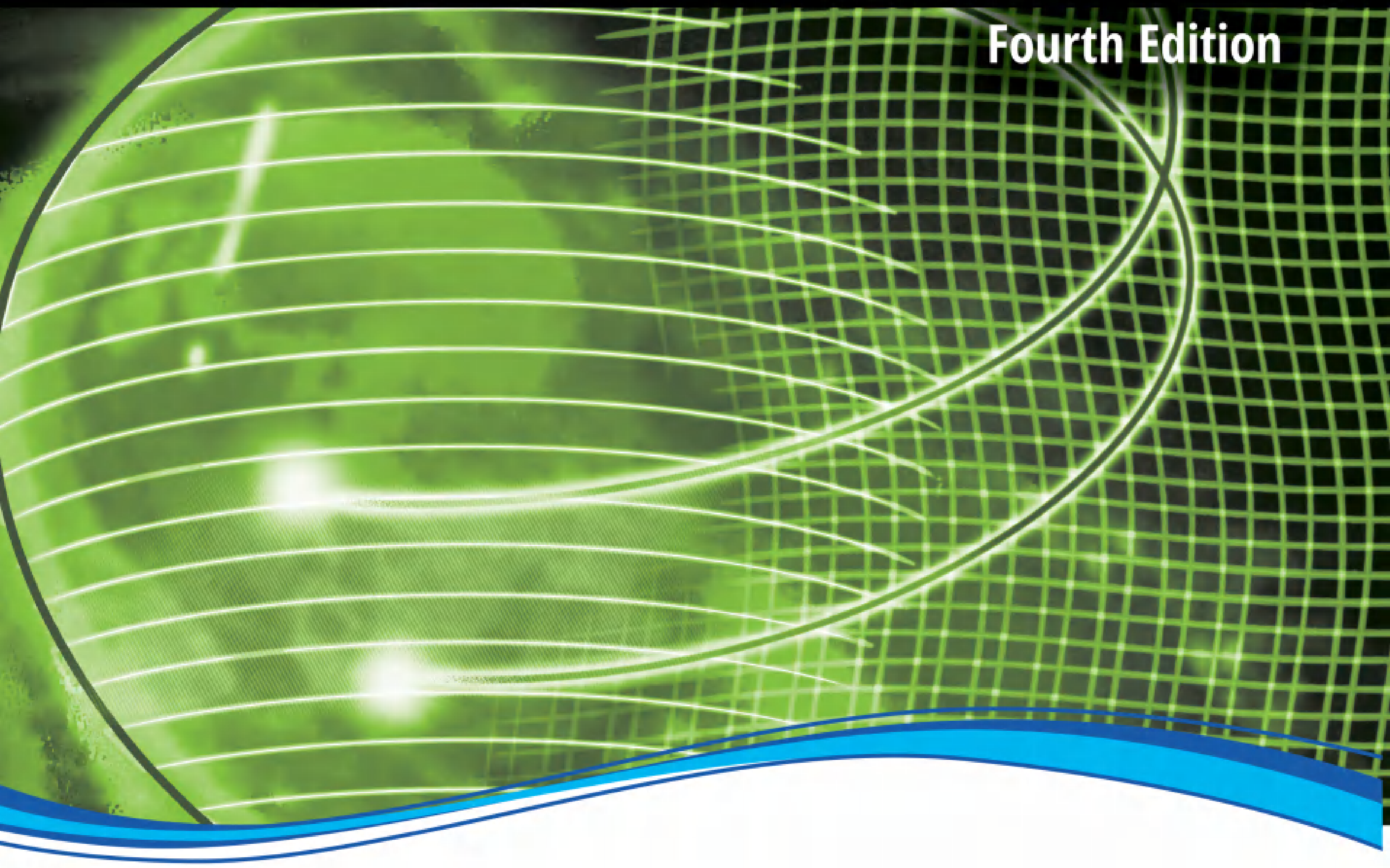
Manual of Water Supply Practices

M36

Water Audits and Loss Control Programs



Fourth Edition

American Water Works Association

M36

Water Audits and Loss Control Programs

Fourth Edition

American Water Works Association

Manual of Water Supply Practices—M36

Water Audits and Loss Control Programs

Managing Editor: Melissa Valentine
Production: Glacier Publishing Services

If you find errors in this manual, please email books@awwa.org. Possible errata will be posted at www.awwa.org/resources-tools/resource.development.groups/manuals-program.aspx.

