grey cast iron which was originally installed with lead, steel, or galvanized steel services and predates World War II. This piping has only presented a moderate corrosion problem despite the age of the piping. Zone 2 also composed of grey cast iron, but installed mostly after the war, has copper services and has exhibited a severe corrosion break frequency compared to the grey cast iron in Zone 1. Owing to the frequent breakage experienced by the grey cast iron a shift to the use of ductile iron (Zone 3) occurred in the mid-60's and this piping material has exhibited in many cases corrosion failures after only a few years of service. More recently, plastic has gained acceptance both from a handling and corrosion resistance point of view, although ductile iron either cement lined or with some external corrosion protection is still being used. These piping systems in Zone 4 exhibit very little corrosion activity at the moment.

Galvanic Corrosion Influence of Copper Water Services

The difference in corrosion behaviour between the piping of Zone 1 and that in Zones 2 and 3 is attributable to galvanic corrosion arising from the interconnection of copper service piping. The corrosion cell established by the coupling of copper to iron is illustrated in Figure 2.

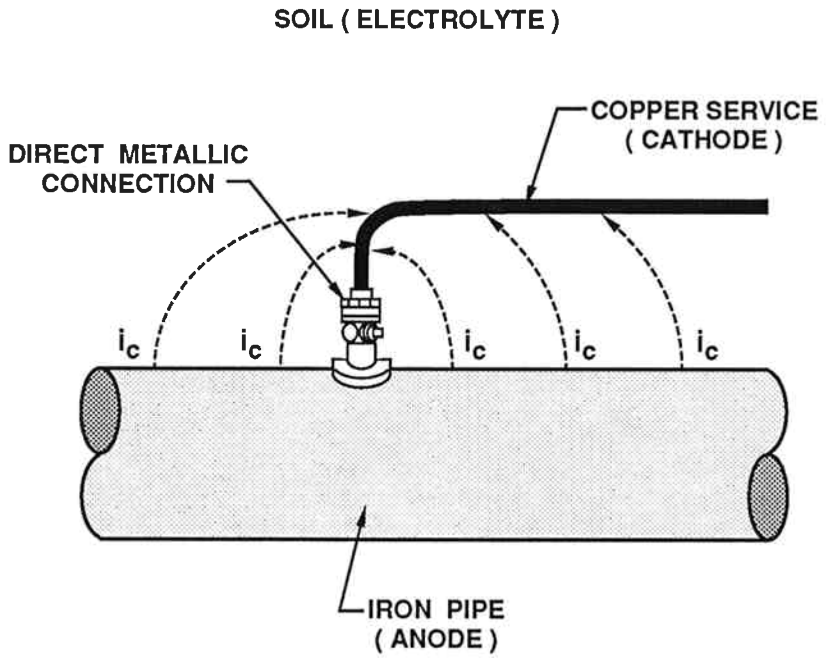

FIGURE 2

Here the iron main is the anode of a corrosion cell and corrodes; whereas, the copper is a cathodel and does not corrode. The rate of this corrosion reaction is very much dependent on the relative surface areas of the copper with respect to the iron. The larger the copper /iron surface area ratio then the larger will be the corrosion rate. The corrosion rate is also influenced by the electrical resistivity of the surrounding soil. The lower the soil resistivity is, then the larger the corrosion rate will be. The dramatic increase in road salt use since WW II has caused a substantial decrease in soil electrical resistivity. The devastating effect of copper on the anticipated life of iron pipe is quantitatively illustrated in Figure 3.

