Public water facilities face a significant economic burden created by the deterioration of their buried water piping systems. AWWA has tracked the critical issues facing the water industry since 2004. In a 2011 report (Murphy), AWWA described that failing water infrastructure and financing water system rehabilitation are the top issues facing the water industry in the United States.

As water system facilities are reaching their financial life expectancy, the need to rehabilitate or replace water mains is increasing.

- In 2001, AWWA estimated that by 2030, US water utility systems will have to spend on average nearly four times as much per year (in 2001 dollars) to replace water piping that will have reached the end of its economic life (AWWA, 2001).
- In 2002 the US Environmental Protection Agency (USEPA) warned that community water systems and not-for-profit water systems in the 50 states, US territories, and tribal areas faced a major funding gap. The USEPA's worst-case analysis (with no revenue growth) estimated a total payment gap for operations and maintenance and capital expenses of $263 billion or about $13 billion per year through 2019 (USEPA, 2002).

Danny J. Klopfker and Jeff Schramuk

Implementing and managing a large water utility’s underground corrosion control program

THE DES MOINES, IOWA, WATER WORKS HAS IMPLEMENTED AN UNDERGROUND CORROSION CONTROL PROGRAM TO MITIGATE CORROSION BY USING CATHODIC PROTECTION TO REDUCE ITS WATER MAIN BREAKS.
This year AWWA projected that restoring the nation’s existing water piping and building new water systems will cost more than $1 trillion over the next 25 years (about $40 billion per year through 2035) and nearly double this cost by 2050 (AWWA, 2012).

As can be seen by these data, deferring water main investments in the short term will only increase the challenge in the coming years—making budgeting for water main repairs and/or pipe replacements a major budget concern for water utilities in the United States.

**CORROSION AND MAIN BREAKS**

Corrosion is a phenomenon that concerns most water utilities in North America, where about two thirds of the installed water main network consists of various forms of ferrous pipes, including cast iron, ductile iron, and steel pipes. Studies have shown that the predominant deterioration mechanism of the exterior of cast and ductile pipes is electrochemical corrosion (Rajani & Kleiner, 2004). Pipe of the same material has been shown to last from as little as 15 years to more than 100 years depending on the soil characteristics alone. Recent studies confirm that that pipe material, diameter, installation date, and soil type are the most important variables in influencing main breaks (Wood et al, 2009). Although many physical actions influence the breakage of a buried water main, the corrosion process often contributes to reducing a water main’s structural resiliency and leads to main breaks (Kleiner & Rajani, 2000). It has been shown that corrosion pits on ductile iron or graphitized zones on cast iron are generally the failure mechanisms that can cause metallic water mains to break—sometimes in as little as 5 to 10 years after their installation (Kleiner & Rajani, 2004).

Cathodic protection (CP) of cast- and ductile-iron mains is a mitigative measure that can reduce premature breaks because of water main corrosion. Although experience suggests that the effectiveness of an individual water utility’s CP program will vary with the area’s unique site conditions, Ontario, Canada, has proven that CP is a cost-effective method of reducing main breaks by protecting and extending the life of its buried mains. On the basis of the results dating back to the mid-1980s, Ontario has expanded its CP program to consist of hot spot, reactive, proactive, and routine corrosion monitoring for both ductile cast-iron and gray cast-iron pipes (Ontario Centre for Municipal Best Practices, 2008).

With consideration of the successful application of CP by several major North American water utilities, Des Moines (Iowa) Water Works (DMWW) implemented a CP program for select water mains, new water transmission mains, and select smaller distribution mains. This article summarizes four CP programs that are reducing failures and extending the service life of DMWW’s water mains.

**HOW DMWW DEALS WITH UNDERGROUND CORROSION**

Both visual and metallurgical examinations indicate that most of the water main breaks in the DMWW distribution system can be directly or indirectly related to corrosion. With 521 mi (838 km) of its 1,380-mi (1,609-km) water distribution system (excluding 380 mi [612 km] of rural water piping) having reached its financial life expectancy and another 99 mi (159 km) reaching its life expectancy by 2020, DMWW is budgeting aggressively for water main replacements. Since 1994 there has been a gradual increase in cast-iron water main failure rates for DMWW (Figure 1). Data through the end of 2011 indicate that there are now about 300 main breaks apportioned over about 747 mi (1,202 km) of its metallic water mains each year—or roughly 40 breaks per 100 mi (161 km) per year. As a comparison, AWWA has suggested that a “reasonable goal” for water system main breaks in North America is 25 to 30 breaks per 100 mi (161 km) of main per year (Deb et al, 1995).

