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The Silver Bullet for Aging Water Distribution Systems?

In folklore, a silver bullet is reportedly the only kind that provides an effective defense against terrible monsters. For the Lone Ranger, silver bullets symbolized justice—law and order. Today, a "silver bullet" refers to any straightforward solution perceived to have extreme effectiveness. The phrase is typically used to infer that some new technologic development or practice will easily cure a major prevailing problem. If the evil monster or major problem is corrosion or pipe-replacement costs, then indeed, polyvinyl chloride (PVC) pipe would be the silver bullet to meet the challenges and costs associated with the aging water infrastructure crisis for water and wastewater systems.

UNDERSTANDING THE TARGET

In response to population growth, the United States installed underground water infrastructure during three main periods: the 1800s, 1900–45, and post-1945. Pipes constructed in each of these three eras will all start to fail at nearly the same time over the next couple of decades for reasons ranging from age and corrosion to inadequate design and poor installation. Additionally, the useful life of the materials has become shorter with each new investment cycle (WIN, 2002).

According to the AWWA report *Dawn of the Replacement Era* (2001), the oldest cast-iron pipes—dating to the late 1800s—have an average useful life of about 120 years. As a group, these pipes will last anywhere from 90 to 150 years, but on average they need to be replaced after they have been in the ground about 120 years. Because manufacturing techniques and materials changed, the 1920s vintage cast-iron pipes have an average life of about 100 years. Manufacturing techniques and materials continued to evolve, resulting in the pipes laid down post-World War II having an average useful life of 75 years. Using these average life estimates and counting the years since the original installations shows that water utilities will face significant needs for pipe replacement over the next few decades. Replacement of pipes installed from the late 1800s to the 1950s is upon us, and replacement of pipes installed in the latter half of the twentieth century will dominate the remainder of the next one.

Utilities are faced with reviewing new methodologies and materials to select the best-fit, right-cost solution to age-old problems. Doing things the same old way and expecting different results does not meet the standards of an effectively managed utility.

Corrosion costs. The majority of pipes needing replacement are failing primarily because of their age and the excessive corrosion that has weakened pipes both externally and internally. Tuberculation is a form of internal corrosion and biofilm contamination that develops in iron pipes and restricts water flow. This restricted water flow can lead to additional problems. Internal corrosion can also be a breeding ground for bacteria. Photographs of old water mains with built-up internal corrosion faster feelings of distrust when the public realizes the utility has been providing them with drinking water from the pipe for the past 50 years. Unlike iron pipe, PVC is not affected by tuberculation. Its smooth, noncorrosive, and bacteria-resistant surface stays clean for decades.

PVC REPORTED TO LEVEL THE CORROSION PLAYING FIELD

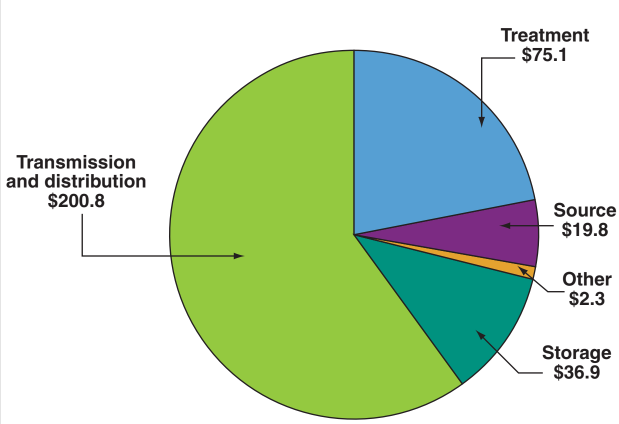
In many ways ductile iron behaves the same as gray cast iron. Some research has concluded that the corrosion behavior and corrosion resistance of ductile and gray cast irons would not be significantly different (Angelfire, 2011). Other studies have indicated that ductile iron might corrode faster than gray cast iron (Angelfire, 2011). Soils with lower resistivity are likely to cause more rapid pitting to ductile iron at rates that increase as the resistivity decreases, according to data compiled from various surveys and studies conducted in the United States, Canada, and Europe (Angelfire, 2011).

