METALLIC WATER MAIN FAILURES

Water main failures are a distressing problem for many
municipalities. In some municipalities the cost of water main failures
reaches astronomical proportions. It is not unusual for municipalities in
densely populated urban areas to experience a failure frequency of one per
year per mile of pipe, with the average cost of leak repair being in the
$1500 to $2000 area, not to mention the disruption to traffic, the lack of
water for fire fighting and the clean-up. Water main failures are due to
several factors as shown in Figure No. 1.

MAJOR CAUSES

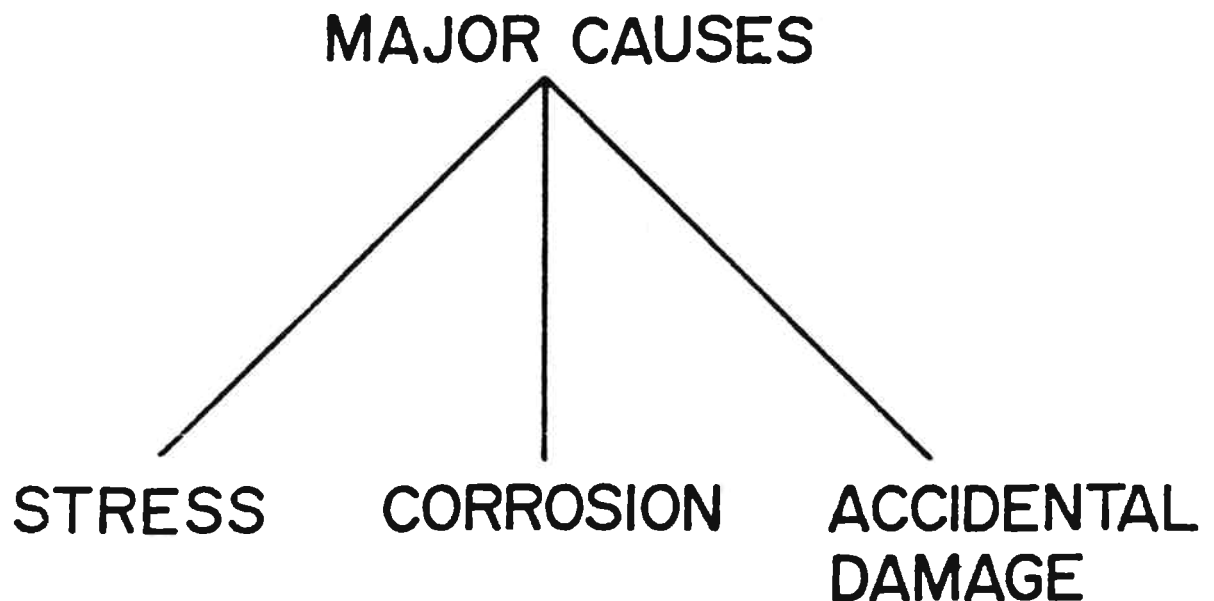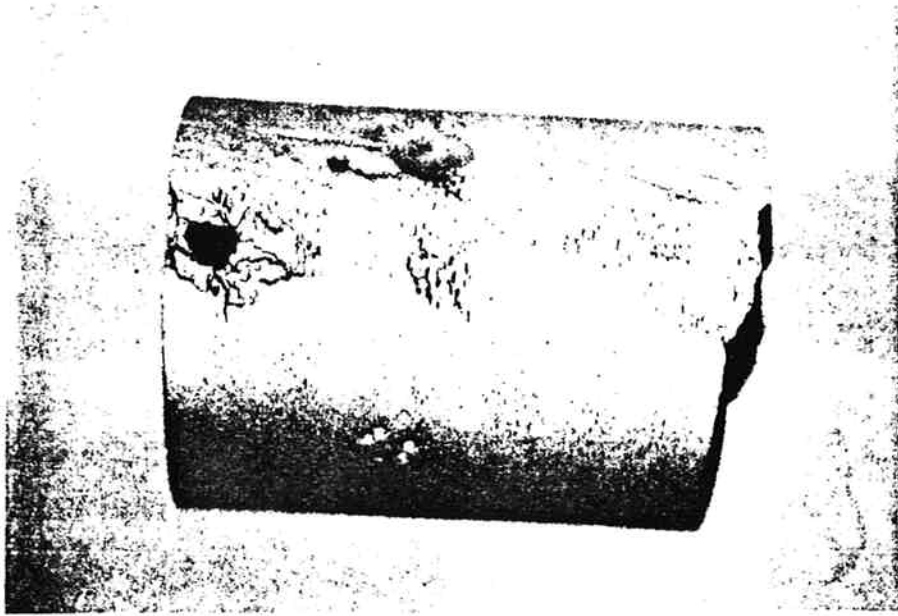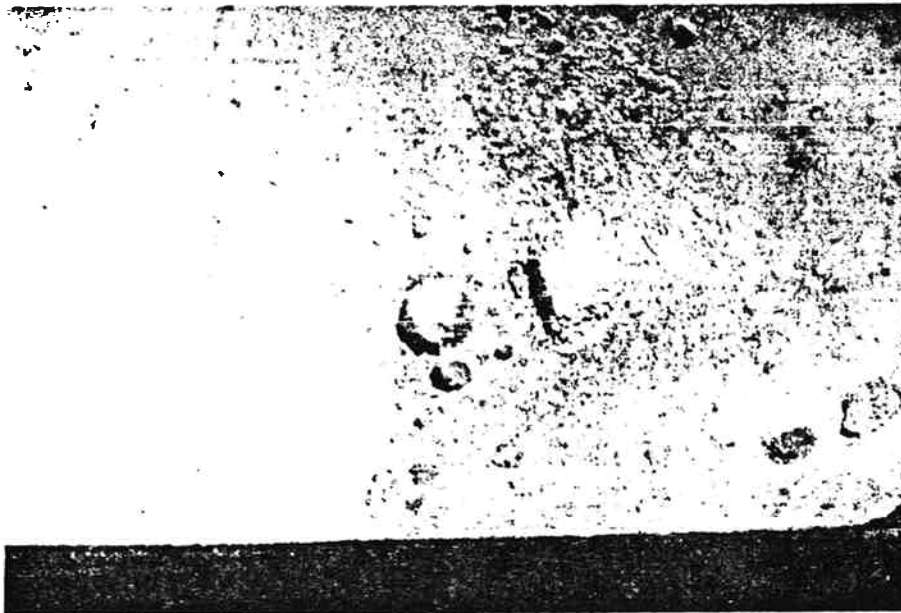## STRESS   CORROSION   ACCIDENTAL DAMAGE