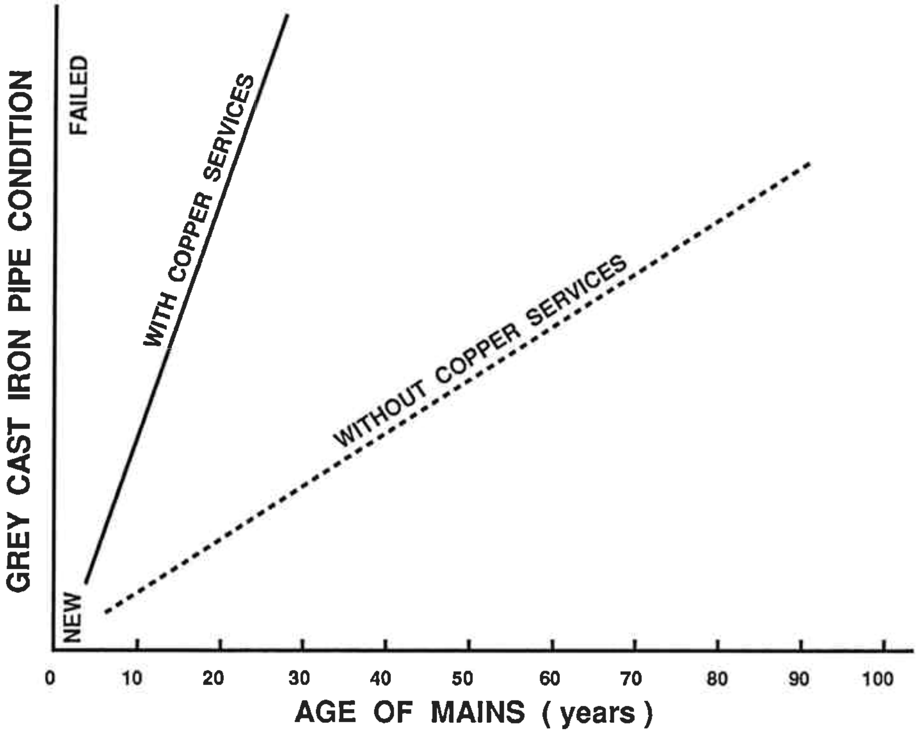

FIGURE 3

Here it can be seen that the life of an iron main can be expected to be a factor of 5 greater for a situation where copper is not connected to the iron compared to the normal situation wherein iron is electrically interconnected to the copper service. It should be further noted that where copper is not in electrical contact with the iron that a life in excess of 100 years for grey cast iron is a reasonable expectation.

A relatively high failure frequency on ductile iron, despite its lesser age compared to the grey cast iron in either Zone 1 or 2, can be attributed to the influence of the copper services as mentioned previously and also to the fact that the wall thickness of ductile iron is substantially less than for the grey cast iron. Examination of Figure 4 showing a typical corrosion depth versus time curve indicates that for grey cast iron having a wall thickness double that of ductile iron, the time to penetration through grey cast iron would be a factor of 4 or 5 longer than for the ductile. It is not surprising then to find ductile iron corrosion failures in as little as 5 years from time of installation.

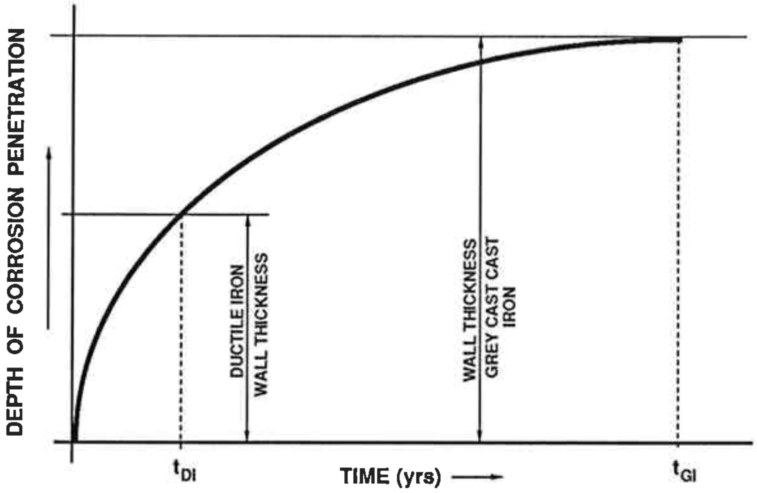

FIGURE 4

Many municipalities who installed cement mortar lined ductile iron pipe in the 60's and 70's have not experienced the high failure frequency that the unlined ductile iron pipe has shown. This does not mean that corrosion activity is any less, but rather that the cement lining is instrumental in maintaining a leak-free pipe as is illustrated in Figure 5. Here, even though corrosion has penetrated the ductile iron, the cement mortar lining will prevent perforation until the corrosion has advanced enough to expose a large surface area of the lining. Ultimately, the lining will fail as a result of a physical disturbance either from the soil side or from the water side. One would expect therefore, failures of this type to occur later in the piping life, but when they occur, they are likely to occur in bunches.