The high cost of mitigating pipe corrosion and distribution water quality issues is starting to be better understood. The useful life of pipe varies considerably, depending on such factors as soil conditions, materials used, and character of the water flowing through it. Corrosion of various metals and concrete is a common problem in some soils. Corrosion affects materials both on the surface and within the soil to various degrees. Streets, highways, sidewalks, houses, and pipelines for gas, sewage, and water are a few examples of the structures and facilities that are exposed to corrosion. Selecting the wrong pipe material or failing to protect pipe can greatly shorten the lifespan of sewer and water lines. Corrosion affects both main lines buried under streets and service lines that connect to homes and businesses. Line maintenance may be continuous and costly where the materials are not suited to the soil. The risk of corrosion is rated in soil survey reports as low, moderate, or high. Soils are rated for corrosivity in a natural condition or the condition evident during a soil survey. Local soil conditions, such as excess moisture and alterations of the landscape, can accelerate corrosion. Additionally, fertilizer and industrial wastes can alter soil conditions and increase their corrosivity (USDA, 2004).

In a sense, corrosion can be viewed as the spontaneous return of metals to their ores. The economic aspects of corrosion are far greater than most people realize. According to a 2001 report (Koch et al), the cost of corrosion in the United States alone was $276 billion per year. Of this, about $121 billion was spent to control corrosion, leaving the difference of $155 billion as the net loss to the economy. Utilities—particularly drinking water and sewer systems—suffer the largest economic impact, with transportation being a close second (Lower, 2009). A real-time estimate is displayed on the corrosion cost clock at www.watermainbreakclock.com.

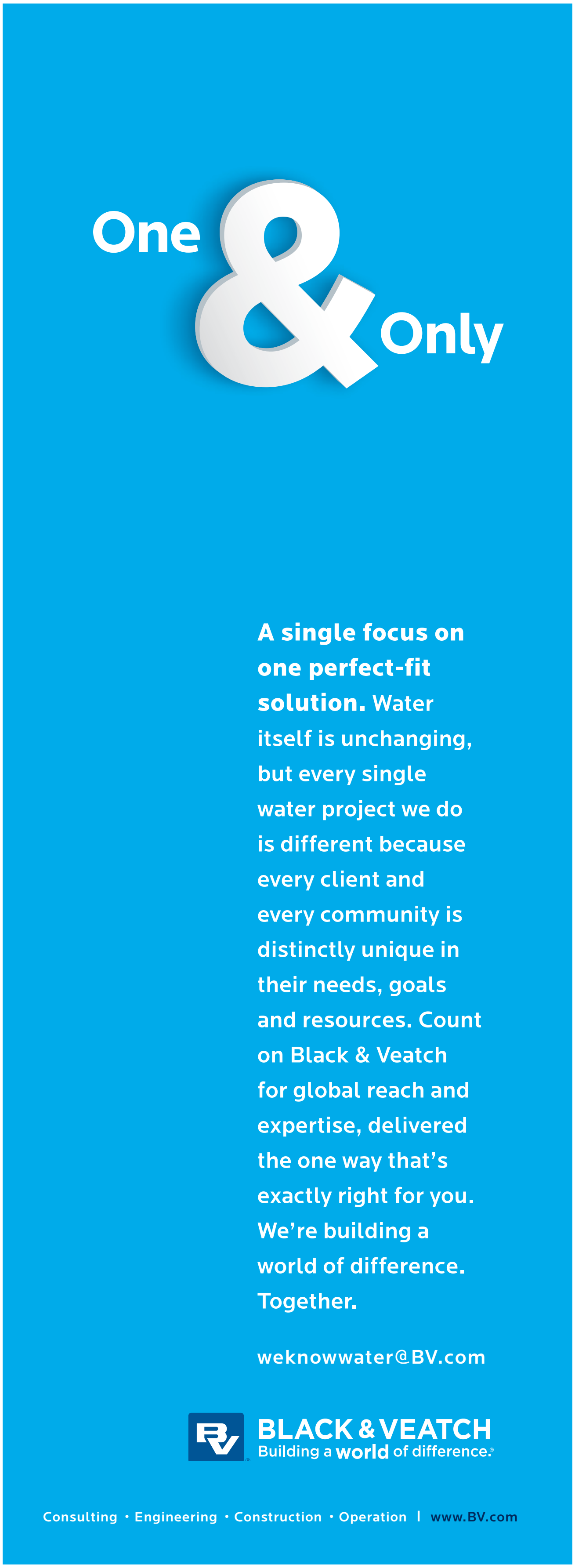
The firing range. The main hot spots for these failures and resulting pipe replacement are in the industrialized population growth centers that were established after World War II. In 2001, the Water Infrastructure Network (WIN)—a consortium of industry, municipal, and nonprofit associations—estimated that as much as $1 trillion over a 20-year period would be needed to sustain water and wastewater systems in the United States when both capital investment needs and the cost of financing were considered (Baird, 2010a). The US Environmental Protection Agency (USEPA) estimated $334.8 billion (in

FIGURE 1 Total 20-year need by project type (in billions of dollars)*



Percentage not equal to 100 because of rounding

**Calculated according to 2007 dollars*



2007 dollars) would be needed to maintain just drinking water systems over the next 20 years (USEPA, 2009).