Although the number of system failures has been rising, the cost of main breaks has also been rising each year. In 2003, the average cost per water main break for DMWW...
was approximately $3,788, but by 2011 the average cost had increased to $5,372. The increasing number and costs of water main breaks coupled with inadequate funding for water main replacement resulted in DMWW implementing in 2004 a corrosion mitigation program to reduce the number of water main breaks and extend the service life on its buried metallic water mains.

**DMWW’S ASSET MANAGEMENT AND CONDITION ASSESSMENT PRACTICES**

Water main breaks have been called routine and just an operational inconvenience; however, this view is short-sighted—water main breaks can create adverse effects with regard to the public’s health, damage to the environment, economic damages for the business community and the water utility, and can be a detriment to public safety (USEPA, 2005). When the risk of main breaks is reduced, the water utility directly benefits its customers by reducing its operating costs.

Asset management is defined as an optimization process that attempts to meet the competing objectives of cost minimization and reliability maximization (Rubin, 2011). A simple framework (Figure 2) of best practices has been established by the USEPA to allow water utilities to implement an effective asset management program (USEPA, 2008).

As part of its asset management program, DMWW maintains an accurate database of its water piping network through a geographic information system. DMWW routinely updates its hydraulic model databases. These databases are used for the risk assessment of main breaks. Acknowledging the probability of a failure and weighing this probability are part of DMWW’s overall risk management program. Collecting historical data and pipeline characteristics, using soil corrosivity tests to identify areas with the greatest likelihood for corrosion, directly examining physical defects requiring pipe repair or replacement, and evaluating these data are also part the process consistent with recommended water infrastructure management practices (Marlow et al, 2010).

**CORROSION DEFINITIONS AND CP**

Corrosion of a buried water main is defined as the electrochemical degradation of the metal as a result of its reaction with its environment. Four components of an electrochemical cell are required to have corrosion take place. Remove any one of the four components: the anode (corroding), the cathode (noncorroding),

![Figure 1: DMWW’s long-term main break data (1994–2011)](image-url)
the anode–cathode connection, or the soil or water (electrolyte) that surrounds the buried pipe, and corrosion will be stopped. However, this is not an easy task because the pipe contains both anodes and cathodes bound into a metallic matrix that cannot be altered. In corrosive environments, water utilities typically attempt to isolate their buried water mains by applying bonded coatings and/or tape to the pipe or by sheathing the pipe in an unbonded plastic film. The theory is that restricting water and oxygen access to the metal surface will reduce the corrosion, but unfortunately, no method to isolate a buried pipe from its electrolyte is perfect, and third-party damage after burial is also a long-term concern many years after the main is installed. Because of these limitations, CP is installed to mitigate the corrosion to buried water mains. Properly designed, installed, and maintained CP systems can add years of additional service life to water mains.

**CP APPLICATION CRITERIA**

The criteria used by DMWW to apply CP has many operational considerations such as critical water service customers (large industrial, commercial facilities, hospitals), critical water main surroundings (under major roadways or in congested public utility corridors), and the ability for crews to quickly repair main breaks and restore service on large water transmission mains. With this rationale, the following sections of this article describe four examples of the application of CP as an economical means to mitigate corrosion on DMWW’s existing distribution water mains and new distribution and transmission mains.

**DMWW’s CP anode retrofit program.** This program has continued uninterrupted since 2004 and the design for 2012 installation has been completed. The sites considered for each year’s installations are selected using several criteria including pipe material, pipe age, the number of failures on the pipe, the condition of the pipe, the ease of installation of the anodes, soil characteristics, traffic disruption, inconvenience to customers, and excavation and restoration costs. Water mains that do not meet DMWW’s customer standards for water service are not considered for the anode retrofit program (ARP). Using an objective ranking model, a short list is created of water main sections to consider for the installation of anodes based on the annual CP retrofit budget.

Early into the ARP, DMWW performed the entire installation including vacuum soil excavation for each anode, attachment of the anode to primarily spin cast-iron pipe via stud arc-welding, installation of both anodes and test wires, and backfilling the anodes with native soil. As the ARP advanced, vacuum excavation (Figure 3) and pavement core drilling were subcontracted while DMWW connected the anodes to the pipe using a battery-operated exothermic welding tool that allowed secure anode connections to be made to pit (sand) cast-iron pipe. DMWW completed test station installations and also made site restorations. Anode holes are now routinely backfilled with a flowable cementitious material in lieu of sand or native soil above the anode. As the ARP has evolved, the Engineering and Public Works Department of the city of Des Moines and the Iowa Department of Transportation have seen a reduction in the number of main breaks beneath their pavement infrastructure.

The selection of a CP criterion to significantly reduce corrosion rates.