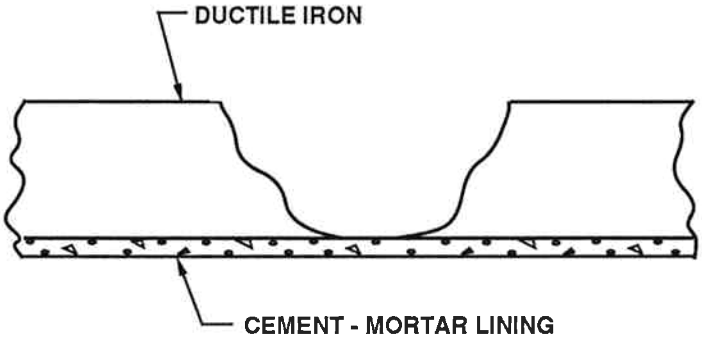

FIGURE 5

Corrosion Prevention

The useful service life of the iron piping systems in all zones, but particularly in Zones 2 and 3 can be extended indefinitely by the application of cathodic protection. The only other solution to keeping these pipes in service involves constant and frequent repair with the attendent repair costs and customer dissatisfaction. The outstanding benefits of the retrofit application of cathodic protection to a corroding waterpiping system can be illustrated by a case history at the small Town of Emo, Ontario. Emo's water distribution system was originally installed around 1970 and consisted of about 6 km of grey cast iron. The first "break " failure was reported in 1974 and by the end of 1981, there had been a total of 38 breaks. A subsequent investigation initiated by the Ministry of the Environment indicated that the soil resistivity was relatively low at around 1000 ohm-cm. and there was considerable copper piping relative to iron piping. Many of the laterals did not extend fully down streets and copper services were run for extreme lengths to complete the water system to residents in less densely populated areas.

A trial cathodic protection system consisting of both zinc and magnesium anodes was installed in 1983 on a 500 metre section of main. This system was evaluated in 1984 and the cost of doing the entire town based on this method was estimated. As the installation costs required to achieve adequate protection was high for this method, it was decided to opt for a number of impressed current systems distributed throughout the town. Accordingly in 1985, 42 small impressed current systems were installed on the water piping as illustrated in Figure 6. Since that installation

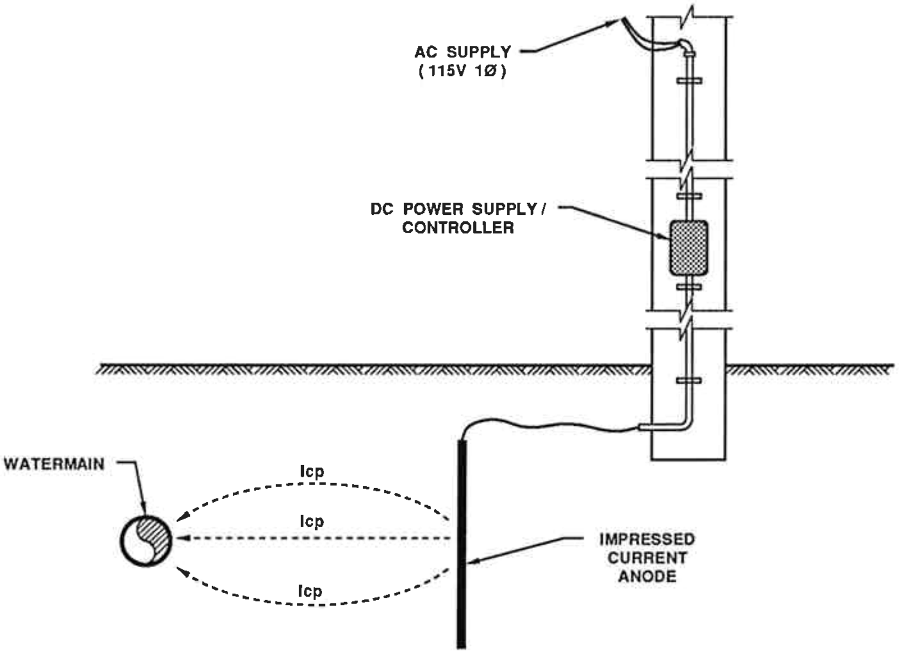

FIGURE 6

there have been only two additional failures as shown in Figure 7, a substantial reduction in the failure rate from 6 per year to 1 per year.[8] Cathodic protection of the water system was accomplished at a cost of less than 10% of the estimated replacement cost of the piping.