Pipe replacement costs. The majority (60%) of the replacement costs are for water transmission and distribution pipes. In 2007, this number was estimated at $200.8 billion (Figure 1). Given that the economic downturn has resulted in deferred maintenance and delayed capital projects, this number is expected to increase to more than $250 billion. If the amount was mostly financed through long-term 30-year debt to achieve intergenerational equity among ratepayers, the figure would increase to $500 billion over the next 20 years. Ultimately, however, the ratepaying public will have to finance the replacement of US water infrastructure either through higher rates or taxes. Local funds are expected to cover the cost of the great majority of the nation's water infrastructure needs in the United States (AWWA, 2001).

"The staggering cost of maintaining, operating, rehabilitating, and replacing our aging water infrastructure requires a new partnership between federal, state, and local government," said Dennis Archer, mayor of Detroit, Mich., and president of the National League of Cities (USEPA, 2011a). Efforts to engage multiple stakeholders in order to lower the cost of borrowing will continue to gain local political support, but efforts will face heavy competition for funding priorities in Washington, D.C. Utilities that have effectively managed their pipe replacement programs and have addressed their corrosion issues do not want to subsidize those that have not.

Utilities are constantly caught between needing to finance the high replacement costs of underground infrastructure and the political pushback resulting from rate increases and affordability issues. The upshot is many managers are turning to long-term capital project and infrastructure financial planning to demonstrate the cost savings of PVC over ferrous materials such as ductile iron and steel, while also addressing corrosion issues and matching long-term performance. Additionally, the completion of long-term infrastructure financial and asset management plans will be critical to attracting and retaining current and future bondholders and investors.

To understand the nature and scope of the emerging infrastructure challenge, AWWA undertook an analysis of 20 US utilities. The analysis projects future investment needs for pipe replacement in these 20 utilities (Figure 2) and provides a forecast called a "Nessie curve." The Nessie curve is a graph of the annual replacement needs for a particular utility, based on when pipes were installed and how long they are expected to last in that utility before it becomes economically efficient to replace them (AWWA, 2001).

Required rampups in water system replacement costs will continue. Long-term, low-cost options need to be openly accepted by all municipalities and utilities. PVC, and even new improvements to PVC, will be required to meet the growing challenge.

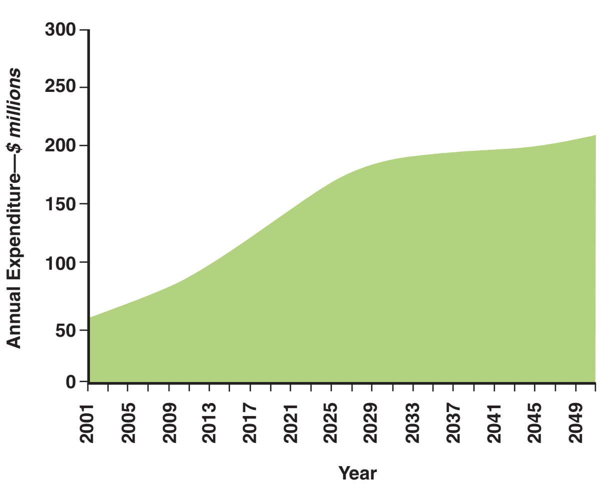
AIMING FOR AFFORDABILITY

The USEPA continues to send forth important new strategic public policies on twenty-first-century water challenges such as "Coming Together for Clean Water: EPA's Strategy for Achieving Clean Water" and "EPA's Clean Water and Drinking Water Infrastructure Sustainability Policy." These approaches promote sustainability and cost-effective planning but remain silent on any clarification about affordability except that the public needs to understand the value of water. The USEPA's writing on the wall about what the value of water and full-cost pricing mean seems to point to a 5% allocation of average household income to water and wastewater services (Baird, 2010b). For many citizens, this represents a 200–400% rate increase when 20% of lower-income families may already be paying more than 4% of their household income for water. As part of the solution, low-cost, sustainable, environmentally friendly PVC pipe should be considered in every open-cut pipe project for replacement needs or system expansion requirements.