Figure No. 1

The above photograph shows corrosion of a cast iron
water main installed in 1964 and replaced in 1979.

The above photograph shows corrosion damage on a ductile
iron water main installed in 1966 and replaced in 1978.

Stress is caused by factors such as frost pressure, lack of support for the pipe or pressure exerted on the main from heavy equipment or equipment working in the immediate vicinity of a water main. Accidental damage from construction equipment can be minimized by careful locates and by hand digging in the vicinity of a water main. Corrosion plays a major part in water main failures. Not only does perforation of the pipe wall occur at pits but the wall thickness may be greatly reduced at corrosion areas leading to increased breakage due to stress.

There are numerous factors that accelerate corrosion of water mains such as shown in Figure No. 2.

CORROSION
(ACCELERATING FACTORS)

— DISSIMILAR METAL COUPLES
— SOIL RESISTIVITY
— ENVIRONMENTAL POLLUTION
— DIFFERENTIAL AERATION
— STRESS (COLD WORKING)
— STRAY CURRENTS
— TEMPERATURE

Figure No. 2

Dissimilar metal couples such as the interconnection of copper services to ductile or cast iron mains can greatly accelerate the corrosion of the cast and ductile iron since the water main is anodic to the copper service. The electrical potential difference between these two metals in a soil environment may be as high as 300 mV. Dissimilar metal couples combined with low soil resistivity may lead to rapid perforation of cast and ductile iron water mains, thus increasing the number of water main failures.

