Awwa Research Foundation
Advancing the Science of Water®

Advancing the Science of Water: AwwaRF and Infrastructure Replacement Needs

Delivering safe, reliable supplies of drinking water to customers' taps depends on the integrity of utility distribution systems. These underground networks, extending over large areas and encompassing multiple connections and points of access, typically constitute the bulk of a water utility's assets. As distribution system pipes and appurtenances age, the need to rehabilitate or replace them can confront utilities with a number of challenges, not the least of which is finding the money to pay for these capital programs.

"The major hurdles for utilities facing infrastructure replacement needs are understanding when replacement will be required, how to schedule it over several decades, and how to pay for it in a fiscally prudent manner," said Gregg Kirmeyer of the consulting firm HDR/EES.

Water utilities that adopt comprehensive asset management programs and implement long-term strategies to sustain the capacity of their distribution systems can improve their financial position as well as their customer service. Maintaining an accurate inventory of infrastructure assets and quantifying renewal needs can help a utility justify large capital expenditures to its governing board, schedule renewal programs over a practical period of time, and decrease costs by improving its bond ratings. Avoiding emergencies such as main breaks not only prevents unplanned service disruptions but also reduces water losses and ensures better water quality.

"AwwaRF identified infrastructure issues as a major research focus as early as the 1980s," said Neil Grigg of Colorado State University. "Utilities have been unsure about how far to push aging distribution systems into disrepair, how long to defer maintenance. Should they let the system go until the pipes break, or should they renew the system ahead of time? Should they be reactive or proactive? The benefit of AwwaRF research is in raising utilities' awareness of these risks and providing tools to quantify the risks. Today, the main tools we have in this area draw heavily from AwwaRF projects."

Kirmeyer echoed these observations. "AwwaRF has played quite a role in increasing awareness of infrastructure replacement needs and in developing tools that can be used in a strategic way," he said.

AwwaRF typically devotes about a quarter of its research funds to infrastructure issues. Its studies on predicting infrastructure replacement needs are helping water suppliers manage distribution system assets, assess the condition of distribution system components, pinpoint renewal priorities, and choose cost-effective rehabilitation and replacement options.

AwwaRF's fundamental contributions in the area of predicting infrastructure replacement needs include:

- Evaluating the general condition of North American water distribution systems and formulating a research agenda based on identified needs,
- Specifying the requirements for building a water distribution system inventory,
- Analyzing trends in main break patterns,
- Cataloging techniques to assess the condition of buried pipes,
- Comparing the tradeoffs between maintenance strategies such as leak control programs and capital programs for rehabilitation and replacement,
- Defining distribution system performance measures and delineating measurement techniques,
- Outlining steps for planning rehabilitation and replacement programs,
- Providing guidelines for setting priorities among overall distribution system renewal needs,
- Integrating decision-making tools for prioritizing and financing infrastructure renewal programs,
- Producing a guidance manual on planning capital expenditures, and
- Synthesizing the findings of infrastructure needs research conducted over the past 20 years.

Beginning With Practical Guidance

AwwaRF's first study of distribution system renewal issues focused on practical approaches and produced a guidance manual to help utilities of varying sizes and capabilities monitor distribution system conditions and plan rehabilitation and replacement programs ("Water Main Evaluation for Rehabilitation/Replacement," Project 54, funded 1983, published 1986, order number 90509). The multifaceted study was directed by Kelly O'Day, with Philadelphia Water Department at the time.

The project team began by analyzing records on broken water mains from six utilities in different regions of the country, comparing data on main break patterns by pipe age, diameter, material, and construction period. They also studied the effects of structural factors—external loads, bedding conditions, corrosion—on water main deterioration. Next they surveyed utilities to catalog analytical techniques being used to evaluate water main conditions. The guidance manual's recommendations for monitoring distribution system condition included analyzing leak and break trends as well as hydrant, valve, and service repairs.

Using computer models, the researchers compared the economic tradeoffs of alternative maintenance strategies such as controlling leaks with capital programs for pipe

rehabilitation and replacement, and they created simple worksheets to help managers calculate unit costs for their own utilities. They specified the requirements for building a water distribution system inventory, including information-gathering procedures, geographic referencing systems, computer mapping capabilities, and hardware and software requirements. Integrating planning strategies for rehabilitation and replacement programs from water utilities across the country, they outlined planning steps that could be adopted by utilities of all sizes, regardless of system needs, budget, or personnel.

"This was a keystone project because it was so early and so many people have referred to it," said Grigg. "This group identified the issues, creating a map of the problems and offering possible solutions."