The main question for policy-makers and utility managers is whether the increasing rate of infrastructure spending that utilities are facing over the next 20 years can be financed by the utilities themselves at rates customers can afford (AWWA, 2001). Accordingly, engineers must consider costs and funding in every planning and design decision. As with Rome, the infrastructure wasn't built in a day. Our water and wastewater infrastructure was built over generations and can be rebuilt at an affordable pace if we make smart decisions now (AWWA, 2006).

Developer fees affordability. Even for growth-related pipe projects and water distribution system expansions, the development community is concerned with the initial cost of the pipe. Developers in many areas are subject to development fees or connection/tap fees to help offset the cost of growth to a municipality or utility (AWWA, 2000). As a result, developers are strongly voicing their concerns over legitimate procurement and bidding practices that include PVC pipe as a low-cost, long-term, durable and sustainable option.

FIGURE 2 Projected expenditures for water main replacement caused by failure for 20 utilities



Utility managers no longer enjoy the benefits of being the silent utility and selecting design practices and materials from the past. In general, design practices in the United States are not drastically different from those used 30 years ago. However, research conducted in Europe and Japan suggests the broad goal of sustainability is not being achieved by current design practices in the United States (USEPA, 2011b).

Ratepayer affordability. As with metal pipes, improvements in PVC pipe manufacturing and design standards have helped improve durability and performance. These factors and cost comparisons have helped reduce the overall financial burden and historical infrastructure liability for ratepayers. In the March 2011 issue of *U.S. Mayor*, Jennifer Hosterman, Pleasanton, Calif., mayor and co-chair of the US Conference of Mayors Water Council, explained that PVC pipe is about 70% cheaper to use and less labor-intensive to install than is ductile iron pipe. Hosterman stated, "Giving taxpayers the best bang for the buck should be the chief goal for mayors and local elected officials across the country," and went on to explain that Pleasanton's approach rests on a dedication to improving customer service, managing tax dollars wisely, and adopting open procurement policies that welcome alternate and better-performing materials like PVC pipe (*U.S. Mayor*, 2011).

Many municipalities and utilities have adopted these polices and in return have saved tens of millions of dollars in capital costs while reducing operational and maintenance costs. Some utilities have chosen to keep rates at a minimum on the basis of these cost savings, while others have reinvested in advanced metering infrastructure to further transform their organization as a twenty-first-century utility. The materials' cost comparisons have also helped increase the public's perception of the utilities' due diligence and in return have helped justify the requirement for future rate increases. Conversely, utilities that fail to adopt open procurement practices to include the financial analysis of PVC materials versus historic pipe purchases are open to harsh criticism by both ratepayers and potential bondholders.

UNDERSTANDING THE WEAPONS IN COMBATING AGING INFRASTRUCTURE

The water industry is moving toward asset management practices. The benefits of this shift are helping utility managers make better decisions regarding condition assessment, life-cycle assessment, and life-cycle costing; leak-monitoring and investigation; prioritization of rehabilitation; and the selection, design, and timing of replacing aging assets.

Life-cycle costing. To assist utilities, asset management firms are regularly applying low-cost PVC sliplining as an intermediate renewal solution and extending the pipeline life by a minimum 40 years. PVC, with 75 to 95 years of minimum expected life and low maintenance, is then typically selected to achieve overall lower life-cycle cost projections. Both US and European sources consider PVC to have a durable life expectancy of more than 110 years. With a common-sense and affordable approach, powerful, secure, and reliable networks of pipes, equipment, and treatments that will provide clean and safe water far into the future can be developed.

Various other life-cycle cost comparisons and assessments have also found PVC to be a prudent choice. The discussion of life-cycle costs should not be confused with academic studies known as "life-cycle analyses" (LCAs). A life-cycle cost comparison looks at the costs to the user of a product from purchase through disposal. LCA, on the other hand, attempts to account for all the environmental effects of a given product—from production through use and disposal. Depending on the data categories that are included, LCAs may provide useful environmental information, but they are not a substitute for a life-cycle cost comparison. Life-cycle costs do not directly depend on the environmental impacts included in an LCA; rather, life-cycle costs reflect durability and ease of maintenance as well as initial costs (Ackerman & Massey, 2003).