Soil resisitivity is a measure of the contamination of soils by chemicals such as de-icing salts, fertilizers, etc. In a recent soil corrosivity survey undertaken in southern Ontario, 33% of the 250 locations sampled had a soil resistivity of under 1000 ohm-cm; 51% fell in the 1000 to 3000 ohm-cm range; and 16% in excess of 3000 ohm-cm. It was further found that at some locations the soil resistivity was less than 300 ohm-cm and the chloride content of the soil was in excess of 3000 ppm. An effect of this high chloride concentration in the soil surrounding the water main can be to increase the corrosion rate by a factor of 2 even without the influence of dissimilar metal couples such as copper services, copper bonding straps, etc. Staehle[1] reported that if the copper-to-iron ratio exceeds 10 the corrosion rate may increase by a factor of 100. See Figure No. 3. With the increase in the cost of serviced lots the trend is to smaller lot frontages. This increases the number of copper services attached to a water main per unit length. This situation combined with a coating such as mill applied asphaltic coating or fibreglass reinforced latex modified cements can lead to a very high copper-to-iron ratio resulting in extremely rapid perforation of water mains.
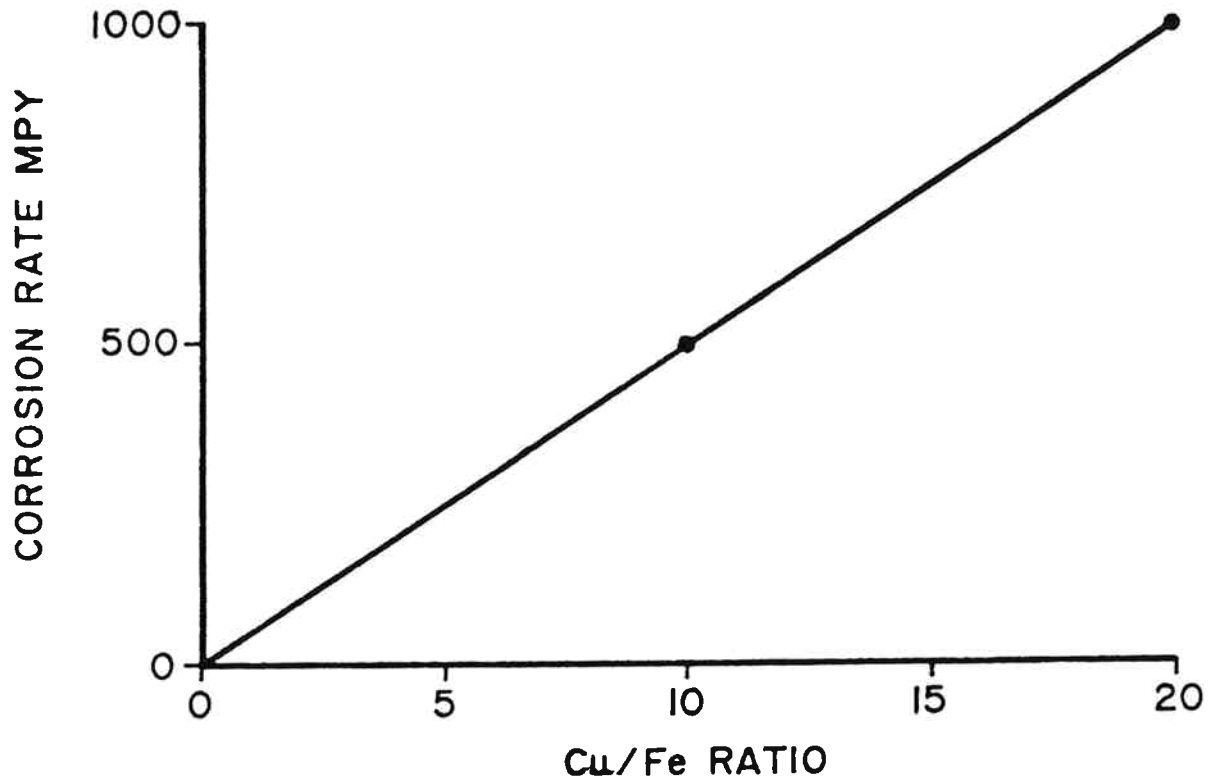
EFFECT OF COPPER TO IRON RATIO IN 3 % NaCl

Figure No. 3

The corrosion experienced on cast and ductile systems is not due to poor pipe but to poor design practices. Water systems should be designed to eliminate dissimilar metal couples and take into consideration environmental controls. Soil analysis should be undertaken prior to tendering of the water main installations and cathodic protection should be considered as a method of extending the life of water systems. Tomashov[2] has reported the probability of perforation of cast or ductile iron piping due to corrosion in various resistivity soils over a 15 year period, as shown in Fig. No. 4. For instance in 10,000 ohm-cm soil, the probability of perforation within this time period is 10% and in 1,000 ohm- cm soil the probability of perforation in the 15 year period is 35% and in 500 ohm-cm the probability of perforation in the 15 year period is 100%. See Figure No. 4.

PROBABILITY OF PERFORATION
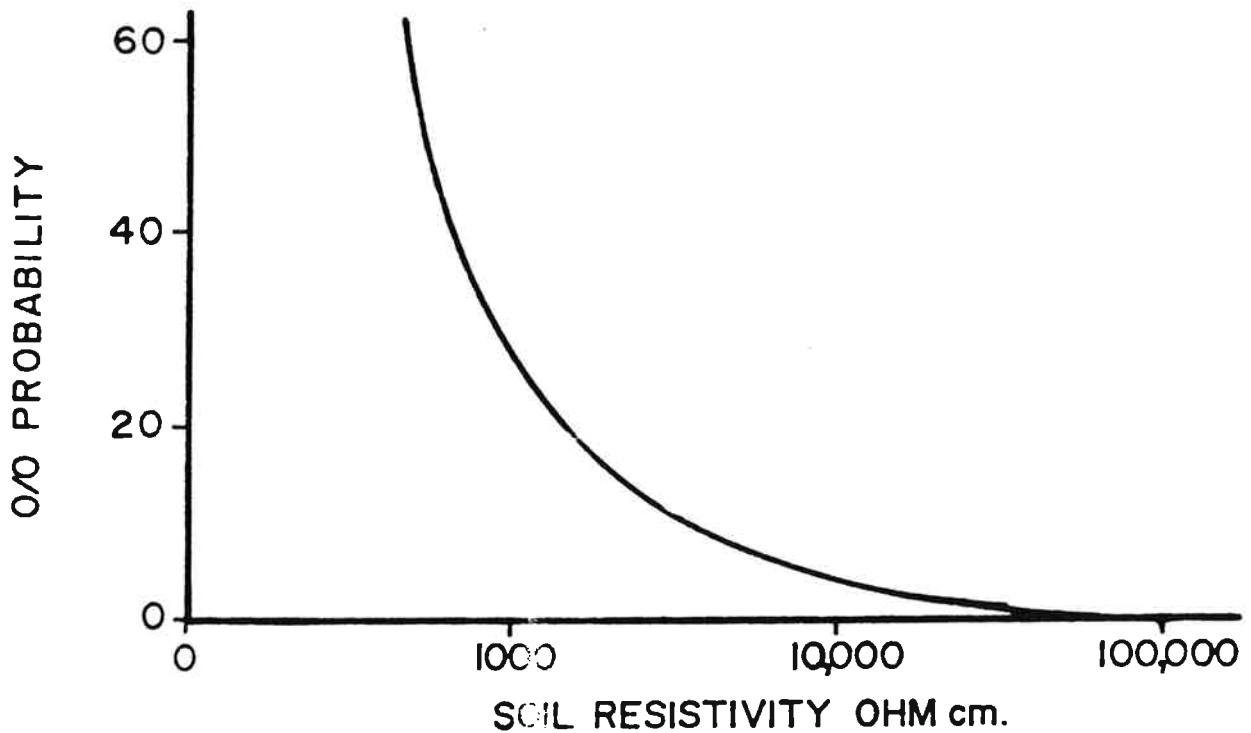## DUE TO CORROSION IN 15 YEARS