Defining AwwaRF's Research Agenda

Five years after O'Day's guidance manual was published, AwwaRF funded a project to assess the condition of selected North American water distribution systems, to extrapolate these findings into a portrait of North American water distribution systems generally, and to come up with a 10-year strategy for researching the most critical infrastructure issues identified ("An Assessment of Water Distribution Systems and Associated Research Needs," Project 706, funded 1991, published 1994, order number 90658). This comprehensive project set the stage for widespread awareness of infrastructure replacement needs and stimulated a national debate about how to resolve the problem.

Led by Kirmeyer, the project team collected distribution system information from a variety of sources, including literature reviews, previous AwwaRF projects, expert workshops, water industry databases, utility surveys, and 20 in-depth interviews with water professionals from small, medium-size, and large utilities across North America. "We wanted to understand the extent of deterioration and the types of problems this was causing with water pressure and water quality," Kirmeyer said.

Based on the needs identified by utility personnel, Kirmeyer's team formulated a strategic goal for AwwaRF—to conduct research that will enable water utilities to plan, design, construct, operate, and maintain transmission and distribution systems in a manner that minimizes water quality deterioration and extends the life and makes efficient use of pumping plants, storage facilities, conveyance systems, and water system appurtenances. To support this goal, the group recommended that AwwaRF fund research projects in four areas: (1) water quality and regulatory concerns, (2) corrosion, permeation, and materials deterioration, (3) distribution system condition assessment and rehabilitation and replacement methods, and (4) distribution system design and operation, including the development of performance standards and greater use of tools such as computer modeling and geographic information systems.

The project team also pinpointed specific projects to be conducted during the ensuing 10 years, basing priorities on the seriousness of the problem identified, the need for one project to precede or expand on another, and time frames mandated by Safe Drinking Water Act regulations.

Establishing Performance Measures

Recognizing the link between distribution system performance and the need for rehabilitation or replacement, AwwaRF next funded a project to define performance measures and delineate measurement techniques ("Distribution System Performance Evaluation," Project 804, funded 1992, published 1995, order number 90677).

Under the direction of Arun Deb of Weston Solutions, Inc., the project team collected information on existing distribution system performance standards from sources such as the Association of State Drinking Water Administrators; North American and foreign water utilities; gas, electric, and telephone utilities; and available literature. Participants in an expert workshop helped identify critical distribution system characteristics that affect customers.

The researchers recommended three criteria for measuring distribution system performance: (1) adequacy—the system's ability to deliver water of acceptable quantity and quality, (2) dependability—the system's ability to *consistently* deliver acceptable water quantity and quality, and (3) efficiency—how well resources such as water and energy are used.

According to the project report, adequacy can be measured by hydraulic parameters such as water pressure and flow; water quality data such as the number of water quality violations related to the distribution system; and records of customer feedback, including complaints. Dependability can be assessed by structural performance measures such as service interruptions, main breaks, and hydrant and valve malfunctions, plus the number of water quality violations of extended duration. Efficiency can be measured by unaccounted-for water losses and the amount of energy used for pumping.

The report pointed out that distribution system performance is complicated because structural, hydraulic, and water quality parameters are interrelated—structural conditions can affect both hydraulics and water quality, and hydraulic conditions such as dead ends can cause water quality problems. Therefore, the report cautioned, solutions to specific distribution system problems must be planned carefully to avoid creating problems elsewhere.

Importing Methods From Abroad

Two subsequent AwwaRF projects introduced North American water utilities to German and Australian techniques for quantifying distribution system replacement needs and optimizing replacement programs.

The first project adapted a computer model developed at the University of Karlsruhe into a software program to help North American utilities forecast pipe rehabilitation needs and rates ("Quantifying Future Rehabilitation and Replacement Needs of Water Mains," Project 265, funded 1995, published 1998; a report with software that runs only on

Microsoft Access 97 is available to AwwaRF subscribers). Known as KANEW, the software enabled a utility to quantify the total amount of pipe it should rehabilitate or replace each year. The software's limitation, however, was its inability to predict exactly which mains needed work.

The Australian import, called the Nessie Curve, projected the gap between actual utility spending and estimated capital outlays needed to maintain the integrity of water distributions systems. When these estimated needs were depicted on a graph, the curve rose so steeply in the early decades of the twenty-first century that it was nicknamed the Nessie Curve because it resembled the shape of the mythical Loch Ness monster. However, Nessie Curve predictions of a wave of distribution system replacement needs were based on the assumptions that a utility's renewal program would have to be completed in a short time and that all its mains would be subjected to the same conditions ("Financial and Economic Optimization of Water Main Replacement Programs," Project 462, funded 1997, published 2001, order number 90821).

"Like KANEW, the Nessie Curve created a lot of buzz," said Grigg, "but it's really just a graph of a utility's cumulative rehabilitation needs for the future." And current thinking indicates that for most utilities, the wave of distribution system needs will be less dramatic than the Nessie Curve foretold.