Life-cycle assessment. One life-cycle assessment study conducted in the Netherlands and comparing PVC and cast-iron pipes using the eco-indicator 99 impact assessment method demonstrated that PVC performs significantly better from an ecologic point of view (Ministry of Housing, Spatial Planning and the Environment, 2000). If pipes are assessed according to the Swiss method of ecologic scarcity (Frischknecht et al, 2006), the findings are essentially the same except for disposal. As a result, recommendations are that both iron pipe and plastic pipes should be collected and recycled separately, if possible. The European Plastic Pipes and Fittings Association (www.teppfa.org/pdf/HSELCAWindspergerStudy.pdf) offers an appropriate collection system methodology. Recycling is the final conclusion for low environmental impact.

Carbon footprint testing. Recio and colleagues (2005) conducted an energy consumption study in which the same mean lifetime (50 years) was assumed, a similar protocol of inspections was followed, and the energy consumption associated with operation and maintenance was the same regardless of the pipe. The study showed that in the case of pipes for drinking water, PVC pipe required the least amount of energy and generated the smallest amount of CO_2 emissions, whereas recycled ductile-iron pipe had the poorest results according to the same measures. Even if recycled material is used in manufacturing the ductile-iron pipe, the energy consumption is still 26% higher than for the PVC pipe. The most unfavorable case corresponds to ductile-iron pipes without recycled material, in which the energy consumption is in the range of 56% higher than PVC (Recio et al, 2005).

Monitoring PVC pipes through leak detection. The National Research Council Canada conducted studies that involved extensive field tests carried out under controlled conditions at a specially constructed experimental leak detection facility in Ottawa, Can. Commonly used acoustic leak detection equipment was evaluated by inviting several experienced leak detection teams from utilities and service companies in Canada and the United States to participate in "blind" leak detection tests. Equipment used by the teams included listening devices and leak noise correlators. Commercial leak noise correlators were generally found to be capable of locating any possible gasketed joint leak in plastic water distribution pipes (NRCC, 2011).

SELECTING THE BEST AMMUNITION

The water industry faces a number of distribution system deterioration problems, including water quality problems related to tuberculation and internal pipe corrosion, low-pressure and high-head-loss problems, system leakage, and main breaks. A properly selected pipe material should help address these common issues.

PVC is strong, lightweight, durable, and resistant to chemicals; it does not corrode. The interior of PVC pipe is also smooth, and because it does not corrode, there is no tuberculation by corrosion by-products. Also, PVC does not serve as a nutrient, which makes it resistant to biological degradation from bacteria and other microorganisms. PVC provides the lowest biofilm formation potential of all the other common water pipe materials being used. The most common joining is the gasketed bell-and-spigot joint, but thermal fusion or butt-weld joints are also used for directionally drilled, trenchless installations for pipeline rehabilitation and relining (*Opflow*, 2005).

PROPER LOADING AND INSTALLATION

Proper installation is vitally important in every pipe project. "Manufacturers of large-diameter PVC pipe place a mark on the spigot of the pipe to indicate the proper insertion depth into the adjoining bell during installation. If proper installation procedures are followed, inserting the spigot into the bell does not create significant stresses in the pipe," stated Steve Folkman, associate professor of mechanical and aerospace engineering at Utah State University in Logan (Folkman, 2011). It is critical that utilities make certain their installation crews are well trained and even have an inspector to ensure complete compliance as a best practice while still achieving a high degree of cost savings. Manufacturers also provide procedures for proper assembly of pipe joints. The Handbook of PVC Pipe (PVC Pipe Association, 2011) offers guidance for the assembly of PVC pipe.

THE BULLSEYE: SUSTAINABILITY THAT'S AFFORDABLE

The USEPA's Aging Water Infrastructure (AWI) research program (www.epa.gov/awi/accomplishments.html)—using research, information, meaningful metrics, methods, and technologies for strategic asset management—will be developed to support the goal of ensuring that our nation's water infrastructure is sustainable. PVC delivers on many of the AWI Research Program's focuses, including:

- reduced life-cycle costs for water infrastructure management,
- extended service life of existing infrastructure,
- reduced high-risk water main breaks,
- improved condition assessment and decision-making capabilities,
- reduced potable water leakage and intrusion potential,
- increased use of performance and cost data for decision support and the adoption of asset management, and
- increased adoption of innovative technologies.