Figure No. 4

It is possible to predict the number of leaks in an ensuing year that a municipality may experience on a ductile iron water main system by graphing cumulative leaks versus time on semi-log paper after 3 to 4 years of leak history. For instance, in Fig. No. 5, on a 200 mile sample of ductile iron piping by 1976 there were approximately 100 accumulated leaks. By 1979 there were approximately 1000 accumulated leaks.

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Based on this time-leak projection, if no remedial measures were taken to control the corrosion rate, by 1983 the accumulative leaks would approach 10,000 (See Fig. No. 5) or 50 leaks per mile of ductile iron water main. Not only would be this be prohibitively expensive to repair but leaks would occur so rapidly that the repair crews would not be able to maintain the water service on a ductile iron water main system.

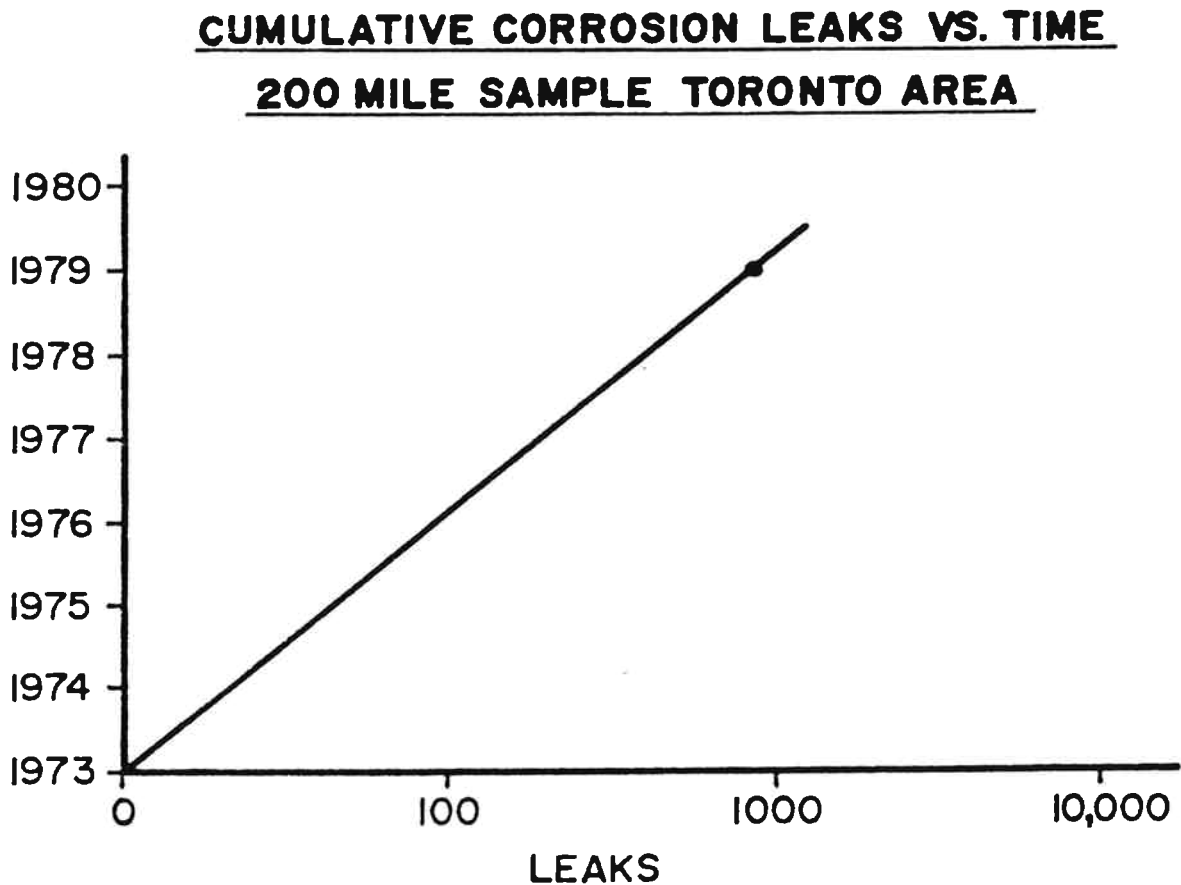## CUMULATIVE CORROSION LEAKS VS. TIME
200 MILE SAMPLE TORONTO AREA

Figure No. 5

The waterworks engineer must take steps to reduce the leak incidence on water distribution systems. This can be done by design considerations, as summarized in Fig. No. 6, and by understanding the environment in which the water main is to be installed. Soil analysis should be undertaken on any street where a ductile or cast iron water main is to be installed. This soil analysis, using the AWWA standard, evaluates soil resistivity, pH, Redox potential, sulphides and moisture content. From a soil corrosivity point of view however this soil analysis should evaluate soil resistivity, pH, Redox potential, soil types and chloride concentration. With this background information, as summarized in Fig. No. 7, the waterworks engineer can then evaluate the various corrosion control methods available. For instance the water main could be backfilled in concrete thus effectively removing the pipe from the environment, but a minimum of 4" of concrete cover completely surrounding the water main would be necessary.

Cathodic protection could be installed as the water main is installed. This would effectively double the life of the water main system and when the sacrificial anodes are consumed new anodes could be installed thus extending the life even further.

DESIGN

- ELIMINATE DISSIMILAR METAL COUPLES
- ENVIRONMENTAL CONTROLS
- SOIL ANALYSIS
- CATHODIC PROTECTION

Figure No. 6

Another consideration may be non-metallic piping. This however should only only be installed if the waterworks engineer is aware of the corrosion problems that can result on the metallic fittings commonly used with non-metallic piping. Copper services, for instance, have always been cathodically protected by the corrosion of the ductile or cast iron water main. On non-metallic piping systems this protection is not present and corrosion of the copper services can result unless they are cathodically protected with a sacrificial anode system. Metallic fittings will corrode unless the fitting is removed from the environment or cathodically protected.

SOIL ANALYSIS

AWWA

- SOIL RESISTIVITY
- PH.
- REDOX POTENTIAL
- SULPHIDES
- MOISTURE

CORROSION ENG/TECH.

- SOIL RESISTIVITY
- PH.
- REDOX POTENTIAL
- SOIL TYPES
- CHLORIDES

Figure No. 7

Traditionally, cathodic protection has been applied by sacrificial or impressed current means as summarized in Fig. No. 9. Sacrificial protection lends itself to new construction, existing systems and 'hot-spot' protection at leaks. Impressed current systems, utilizing a rectifier and ground bed should only be used with extreme caution. Water main systems require considerable current for cathodic protection and the installation of impressed current cathodic protection systems can lead to corrosion of the water main at electrical discontinuities which often occur at broken bonds and at fittings where electrical continuity of the water main is not provided. An impressed current cathodic protection system can also lead to corrosion of other underground utilities such as gas lines, concentric neutrals on power cables and lead sheaths on telephone cables.

Cathodic protection is indeed a viable method to control water
main failures if it is applied correctly and judiciously. For instance,
the first leak on an existing 1600 foot long, 6" dia. ductile iron water
main appeared in 1975. By November of 1978, 20 leaks had accumulated or an
average of 1 leak per 80 ft. of water main. Since the installation of a
cathodic protection system in November of 1978, no further leaks have
occurred. See Figure No. 8.