"U.S. water distribution systems were developed over many decades," Kirmeyer said. "Rapid growth occurred after World War II, when materials perhaps weren't as advanced as they are now. So a wave of infrastructure needs will rise up, stay high for a few years, and then gradually taper off. But I don't think this is a crisis. The problem will level off after a relatively short period—maybe 10 to 30 years."

Grigg agrees. "Some people think the need for distribution system rehabilitation is a ticking time bomb. I would say utilities have made progress in becoming aware of these needs and the situation will probably turn out to be manageable as we spread repairs out over time. Highways and water lines are similar in that they last a long time if you begin to respond when they first start to deteriorate."

Inspecting Buried Pipelines

As utilities became more aware of the importance of monitoring the condition of their distribution systems, AwwaRF funded a project to test the feasibility of inspecting buried water mains without excavation and coupon sampling ("Nondestructive, Noninvasive Assessment of Underground Pipelines," Project 355, funded 1996, published 2002, order number 90873). Other industries were using noninvasive techniques to inspect buried pipelines, and it was hoped these methods could be adapted for use with water distribution systems.

The project team, led by Michael Dingus of Texas Research Institute Austin, Inc., surveyed the 100 largest U.S. water utilities to gather data on utility experience with these methods. Field tests showed that nondestructive techniques for evaluating metallic pipes

were readily available and that promising methods for concrete pipe were being developed. Although nondestructive inspection methods for polymeric pipe were not well developed at the time, several techniques were being explored.

Follow-up research on nondestructive methods for inspecting concrete pipe included work on the remote field eddy current (RFEC) technique ("Electromagnetic Inspection of Prestressed Concrete Pressure Pipe," Project 2564, funded 1998, published 2001, order number 90854). The final report from another project on condition assessment included a comprehensive survey of inspection devices for large-diameter transmission mains, along with limited information on costs ("Workshop on Condition Assessment Inspection Devices for Water Transmission Mains," Project 2871, funded 2002, published 2004, order number 91028F). And a related project on continuous structural monitoring of pipelines identified additional potentially valuable techniques ("Techniques for Monitoring Structural Behavior of Pipeline Systems, Project 2612, funded 1999, published 2004, order number 90961).

Partially as a result of AwwaRF-funded research, RFEC is now a generally accepted and commercially available technique for inspecting prestressed concrete cylinder pipe, some additional methods for inspecting cast iron pipe are commercially available, and utilities are beginning to use some of the continuous structural monitoring techniques—especially fiber optic structural monitoring cables—identified in Project 2612. However, these methods can be costly because most of them, including RFEC, require interior access to the pipes (which usually necessitates retrofitting), and the pipes must be dewatered. Most of these AwwaRF reports noted the importance of considering inspection requirements when water pipelines are designed.

"AwwaRF has put a lot of emphasis on condition assessment technologies because replacement should be related to a pipe's true condition and future useful life," said Kirmeyer. "AwwaRF studies have also developed techniques to extend that useful life—for example, lining and rehabilitation techniques. These strategies may not be quite as good as installing new pipe, but they're much cheaper and may allow the pipe to last another 50 to 75 years."

Setting Rehabilitation and Replacement Priorities

Because utilities need to schedule pipe rehabilitation and replacement programs over manageable time frames, establishing priorities within overall distribution system renewal needs is a vital task. Ironically, one of the best sources of information for weighing these priorities is the very phenomenon renewal programs are intended to avoid—water main failures. To guide utilities in gathering data on water main leaks and breaks and using these databases to set pipeline renewal priorities, AwwaRF funded another study directed by Deb ("Prioritizing Water Main Replacement and Rehabilitation," Project 459, funded 1997, published 2002, order number 90898).

Historic data on main breaks allow utilities to analyze trends in the occurrence and causes of pipe failure, enabling them to predict future failures more accurately. Still, Deb and his

team reported that at the time of this study, only 70 percent of North American and 85 percent of European utilities maintained computerized records of main failures. Emphasizing the value of these databases, the project report advised utilities to collect and store data on the type of break; date and address; pipe material, diameter, and age; soil conditions; type and cost of repair, including crew time; and results of laboratory and field tests on pipe samples. Depending on the extent of the data, they can be used for simple trend analyses or sophisticated mechanistic models to help utility planners prioritize distribution system renewal investments.

The project team estimated that addressing distribution system renewal needs at U.S. water utilities would cost $77 billion to $325 billion over the ensuing 25 years. The wide range of this estimate indicates the difficulty of predicting infrastructure replacement needs for large numbers of utilities. However, the team also developed a mechanistic model of the corrosion process and the loss of pipe strength it causes. This model can be used to calculate a pipe's vulnerability to failure and can be calibrated for a given location using the utility's main break database. Once the model is calibrated, it can help a utility determine rehabilitation and replacement priorities for individual cast iron pipes.