PVC is considered in the top 20 engineering advancements according to a 1999 issue of *Engineering News Record*. The Australian Green Building Council, administrator of the PVC credit as part of that country's GreenStar Program, understands the importance of low-cost, sustainable materials, stating: "PVC cannot be ruled out as a material for use in the built environment" (PVC Forum, 2010).

TAKING AIM AT THE TARGET

The water industry must continue to apply condition assessment and asset management techniques to infrastructure repair/replacement programs, and to incorporate affordable solutions into new prioritized capital plans to reach an acceptable level of sustainability. Many utilities have selected PVC as a means to accomplish these achievable goals, as demonstrated by the existence of more than 1 million miles (260 million bell-and-spigot connections) of PVC water pipe throughout North America.

In other places around the world, PVC piping is recognized as a beneficial product that is a bacteria-resistant material. PVC helps maintain the quality of water when it flows from local borehole wells to various communities in rural Africa. The bacteria-resistant

PVC piping is essential to ensuring that residents continue to receive safe and clean water (Duffy, 2007).

According to Bryan Karney, professor of civil engineering at the University of Toronto, a national program to replace older pipes with hydraulically efficient plastic pipes could achieve greenhouse gas emission reductions amounting to 5% of Canada's obligations under the Kyoto Protocol. PVC was chosen because it is corrosion-proof and leak-resistant; the ultrasmooth surface means that less energy is required to pump water from source to tap (Hollands, 2008).

PVC pipe has gained significant popularity worldwide, not only because of its competitive price, but also because of its longevity. A study presented in Milan, Italy, at a worldwide pipe symposium reported that vinyl pipe installed 70 years ago in Germany could easily function for another 100 years. Longer-lasting and lower-maintenance infrastructure assets such as PVC save taxpayer dollars by making water systems more efficient. In Canada, Calgary and Edmonton are saving an estimated $5 million a year in avoided water main–repair costs because of their extensive use of PVC pipe (Hollands, 2011).

WHERE IS THE SMOKING GUN?

PVC pipes do not contain lead or cadmium and are governed by strict standards and extensive quality control checks, including hydrostatic proof tests performed on each pipe. Green consumerism has jumped the gun on applying plastics concerns to long-term sustainable and affordable underground PVC piping solutions. Modern PVC pipes used in water systems should not be characterized as plastic bags. Opponents fail to mention that there is an "unacceptable" category for underground long-life PVC pipes (PVC, 2011). PVC is recognized by many as a silver bullet to meet the challenges and costs associated with the aging water infrastructure crisis for water and wastewater systems. PVC is a versatile material and is indeed a game changer for a nation dealing with corrosion issues while looking for financially sustainable infrastructure to meet both replacement and expansion needs.

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REFERENCES

Ackerman, F. & Massey, R., 2003. The Economics of Phasing Out PVC. Global Development and Environment Institute. Tufts University, Somerville, Mass. http://ase.tufts.edu/gdae /policy_research/ healthEnvironment.html publications (accessed Apr. 29, 2011).

Angelfire, 2011. External Corrosion and Protection of Ductile Iron Pipe. www.angelfire.com/pop/myfile/EXTDIPhtml.htm (accessed Apr. 30, 2011).

AWWA, 2006. *Water Infrastructure at a Turning Point: The Road to Sustainable Asset Management.* AWWA WITAF Report. Denver.

AWWA, 2001. *Dawn of the Replacement Era: Reinvesting in Drinking Water Infrastructure.* AWWA, Denver.

AWWA, 2000 (5th ed.). Manual M1. *Principles of Water Rates, Fees, and Charges.* AWWA, Denver.

Baird, G.M., 2010a. A Game Plan for Aging Water Infrastructure. *Jour. AWWA,* 102:4:74.

Baird, G.M., 2010b. Water Affordability: Who is Going to Pick Up the Check? *Jour. AWWA,* 102:12:16.

Duffy, A., 2007. New Pipes Mean Renewed Life for Thousands in West Africa. World Vision. Seattle. www.worldchlorine.org/publications/ news/WV_press042007.html (accessed Apr. 27, 2011).

Folkman, S., 2011. Personal communication.

Force, J., 2010. Doubling Up. *Municipal Water & Sewer.* www.mswmag. com/editorial/2010/11/doubling-up (accessed May 17, 2011).