**FIGURE 2 Asset management: The core framework**

1. What is the current state of your assets?
2. What level of sustainable service is required?
3. Which assets are critical to sustainability?
4. What are minimum cycle costs?
5. What is the long-term funding strategy?

USEPA, 2008
for a bare cast-iron water main does not require the same conservative NACE International criteria that are applied to well-coated steel pipelines that convey hazardous gases or liquids (NACE International, 2002). Using data from several Canadian water utilities (Raymond, 1998; Wright & Nicholson, 1991), studies have shown that after a relatively short transition period (Rajani & Kleiner, 2006), the ARP significantly reduces the rate of corrosion on existing water mains during the life of the CP system. Field data indicate that a 25-year-life-extension for water mains installed with the ARP is a realistic expectation.

Cost analysis: ARP versus water main replacement. Between 2004 and 2011, CP anodes were installed on approximately 82,700 ft (25,207 m) of 6- (15-cm) through 16-in. (41-cm) pipe at a cost of more than $1 million. This amount includes both the costs for the anode installation as well as indirect costs such as periodic maintenance and underground locating costs. Assuming that the life expectancy of a new water main is 100 years and the life expectancy of the CP system is 25 years, the net annualized savings of using ARP are 86% of water main replacement costs. After implementing the ARP in 2004, DMWW has achieved an average reduction of 90% in the number of water main breaks at a cost of less than 10% of main break repair or replacement (Figure 4).

Cost analysis: ARP versus water main repairs. Because capital budgets are not available to replace all the water mains needing to be replaced, an alternative scenario is presented that ignores that the pipe has reached its financial life expectancy and needs to be replaced. In this case, it is useful to compare the cost of DMWW’s ARP installations with the ongoing cost of main break repairs, which otherwise could be significantly reduced through CP. Using DMWW’s 2011 main break repair cost of $5,400, the total cost to continue repairing these mains over 25 years would have been nearly $3 million. Using an anode life estimate of 25 years, DMWW’s ARP installations would lower the number of main breaks by at least 90% (on pipes with CP), yielding a net annualized savings of 63% versus the “repair-main-break-only” option. A summary of the costs associated with DMWW’s 2004–11 ARP versus the repair-only alternative is shown in Figure 5.

Hot-spot CP anodes at water main breaks. With an average cost of more than $5,000 to excavate, repair, and restore the site at a water main break, in 2005 DMWW began to install sacrificial anodes at main breaks. This reactive practice, which DMWW calls the Hot Spot Program, is consistent with recommendations provided by the Water Research Foundation to document all water main break repairs and install a sacrificial anode every time the main is exposed for repairs (Awwa Research Foundation, 1995). To alleviate connection problems on various pipe materials in a wet environment, DMWW uses a proprietary connection device to securely attach the anode lead wires to all types of ferrous water mains.

After implementing the Hot Spot Program in 2005, DMWW found that more than 50% of the current from a 32-lb sacrificial anode placed within 3–5 ft (0.9–1.5 m) of the water main will be picked up within

![Typical anode retrofit installation method](image_url)
15–25 ft (4.6–7.6 m) on each side of the anode. In most soils, a sacrificial anode will provide CP current to mitigate at least 90–95% of new corrosion on the water main at a cost of about 3% of an average water main break.

**CP for new water transmission mains.** Prestressed concrete cylinder pipe, poly-wrapped ductile-iron pipe (DIP), and coated welded-steel pipe were approved by DMWW for new large-diameter (≥ 24 in. [61 cm]) water transmission mains. Normally, prestressed concrete cylinder pipe is installed with joint bonding and corrosion monitoring test stations. In recent years, only about 5,000 ft (1,524 m) of welded-steel pipe has been installed by DMWW for a new transmission main; the pipe is then installed with CP. In addition, since 2005 DMWW has installed approximately 75,000 linear ft (22,860 m) of large-diameter, poly-wrapped DIP with sacrificial anodes installed parallel to the pipeline.

Corrosion of ductile pipe used to construct water transmission and distribution systems has gained wider publicity in the water utility industry (Rajani & Kleiner, 2003). The water industry, corrosion engineers, and pipe manufacturers often disagree, however, when discussing the most appropriate corrosion control measures for this pipe material (Bonds et al, 2005; Dechant & Smith, 2004; Spikelmire, 2002). When confronted with aggressive soil environments for new ductile-iron water mains, many civil engineers will specify that the pipe be encased with loose polyethylene sheathing (poly wrap) per AWWA standards (AWWA, 2009). Although many corrosion engineers consider poly wrap to be an ineffective means of corrosion protection on DIP (Szeliga, 2007, 2005), the National Academy of Sciences has stated that if manufactured and installed correctly, polyethylene encasement with CP provides a “betterment” to bare and as-manufactured versus ductile-iron pipe without CP in highly corrosive soils (NRC, 2009).