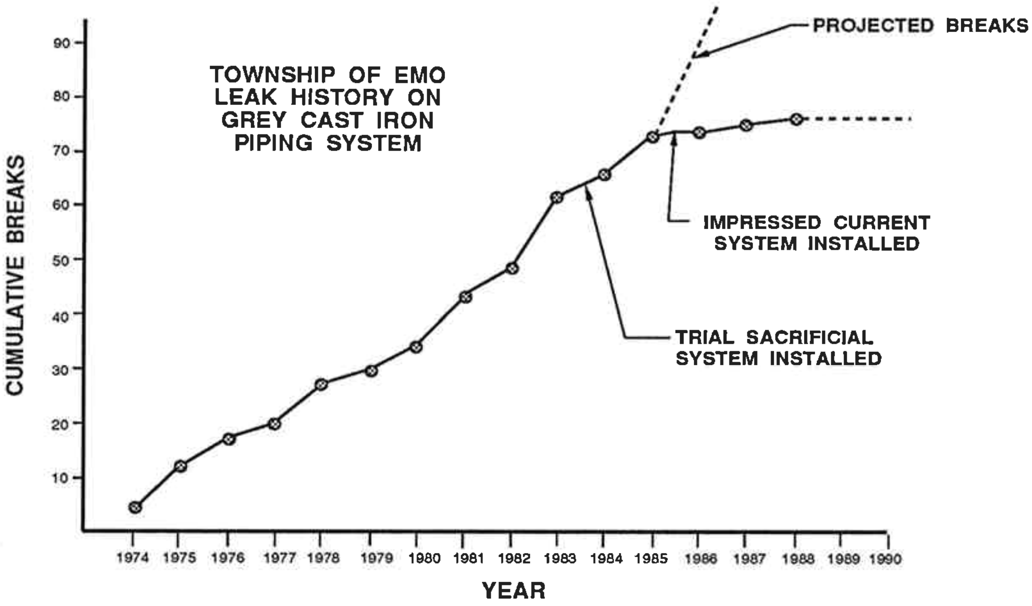

FIGURE 7

Similar results can also be obtained using sacrificial anodes. For instance, in 1978 a 1200 foot length of 6 inch ductile iron piping was protected using 32 lb. sacrificial magnesium anodes installed as in Figure 8 on about 12 meter spacings. This piping which had been installed in the

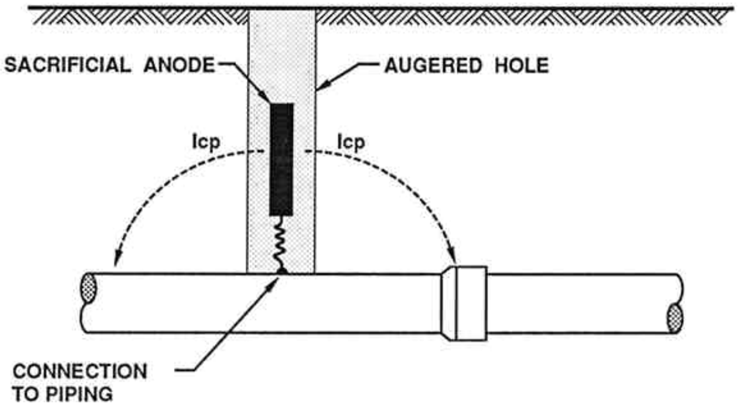

FIGURE 8

late '60s, first suffered a corrosion failure in 1974 and by 1978, there was a total of 20 failures on this relatively short length of main. Since cathodic protection was installed in November 1978 there have been two failures in the following 9 years as illustrated in Figure 9. Had cathodic protection not been applied in 1978, the entire section would have probably been replaced by now.