Library of Congress Cataloging-in-Publication Data

Names: Kunkel, George A., Jr., author. | American Water Works Association.
Title: Water audits and loss control programs / by George A. Kunkel, Jr.
Other titles: M36, Water audits and loss control programs
Description: Fourth edition. | Denver : American Water Works Association, 2016. | Series: AWWA manual ; M36 | Based on: Water audits and loss control programs. 3rd ed. c2009.
Identifiers: LCCN 2015037692 | ISBN 9781625761002
Subjects: LCSH: Water consumption--Measurement. | Water--Waste--Measurement. | Water leakage--Prevention. | Loss control.
Classification: LCC TD499 .W38 2016 | DDC 628.1/440287--dc23
LC record available at http://lccn.loc.gov/2015037692

ISBN-13 978-1-62576-100-2
eISBN-13 978-1-61300-339-8

Printed in the United States of America
American Water Works Association
6666 West Quincy Avenue
Denver, CO 80235-3098
awwa.org

Printed on recycled paper

Contents

Figures

Tables

Preface

Accountable Water Management—Progressive Thinking and Solutions

North American water utilities have been highly successful in providing safe, reliable water supplies that have been a foundation for growth and prosperity. Benefiting from abundant natural resources, suppliers have succeeded in establishing high expectations for quality water service. In the closing years of the 20th century, however, changes not seen before on the continent were witnessed. Some of the fastest growing cities in the United States are located in sunbelt areas with limited water resources and a reliance on water supplies that have been developed and conveyed from distant water sources.

Multiyear periods of drought have begun to plague many areas of the United States. Water restrictions and shortages have become routine in many areas as a result of these circumstances, sometimes coupled with poor infrastructure reliability of individual water systems. For many water systems in the older parts of North America, aging infrastructure is exerting a toll as failures and high leakage rates increase and compromise system efficiency, frequently disrupting the reliable provision of services. Enhanced water quality and environmental protections along with funding constraints make development of new water resources more difficult, costlier, and less attractive than in prior eras.

In North America, a growing focus on *water conservation* has evolved to address these challenges. Conservation efforts have been successful in stemming customer water demand via the use of water efficiency measures such as low-flow plumbing fixtures, conservation water rates, and public education. It is essential that these successful efforts continue because all water users have a responsibility to use water wisely. In the broader context of water supply management, water suppliers also have a responsibility to manage valuable water resources wisely. This tenet—*the accountable and efficient management of water supplies by utilities*—is the central focus of the water audit methodology and water loss control programs described in this manual.

While successfully delivering quality water supplies for up to two centuries, the North American water industry has often done so with uncertain accountability controls and high losses of both treated drinking water, mostly from leakage, and revenue caused by inaccurate metering, errant billing, and unauthorized consumption. Because the seemingly endless water resources of yesteryear are no longer available in many regions, water suppliers must manage water resources with a greater sense of stewardship and efficiency than in the past.

The first edition of this manual was published in 1990 and detailed the water audit method advocated by the California Department of Water Resources and adopted by the California-Nevada Section of the American Water Works Association (AWWA). The second edition was published in 1999 and provided relatively minor updates to the first edition. The third edition (2009) included a major advancement in water audit methodology, giving water utilities greater guidance in improving accountability and economically controlling water and revenue losses. This fourth edition significantly enhances all the chapters and outlines new details on production meter testing, real (leakage) loss reduction, descriptions of several free software tools, and examples of regulatory approaches.

Historically, standard methods to audit water supplies and control losses were lacking throughout most of the world. In 2001, a survey of U.S. state and regional water oversight agencies revealed that inconsistent definitions for water loss existed with few reliable water auditing or loss control measures in place. Regulatory requirements were sparse on this issue in the United States. However, available data along with many case study and anecdotal accounts suggested that the occurrence of high-loss water supplies is widespread.