Frischknecht, R.; Steiner, R.; & Jungbluth, N., 2006. The Ecological Scarcity Method: Eco-Factors 2006. Federal Offices for the Environment, Bern, Switzerland. www.bafu.admin.ch/publikationen/ publikation/01031/index.html?lang=en (accessed May 11, 2011).

Hollands, B., 2008. Reducing Waste and Inefficiency in Water Distribution. Canadian Taxpayers Federation. www.undergroundsolutions.com/articles/ Municipal_TheTaxpayer.pdf (accessed May 1, 2011).

Hosterman, J., 2011. Pleasanton's Underground Infrastructure: Sustainability, Cost-Efficiency Through Better Materials Procurement Practices. www.usmayors.org/usmayornewspaper/ documents/03_28_11/032811USMayor.pdf (accessed Apr. 15, 2011).

Koch, G.H.; Brongers, M.P.H.; Thompson, N.G.; Virmani, P.Y.; & Payer, J.H., 2001. Corrosion Costs and Preventative Strategies in the United States. FHWA-RD-01-156. US Federal Highway Administration, McLean, Va. http://events.nace.org/publicaffairs/ images_cocorr/ccsupp.pdf (accessed May 10, 2011).

Lower, S., 2009. *Electrochemical Corrosion.* Chem1 Virtual Textbook. Simon Fraser University. www.chem1.com/acad/webtext/elchem/ ec7.html (accessed May 1, 2011).

Ministry of Housing, Spatial Planning and the Environment, 2000. Eco-indicator 99 Manual for Designers. www.pre.nl/download/ manuals/EI99_Manual.pdf (accessed May 11, 2011).

NRCC (National Research Council Canada), 2011. National Research Council Canada. Leak Detection Methods for Plastic Water Distribution Pipes. www.nrc-cnrc.gc.ca (accessed April 28, 2011)

PVC Awareness. 2011. PVC—The Misinformation. www.pvcawareness. com/PVCTheMisinformation.htm (accessed May 2, 2011).

PVC Forum, 2010. New Green Star PVC Credit Issued in Australia. www.seepvcforum.com/en/article_groups/2/articles/99 (accessed Apr. 27, 2011).

PVC Pipe Association, 2011 The Handbook of PVC Pipe. Uni-Bell PVC Pipe Association, Dallas, Texas. www.uni-bell.org/ resources.php?c=9 (accessed Apr. 30, 2011).

Recio, J.M.B.; Guerrero, P.J.; Ageitos, M.G.; & Narvaez, R.P., 2005. Estimate of Energy Consumption and CO2 Emissions Associated With the Production, Use and Final Disposal of PVC, HDPE, PP, Ductile Iron, and Concrete Pipes. Universitat Politècnica de Catalunya. Barcelona, Spain. www.solvaymartorell.com/static/wma/ pdf/8/1/7/5/Pipesfinalreport.pdf (accessed May 2, 2011).

USDA (US Department of Agriculture), 2004. Natural Resources Conservation Service, National Soil Survey Center. Understanding Soil Risks and Hazards. Lincoln, Nebraska.

USEPA (US Environmental Protection Agency), 2011a. Aging Water Infrastructure (AWI) Research. Collaboration. www.epa.gov/awi/ collaboration.html (accessed Apr. 26, 2011)

USEPA, 2011b. Aging Water Infrastructure (AWI) Research. Sustainability. www.epa.gov/awi/sustainability.html (accessed Apr. 26, 2011)

USEPA, 2010. EPA's Clean Water and Drinking Water Infrastructure Sustainability Policy. water.epa.gov/aboutow/upload/ Sustainability-Policy.pdf (accessed Oct. 6, 2010).

USEPA, 2009. Drinking Water Infrastructure Needs Survey and Assessment. Fact Sheet. http://water.epa.gov/infrastructure/ drinkingwater/dwns/factsheet.cfm (accessed Apr. 26, 2010).

USEPA, 2002. The Clean Water and Drinking Water Infrastructure Gap Analysis. EPA 816-R-02-020. Office of Water, Washington. www.epa.gov/ogwdw/gapreport.pdf (accessed Apr. 26, 2011).

WIN (Water Infrastructure Network), 2000. Clean and Safe Water for the 21st Century. www.win-water.org/reports/ winreport2000.pdf (accessed Apr. 26, 2011).