To estimate the CP requirements for a new transmission main, predesign drawings that describe the proposed main’s overall routing plan and profile are reviewed. A preconstruction soil resistivity survey is performed along the proposed right-of-way. Examination of the soil environment is currently considered

---

**FIGURE 4** DMWW economics: Water mains installed with ARP

<table>
<thead>
<tr>
<th>ARP Unit Cost—$/ft</th>
<th>ARP Cost versus New Pipe—%</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.00</td>
<td>0.00</td>
</tr>
<tr>
<td>9.00</td>
<td>2.00</td>
</tr>
<tr>
<td>10.00</td>
<td>4.00</td>
</tr>
<tr>
<td>11.00</td>
<td>6.00</td>
</tr>
<tr>
<td>12.00</td>
<td>8.00</td>
</tr>
<tr>
<td>13.00</td>
<td>10.00</td>
</tr>
<tr>
<td>14.00</td>
<td>12.00</td>
</tr>
<tr>
<td>15.00</td>
<td>14.00</td>
</tr>
</tbody>
</table>

**ARP**—Anode Retrofit Program, **DMWW**—Des Moines Water Works

When the risk of main breaks is reduced, the water utility directly benefits its customers by reducing its operating costs.
the best approach to evaluating corrosion on an unprotected pipeline (USEPA, 2009) and is also used to determine the alloy, size, and spacing of the CP design.

Low-resistivity soils are considered to be more corrosive than high-resistivity soils, and although no national standard exists, most corrosion engineers and the US government consider soil resistivity values less than 2,000 and between 2,000 and 5,000 Ω-cm to be seriously corrosive and very corrosive, respectively, to buried ferrous piping (USDOD, 2005). Many of DMWW’s new water transmission mains are installed in soils having resistivity values of between 1,500 and 3,000 Ω-cm at pipeline depth.

After requiring that CP be installed on all new large-diameter, polyethylene-wrapped ductile-iron water transmission mains, the program has shown that the total initial cost to install a CP system is less than about 3% of the total construction cost of the new main. When calculated using a 25-year life expectancy of the CP system, this approach has shown that the annualized cost is less than 0.2% of the total construction cost.

CP for small metallic water distribution mains. DMWW began using C-900 Standard polyvinyl chloride for its distribution water mains in the 1980s. As a result, many anticipated problems with corrosion of smaller water mains have been managed successfully. However, because polyvinyl chloride pipe and its joints are susceptible to permeation by petroleum-contaminated soils or groundwater, DMWW also installs polyethylene-wrapped DIP with hydrocarbon-resistant gaskets in the plume areas of contamination from leaking underground petroleum storage tanks.

DMWW protects these ductile-iron installations with CP using sacrificial anodes at predetermined intervals along the new water mains. Pipe joints are rendered electrically continuous during construction with all service laterals and piping tie-ins being electrically isolated. Because of their simplicity, these CP installations have been inexpensive.

CP operation and maintenance. DMWW’s CP installations do not require rigorous monitoring other than to confirm that test stations remain in place, that all wiring connections remain intact, and that all electrical isolation devices continue to function properly. Using inexpensive test equipment, DMWW uses its employees and summer engineering interns to measure pipe-to-soil potentials and anode direct current outputs at all test stations using standardized color-coded test wires and simple test diagrams and data sheets. During this monitoring, DMWW staff members are usually able to make minor repairs to the CP test points. Any data anomalies are reported to a NACE-certified CP specialist for interpretation.
THE BOTTOM LINE
DMWW’s Underground Corrosion Control Program has shown that the various CP installations can extend the service life of its water piping network at a cost that is much lower than either pipe repairs or main replacement. By installing CP as a good engineering practice, DMWW has increased the service life of its water mains, maintained a more reliable water service to its customers, and augmented the health and security of its water supply infrastructure.

ABOUT THE AUTHORS
Danny J. Klopfer is the infrastructure planning manager at Des Moines Water Works (DMWW), 2201 George Flagg Pkwy., Des Moines, IA 50321; klopfer@dmww.com. He is responsible for developing and coordinating DMWW’s utilities asset management and infrastructure reinvestment program, developing and reviewing engineering studies related to water systems, and coordinating infrastructure projects with other agencies. Jeff Schramuk is a certified cathodic protection specialist with CP Solutions Inc., Bartlett, Ill.; jeffs1167@comcast.net.

REFERENCES

http://dx.doi.org/10.5942/jawwa.2012.104.0082