CATHODIC PROTECTION
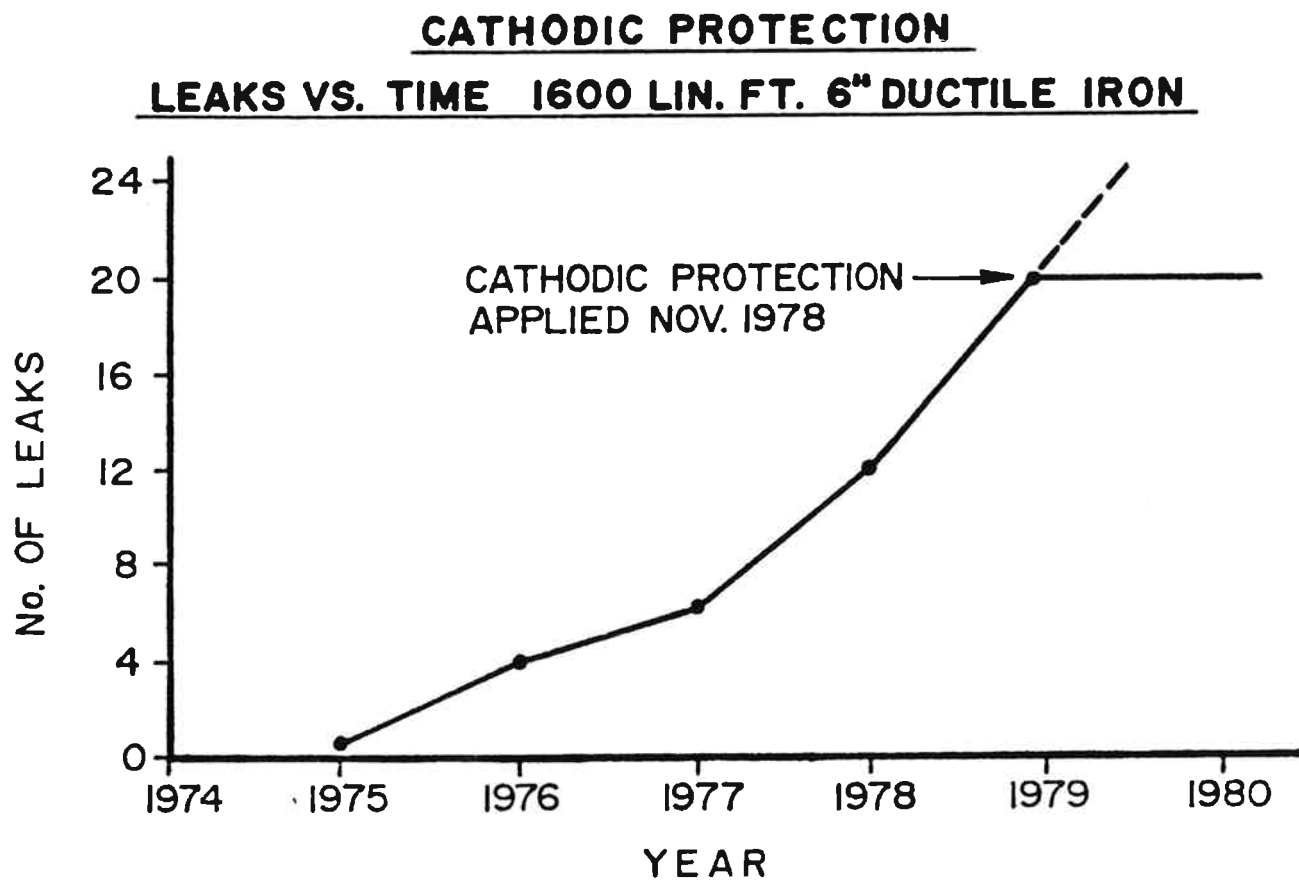## LEAKS VS. TIME 1600 LIN. FT. 6" DUCTILE IRON

Figure No. 8

In the past 2 years the author has been involved in the cathodic
protection of approximately 50,000 lineal feet of ductile iron piping.
Since the installation of these cathodic protection systems, no leaks have

been recorded. The cost of installing a cathodic protection system on existing ductile iron water main systems is approximately 10% of the replacement cost. This may seem expensive at first. However, comparing the cost of the cathodic protection to the cost of repairing leaks, the payback can be less than 1 year. For instance, in the case history previously mentioned, which consisted of 1600 lineal feet of 6" dia. ductile iron piping, a leak projection analysis predicted that in 1980 sixteen leaks should occur. If we assume a repair cost of $1,500 per leak, the cost of leak repair on this street alone would have been $24,000. The cost of cathodic protection was less than $8,000. Not only did the municipality save money by cathodically protecting this ductile iron piping but they eliminated problems associated with lack of fire protection, street collapse and complaints from the public due to lack of water. It also released crews to do other maintenance work.

CATHODIC PROTECTION
FOR WATER MAINS

SACRIFICIAL: — NEW CONSTRUCTION

— EXISTING SYSTEMS

— HOT SPOT

IMPRESSED: DANGEROUS

Figure No. 9

What type of anodes should be used for cathodic protection of water main systems? Traditionally, three materials have been used as sacrificial anodes; magnesium, zinc, and aluminum. Aluminum and zinc anodes are usually used in sea water environments, whereas magnesium has traditionally been used in the soil environment due to its high driving potential. Comparison of the current output of a 32 lb. magnesium anode with a 24 lb. zinc anode packaged in the same backfill material which would contain gypsum, bentonite, and sodium sulphate, in 1000 ohm-cm soil reveals that the magnesium anode would produce three times the current of the zinc anode. If we compare this to a bare S-12 (12 lb) or S-5 (5 lb) zinc anode the current output ratio would be approximately 120 times, as shown in Figure No. 10.