Improvement in this state of affairs emerged in the 1990s. The United Kingdom's National Leakage Initiative brought forth valuable research findings that were applied in new policies and practices leading to significant leakage reductions. From 1997 to 2000, AWWA participated on the Water Loss Task Force organized by the International Water Association (IWA). The Water Loss Task Force (now the Water Loss Specialist Group) drew on the best practices included in the various water audit methods in use worldwide, including the United States, to assemble a *best management practice* methodology that features a set of rational terms and definitions, and an array of robust performance indicators that allows an objective gauging of loss levels. In 2003, AWWA's Water Loss Control Committee published the report "Applying Worldwide Best Management Practices in Water Loss Control" in *Journal AWWA*. In this report, AWWA advocates the use of the IWA/AWWA method and performance indicators.

This manual explains the IWA/AWWA water audit methodology in a user-friendly manner and provides an overview of some of the best loss control techniques that can currently be implemented for a sustainable water loss control program. Chapter 1 provides a brief introduction while chapter 2 discusses the regulatory approaches within North America. Chapter 3 gives detailed instruction on the water audit process and highlights use of the AWWA Free Water Audit Software. Chapters 4 and 5 describe the impacts and the methods to control apparent losses, respectively. This includes ways to recoup missing revenues by controlling these nonphysical losses. Chapters 6 and 7 discuss the impacts of real (physical) losses, which are largely leakage, and the methods to control these losses, including proactive leakage detection and pressure management. Chapter 8 gives guidance on the organizational steps a water utility can take to manage and sustain the water loss control program, while Chapter 9 offers valuable insights for small systems in managing their losses.

A glossary of terms and definitions is also provided. Appendices include a new section on production meter testing and data management, blank forms, water resources considerations, a detailed description of the AWWA Free Water Audit Software, and analysis of water audit data from several hundred North American water utilities. For water utilities just getting started, the AWWA Free Water Audit Software can be downloaded directly from the AWWA Web site and used to obtain a preliminary quantity of losses and their costs. This can be followed up by field measurements and investigations to gradually enhance and validate the water audit, and these steps are clearly described throughout this manual. Examples are included within the manual for the fictitious County Water Company, illustrating the means to compile the water audit and initiate control of both apparent and real losses.

Water utilities now have effective tools and methods to promote accountability and efficiency in their supply operations. Water utility managers will be called on to assess their inefficiencies and take corrective action, and the methods contained in this manual will help them do it reliably.

Acknowledgments

The AWWA Technical & Educational Council, the Distribution & Plant Operations Division, and the Water Loss Control Committee gratefully acknowledge the contributions made by those volunteers who drafted, edited, and provided the significant and critical commentary essential to updating M36. The Technical Review Board members dedicated many hours in the final stages of preparation for this fourth edition to ensure the overall technical quality, consistency, and accuracy of the manual.

Technical Review Board Members

George A. Kunkel Jr., Chair, Philadelphia Water Department, Philadelphia, Pa.
Lindsey Geiger, AWWA, Denver, Colo.
Will J. Jernigan, Cavanaugh, Asheville, N.C.
Thomas M. Kennedy, Rainbow Municipal Water District, Fallbrook, Calif.
Chris Leauber, Water & Wastewater Authority of Wilson County, Lebanon, Tenn.
Gary B. Trachtman, ARCADIS Inc., Birmingham, Ala.