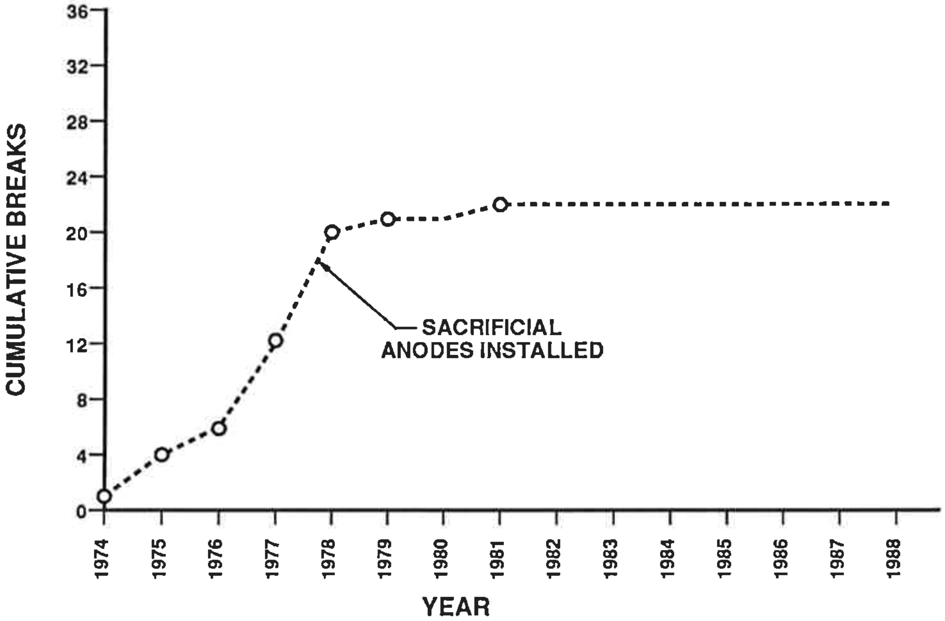

FIGURE 9

Cathodic protection therefore can be effectively retro fit to existing iron piping systems to produce dramatic reductions in "break" rates thereby extending the service life indefinitely. It can be concluded that the present failure rate of 25 per 100 km per year could easily be reduced to 10 by the prudent application of cathodic protection and a resulting savings of $15 million realized.

Cost-Effectiveness

Compared to the cost of replacement or the cost of frequent emergency repairs, the cost of a cathodic protection programme to extend the life of existing water distribution systems is very economical. For example, the sacrificial system used in the previous example was installed for a total cost of $5,200.00 in 1978. This would have represented the cost of the half dozen failures on that length of pipe which were occurring each year. Accordingly, it is reasonable to expect that in the year 1979, one could have anticipated at least another half a dozen leaks. The payback period for this cathodic protection expenditure was one year. The remaining 8 years of life to this point in time have been a bonus. The programme is most economically effective when applied to piping which is exhibiting a high leak frequency. Normally the anodes are installed in vertically augered holes and attached to the piping by welding with anode spacings in the 10–15 metre range. Generally, the major cost of a sacrificial anode programme is not so much the cost of the anode material itself but in the cost of the excavation required to position the anode properly. Accordingly, cathodic protection to a limited degree can be installed in a more cost effective manner when an anode is attached to the piping at any location where the piping system is excavated for any reason. The price of the anode is small compared to the cost of the excavation. Many municipalities have also adopted a cathodic protection programme which addressess the most serious failure locations with a concentrated anode approach and are supplementing this programme by installing sacrificial anodes at every opportunity when the piping is exposed. Implementing this kind of cathodic protection programme over a long time period will result in substantial service life extension at a cost much less than the replacement cost of the piping system.

Much has been said recently in the literature about the replacement costs of a disintegrating water piping system. Cathodic protection represents a cost-effective method of avoiding expensive reconstruction costs. Whereas the reconstruction costs may range from $450–$550 per metre, typical cathodic protection costs are in the range of $30–$50 per metre which is less than 10% of the replacement cost for the piping. When one considers that cathodic protection will extend the life of the piping system as long as the cathodic protection system is operating, then a substantial cost benefit results. In fact the interest on the money saved by not having to re-construct a pipeline easily pays for the cathodic protection which will extend the life of the piping system indefinitely.

It is interesting to compare the water piping systems with respect to oil and gas transmission systems. There is more oil and gas piping in Ontario than there is water distribution piping, yet the corrosion failure rate on oil and systems is less than 1 per 100 km. As both water and hydrocarbon piping are primarily composed of ferrous metal and share similar ground conditions, then there must be a very good reason as to why there is a such a dramatic difference in the failure rates from one piping system to another. The only signicant difference is the fact that all the hydrocarbon systems are cathodically protected at the time of installation and that cathodic protection is maintained.

Rather than looking to the government to fund watermain re-construction, the municipal waterworks departments should be looking towards implementing a comprehensive cathodic protection programme which is recognized as the only effective way of preventing corrosion on existing iron piping systems. [9] Clearly this is the only way our society can afford to maintain our existing iron water distribution systems.

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