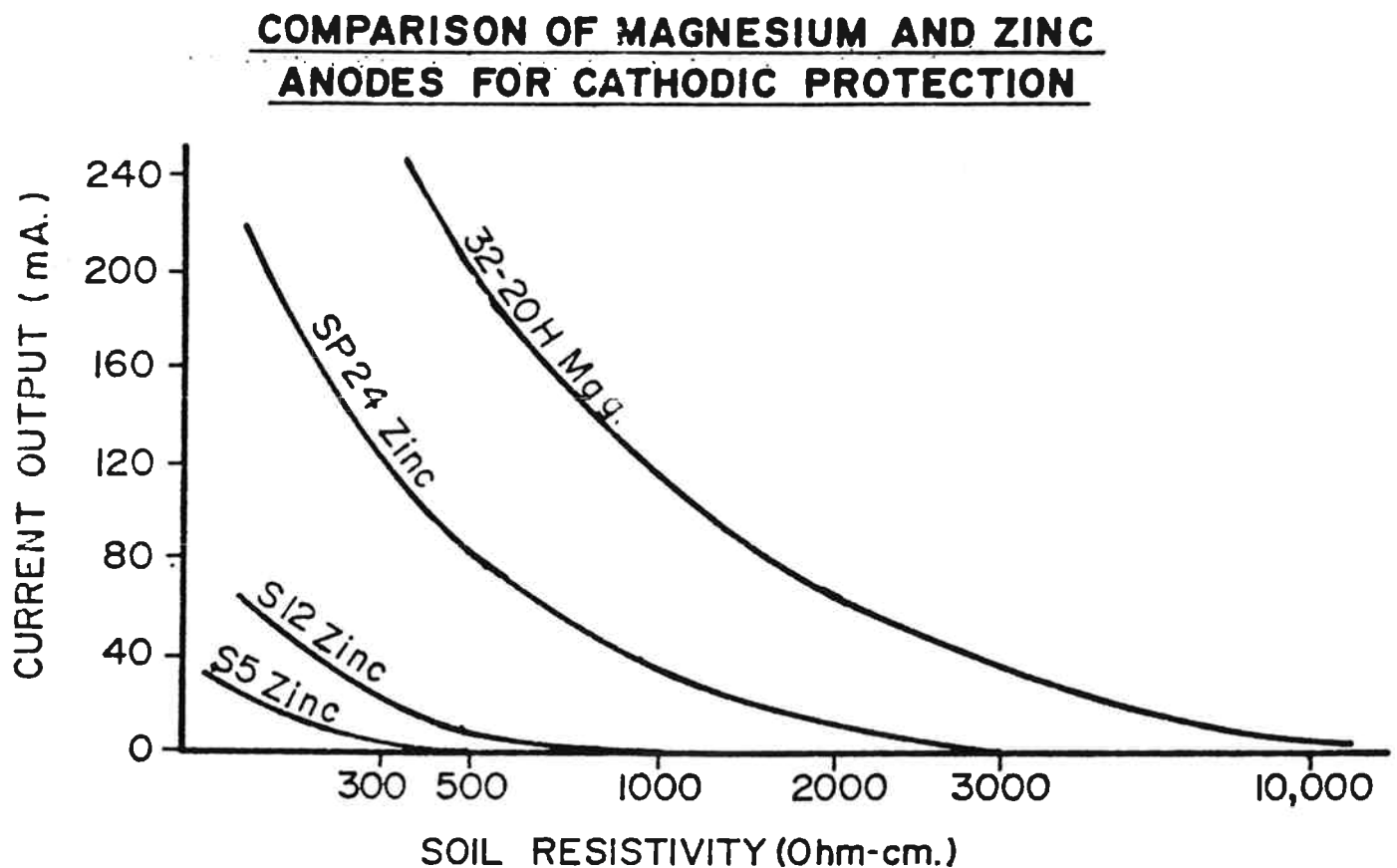## COMPARISON OF MAGNESIUM AND ZINC ANODES FOR CATHODIC PROTECTION

Figure No. 10

This, of course, results in less magnesium anodes being required to achieve equivalent protection. Since the cost of installing anodes is primarily related to the labour cost then the fewer anodes that can be installed, the less expensive the cathodic protection system. The danger in using zinc anodes is the effect of bicarbonates on the zinc potential. Where the bicarbonates and carbonates in the soil exceed the sulphates and chlorides the zinc may passivate. In this condition of high bicarbonates the zinc potential may drop to as low as 400 mV with reference to copper/copper sulphate, thus resulting in a condition where the zinc is cathodic rather than anodic to the cast or ductile iron water main as shown in Fig. No. 11. This will result in increased corrosion of the ductile and cast iron piping.

EFFECT OF BICARBONATES ON ZINC POTENTIAL

$$\text{WHERE: } \frac{\left[HCO_3^-\right]}{\left[CO_3^{-2}\right]} > \frac{\left[SO_4^{-2}\right]}{\left[Cl^-\right]}$$