Contributors to the 4th Edition

George A. Kunkel Jr., Chair, Philadelphia Water Department, Philadelphia, Pa.
Elio F. Arniella, Smart Water Analytics, Atlanta, Ga.
Reid Campbell, Halifax Water, Halifax, N.S., Canada
Andrew Chastain-Howley, Black & Veatch, Arlington, Texas
James E. Fisher, Echologics Engineering Inc., Erlanger, Ky.
Craig Hannah, Johnson Controls Inc., Lubbock, Texas
Ramsey T. Hemaidan, Pure Technologies, Littleton, Colo.
David M. Hughes, American Water, Voorhees, N.J.
Will J. Jernigan, Cavanaugh, Asheville, N.C.
Thomas M. Kennedy, Rainbow Municipal Water District, Fallbrook, Calif.
Allan Lambert, ILMSS Ltd., Llandudno, Wales, United Kingdom
Kevin Laven, Echologics Engineering Inc., Mississauga, Ont., Canada
Paul Meschino, Utility Service Co., Inc., Atlanta, Ga.
Edward R. Osann, Natural Resources Defense Council, Washington, D.C.
Stephen K. Rupar, Tata & Howard, Inc., Meriden, Conn.
Michael D. Simpson, M.E. Simpson Company, Inc., Valparaiso, Ind.
Brian M. Skeens, CH2M HILL, Atlanta, Ga.
Daniel Strub, Austin Water Utility, Austin, Texas
Reinhard Sturm, Water Systems Optimization, Inc. San Francisco, Calif.
Julian Thornton, Thornton International Brazil, Mairipora, São Paulo, Brazil
Russell G. Titus, New Jersey American Water, Hillsborough, N.J.
Gary B. Trachtman, ARCADIS Inc., Birmingham, Ala.
John H. Van Arsdel, M.E. Simpson Company, Inc., Valparaiso, N.J.

This page intentionally blank.

Chapter 1

Introduction: Auditing Water Supply Operations and Controlling Losses

Community water supply systems around the world have been instrumental in improving the human condition by providing essential water to promote public health and safety and to serve as a basis for economic development. For hundreds of years, societies have constructed infrastructure to withdraw water from available sources, to treat it to an acceptable standard, and to distribute it to communities, typically through buried piping distribution systems. Yet, for all their success in quenching human needs, many water utilities operate with considerable inefficiencies in terms of water and revenue losses. As the world grapples with the dilemma of a growing population but a finite amount of water, these inefficiencies need to be brought under a reasonable level of control. This manual offers water utilities a set of tools and approaches to instill accountability and control losses, including

- step-by-step procedures to conduct a water audit to assess the efficiency of the water distribution system and water accounting practices;
- definitions and implications of apparent (nonphysical) losses and real (physical) losses;
- specific techniques to identify, measure, and verify all water sources, consumption, and losses;
- example data inputs and sample calculations for each step of the water audit;
- references to freely available software tools to compile the water audit and plan leakage management activities;
- a road map to control apparent losses in metering and billing operations and to recover missed revenues;

- steps to implement a leakage and pressure management program to control real losses and preserve source water resources;
- planning steps to assemble the proper resources, information, and equipment to launch and sustain the accountability and loss control program;
- approaches for short-term and long-term goal setting for the loss control program;
- considerations for small water systems; and
- discussions and listings of actual water audit data and descriptions of successful water loss control being applied by North American water utilities.

Many water utilities suffer a variety of losses. Most operators recognize distribution system leakage, categorized under the heading *Real Losses*, as a primary type of loss. However, water suppliers also suffer losses from poor accounting, customer metering inaccuracies, and unauthorized consumption. These losses are collectively labeled *Apparent Losses* and have a negative impact on utility revenue and consumption data accuracy. While it is essential that system operators employ means to control such losses, the initial step is to assemble a water audit to identify the nature and volumes of losses existing in a water utility, and the water resources and financial impacts that these losses exert.

THE WATER AUDIT AND WATER BALANCE

Good management of any resource requires that the supplier maintain accurate records of transactions and deliveries of the commodity provided to its customers. The *audit* is a common function in the world of finance and accounting, and it typically denotes activities that systematically review an organization's financial records and accounts to confirm their accuracy. Similarly, the *water audit* involves a review of records and data that traces the flow of water from its source and treatment, through the water distribution system, and into customer properties. The water audit usually exists in the form of a worksheet or spreadsheet that details the variety of supply, consumption, and loss components that exist in a community water system. The *water balance* summarizes these components and provides accountability, as all of the water placed into a distribution system should, in theory, equal all of the water taken out of the distribution system.