The project report includes a CD-ROM developed with Microsoft software and successfully tested for use with subsequent versions.

Customer expectations can also play a role in setting priorities for pipeline renewal. Another AwwaRF project assessed customer perceptions, attitudes, and expectations about water main reliability; evaluated their tolerance for service disruptions and construction effects; and estimated their willingness to pay for expected levels of service ("Customer Acceptance of Water Main Structural Reliability," Project 2870, funded 2002, published 2005, order number 91081). The project produced a decision tool to help utilities quantify these factors and recommended strategies for communicating asset management plans to customers.

Planning Capital Expenditures

Recognizing the hefty capital expenditures associated with rehabilitating or replacing aging infrastructure assets, AwwaRF underwrote a project to integrate decision-making tools for prioritizing and financing distribution system renewal programs ("Capital Planning Strategy Manual," Project 2520, funded 1998, published 2001, order number 90838). One of the project goals was to help utilities align capital programs with stakeholder goals and objectives.

The research team, led by Bevin Beaudet and William D. Bellamy, enlisted the help of a group of capital planning practitioners representing a dozen utilities and outlined a seven-step process for capital planning. Planning steps ranged from defining the agency's mission to framing capital planning issues through project identification, selection, and implementation. Planning tools developed or adapted for the project included strategies to improve problem framing (scenario planning) and project prioritization (decision analysis

tools). Utilities can also use the tools to examine the cost–benefit relationship of competing capital projects in order to make the most of their capital resources.

The project culminated in a manual produced as a CD-ROM. The CD also allows utility staff and stakeholders to get an overview of capital planning issues through an executive summary video that highlights the main features of each planning step.

"Infrastructure costs depend on the age of the city and demographic trends," said Kirmeyer. "If your utility serves an old upper-Midwestern industrial city that is losing population, your infrastructure replacement needs may taper off a lot. If you're in an area that's continuing to grow, you'll need new capital programs at the same time you face the cost of renewing or replacing systems that were installed 60, 80, or 100 years ago."

Synthesizing the Data on Managing Distribution System Assets

Two relatively recent AwwaRF projects collected the results of various infrastructure research efforts in order to make the information more accessible to utilities. In the first study, Dan Ellison of Boyle Engineering Corporation summarized data from previous AwwaRF projects and other sources and produced a report titled "Distribution Infrastructure Management: Answers to Common Questions" (Project 2629, funded 1999, published 2001, order number 90846). The report describes the elements of a comprehensive infrastructure management program and points readers to key references aimed at solving numerous infrastructure problems.

The second study, conducted by Grigg, culminated in a report called "Assessment and Renewal of Water Distribution Systems" (Project 2772, funded 2001, published 2004, order number 91025F). In addition to synthesizing the knowledge base surrounding infrastructure renewal issues, Grigg conducted interviews and held workshops that included water utility professionals from across the United States, Canada, and Australia. He used an "issue tree" to illustrate the challenges associated with addressing infrastructure needs and to provide a structure for analyzing problems.

According to Grigg, the report presents information in three categories. "An overview section, Planning and Prioritization, captures management issues such as setting priorities, identifying funding sources, budgeting, and creating decision support systems. The second section, Condition Assessment, focuses on engineering issues—inspecting underground distribution systems and quantifying the risks so planners will know which pipes need to be renewed and when. The third section, Techniques for Repair, Rehabilitation, and Replacement, considers construction methods."

Contemplating Future Research Needs

Asked which aspects of infrastructure needs warrant further study, Grigg replied, "Condition assessment is the most critical area—assessing exactly what the problems are, how serious they are, and their relationship to community goals. We need more research to figure out the linkages between distribution system condition and public health,

distribution system condition and the risk of catastrophic failures, distribution system condition and energy consumption, and distribution system condition and service delivery."

Kirmeyer is currently working on a big-picture AwwaRF project to develop a roadmap of research needs related to asset management. He is focusing on research initiatives in six areas: "asset management framework models, risk management, condition assessment and performance monitoring, decision-making regarding capital improvement programs, information technology and data management, and operation and maintenance practices."

Grigg said AwwaRF funding is critical in the quest for more asset management data. "As a primarily public industry, water utilities don't fund research the way private industry does," he noted. "Utilities need an organized way to study their most serious problems, and AwwaRF is the main mechanism for that."

Kirmeyer concurs. "AwwaRF is the only organization that can leverage the interests of a host of subscribing utilities and look ahead at where things are going. If utilities are able to earmark a little of their revenue for the greater good, they can stay ahead of the next issues that are going to hit them. AwwaRF projects allow utilities to get past day-to-day operations and focus on the long term."