FREELY CORRODING DUCTILE IRON

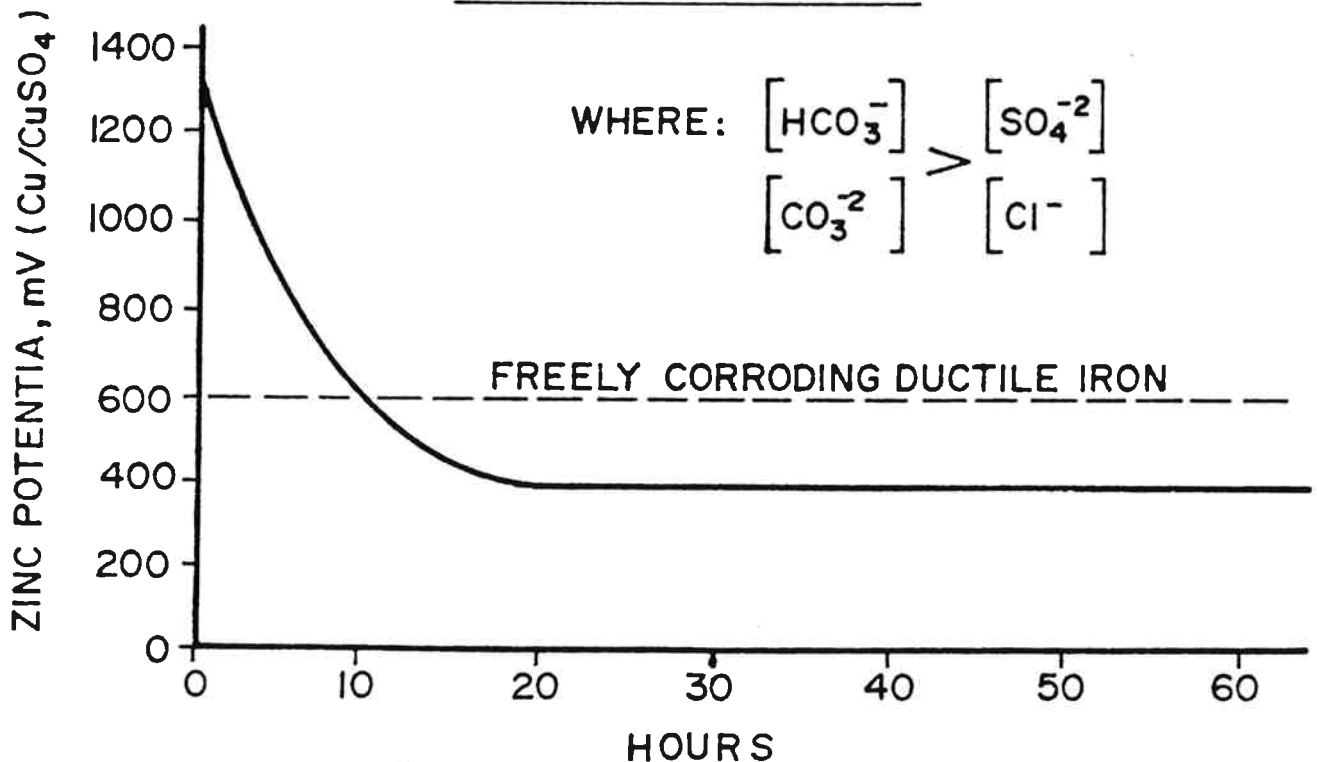ZINC POTENTIA, mV (Cu/CuSO₄)

HOURS

Figure No. 11

Furthermore, a large supplier of zinc anodes for the North American market does not recommend the installation of zinc anodes in the soil unless they are prepackaged with a suitable backfill material containing gypsum, bentonite, and sodium sulphate to prevent anodic passivation of the zinc. Thus magnesium is the most suitable sacrificial anode material for use in cathodic protection of water mains. Fig. No. 12 shows the spacing of magnesium anodes required for cathodic protection of ductile iron water mains in clay soils:

SPACING OF MAGNESIUM ANODES REQUIRED FOR CATHODIC PROTECTION OF DUCTILE IRON WATER MAINS IN CLAY

SIZE	SPACING
4" DIA. ⟶	75 FT.
6" DIA. ⟶	50 FT.
8" DIA. ⟶	37.5 FT.
10" DIA. ⟶	30 FT.
12" DIA. ⟶	25 FT.

Figure No. 12

The recommended size of magnesium anode for cast or ductile iron water main systems is a 32 lb., 22" long magnesium anode packaged in a gypsum, bentonite, sodium sulphate backfill. These anodes when used at the spacings shown in the table will have a life expectancy of 15 to 20 years. Since magnesium will self-corrode it is not advisable to use a larger size magnesium anode since efficiency will be reduced by self-corrosion of the anode material. In sandy soils magnesium anodes of other lengths may be used to accomplish cathodic protection since the current output of the magnesium anode is determined by its diameter and length. This allows the magnesium anode to be sized for the particular environment in which it is to be installed.

In conclusion, cathodic protection is a viable method of reducing water main failures, thus reducing the cost of operation of a water distribution system. Cathodic protection can be supplied during new construction to existing water systems and by the municipality as 'hot-spot' protection when leaks occur on the cast or ductile iron systems.

REFERENCE

1. Staehle, R.W.; Galvanic and Stray Current Corrosion; Causes and Prevention. Ohio State University.

2. Tomashov, N.D.; Theory of Corrosion and Protection of Metals.