In 2000, the International Water Association (IWA) published the manual *Performance Indicators for Water Supply Services* (Alegre et al. 2000). This publication includes a description of a water audit method developed during the period of 1997–2000 by the IWA Water Loss Task Force (now called the Water Loss Specialist Group), which at the time was a five-country group that included participation by the American Water Works Association (AWWA).* Until then, a multitude of different water auditing practices had existed around the world, and the primary focus of the task force was to draw on the best practices of the various approaches and craft them into a single, standard best management practice methodology. The method needed to be applicable worldwide, across the spectrum of differing system characteristics and units of measure. Many of the features of the resulting best practice methodology were drawn from the original AWWA Manual M36, *Water Audits and Leak Detection*, published in 1990 and revised in 1999. Shortly after the task force published its new methodology, the AWWA Water Loss Control Committee (WLCC) voiced support for the method in its committee report "Applying Worldwide Best Management Practices in Water Loss Control" published in the August 2003 edition of *Journal AWWA* (Kunkel et al. 2003). In support of this approach, the WLCC comprehensively revised and expanded Manual M36 in creating the third edition (2009). This edition carefully detailed

* The IWA Water Loss Task Force has grown considerably and was elevated to become the IWA Water Loss Specialist Group in 2011.

the best practice water audit method and provided significant guidance on innovative loss control technologies and approaches for planning the loss control program.

This fourth edition of Manual M36 continues to promote the standard, best practice water audit method created by IWA and AWWA, and the method is explained in detail in chapter 3. The WLCC recommends this method as the current best management practice structure for water utilities to compile a water audit of their operations. In addition to reliably tracking water consumption and losses using this method, water utilities also have a variety of effective means to economically control apparent and real losses. Great innovation in loss control approaches and technologies has occurred since the early 1990s. Many of these techniques are explained in chapters 5 and 7. The final chapters of this manual provide guidance on planning and sustaining the loss control program and considerations for small systems.

This fourth edition improves on the third edition manual in several ways. First, the AWWA Free Water Audit Software (2014), which was briefly mentioned in the third edition, is now fully integrated into the guidance and examples of this edition and is the tool of choice recommended by the WLCC for water utilities to conduct the annual water audit. The WLCC created and issued the Audit Software in 2006 and has since issued several upgraded versions. Version 5.0 was issued in 2014.

Second, an entirely new section (appendix A) has been included to detail the methods to ensure valid, accurate water production data and to identify best practices to accurately quantify the *Volume of Water Supplied* to the water distribution system. Production water volumes, which are the supply volumes at the water source or supply leaving water treatment plants, represent the largest and most important quantities in the water audit, and the fourth edition provides highly detailed guidance in ensuring reliability in these quantities. A third major addition to the manual is a comprehensive description on the use of a free software tool known as the Leakage Component Analysis Model (LCA Model). This model became available to the water industry in 2014 as part of a research project administered by the Water Research Foundation and sponsored by the US Environmental Protection Agency (WRF 2014). The LCA Model offers a clear and concise method to analyze data on leak and water main break events occurring in a water utility, and uses the data to define the parameters of an economic leakage and pressure management program tailored for the needs of the individual water utility. The LCA Model offers a user-friendly instrument to automatically execute the calculations that were merely listed in the third edition.

Finally, the fourth edition includes numerous examples and data of validated water audits from hundreds of North American water utilities. The use of the AWWA water audit has increased dramatically since the release of the third edition of Manual M36 in 2009; and the fourth edition provides a representative glimpse into the validated data that is fast being compiled by the North American water industry. The fourth edition offers updated and improved content that supersedes the third edition, and readers will find this new edition to be invaluable in their efforts to establish sound accountability and efficiency in their water supply operations.

THE IMPORTANCE OF WATER AUDITS AND LOSS CONTROL

Strong water loss control produces benefits in four primary ways:

1. Through water resources management, by limiting unnecessary or wasteful source water withdrawals
2. Financially, by optimizing revenue recovery and promoting equity among ratepayers

3. Operationally, by minimizing distribution system disruptions, optimizing supply efficiency, and generating reliable performance data
4. Through system integrity, by reducing the potential for contamination in the water distribution system

Water suppliers have obligations in all of these areas: they must act as stewards of the valuable water resources they manage; they must be fiscally responsible to their customers, shareholders, and bondholders; and they must maintain safe, reliable operations that provide quality water service to their communities. Properly executed water auditing and loss control programs help water utilities meet their obligations in all of these areas, to the benefit of their customers and their own bottom line. The specific benefits of water auditing and loss control include the following:

- *Reduced apparent losses*. Reducing apparent losses creates a financial improvement by recovering lost revenues from customers who have been undercharged or have gained water in an unauthorized manner.
- *Reduced real losses*. Reducing real losses saves water purchase and operating costs including power, maintenance, and treatment costs. Because leakage volumes are a considerable portion of system input for many water utilities, expansion of water supply infrastructure might be deferred if successful leakage control is achieved. Likewise, better use of existing resources may ease drought restrictions or allow economic development to occur without exploiting new water resources. Reducing leakage volumes results in a corresponding reduction in the operation of equipment, thereby extending the interval between scheduled maintenance.
- *Improved data integrity*. Sound water auditing improves the accuracy and integrity of water system input volumes and customer consumption. Knowing true water consumption patterns promotes better water resources management, confirms water conservation benefits, and aids long-term planning.
- *Better use of available water resources*. Controlling losses helps stretch existing supplies to meet increasing needs, thus avoiding the exploitation of new water sources. Environmental impacts are limited given that no more water is withdrawn from sources than is absolutely needed.
- *Increased knowledge of the distribution system*. During the water auditing process, distribution personnel become familiar with the distribution system, including the location of mains and valves, pressure levels, and demand variations. This familiarity helps the utility to respond quickly to emergencies, such as water main breaks, and provides a basis for optimization of supply operations.
- *Increased knowledge of the customer metering and billing systems*. The water auditing process provides the auditor the opportunity to review the workings of the customer billing system. For many water utilities, inadvertent procedural or programming gaps exist in billing operations, allowing certain customers to receive water without paying for it.
- *Safeguarding of public health and property*. Improved maintenance of the water distribution system helps reduce the likelihood of property damage and safeguards public health.
- *Improved public relations*. Consumers appreciate maintenance of the water distribution system. Field teams performing loss control activities provide visual assurance that the distribution system is being maintained. Consumers also appreciate value for their money. They expect high-quality service at a reasonable price.

Efficient delivery of high-quality water, along with affordable, equitable water rates, creates a strong reputation for the water utility in the minds of its customers.

- *Reduced liability*. By protecting public property and health and providing detailed information about the distribution system, water audits and loss control programs help protect the utility from expensive lawsuits.
- *Reduced disruption to customers*. More leaks are repaired on a proactive basis rather than developing into large leaks or main breaks that disrupt service and cause damage and customer ill will.
- *Improved asset management*. By effectively managing leakage and optimizing pressure in the water distribution system, water main and service connection leakage can be reduced and pipeline asset life can be extended.
- *Favorable reviews from the financial community*. Effective operations and accountability instill credibility for the water utility in the eyes of the financial community, helping the utility to secure funding to sustain sound upkeep of the operation well into the future.

In summary, water and revenue losses are wasteful to the water utility, its customers, the environment, and society at large, while good accountability and loss control offer many benefits. It is likely that many, if not most, North American water utilities can strongly benefit from improvements in their level of accountability and loss control practices. In this way, this manual serves as a valuable guide for water utilities.

GETTING STARTED

Just as a proactive water utility carefully tracks its finances, effective utilities should also track the water supply that they manage. Historically, the motivation for a water utility to compile the annual water audit was strictly voluntary. However, since 2000, several American states have enacted requirements for annual water audits, and the number of water utilities routinely compiling water audits is growing. For most water utilities, getting started is the largest hurdle. Perhaps in prior generations, utility personnel did not know where to turn for guidance on how to get started in the water audit process. However, today's water utilities have available to them the detailed guidance provided in this manual: the AWWA Free Water Audit Software (2014), the LCA Model, and information on AWWA's Web site (www.awwa.org). Hence, utility personnel can readily obtain and employ the tools and guidance to quickly identify and quantify their losses and the impacts. In as little as several hours, readily available data can be accessed and input into the standard water audit format, revealing preliminary loss control standing and cost impacts. *The most important step is to just get started, and the guidance and tools provided in this manual give utilities everything they need to do this!*

THE FUTURE OF WATER SUPPLY EFFICIENCY

In 2001, AWWA commissioned an extensive survey of state and regional water resource and environmental agencies in the United States to uncover the extent and usefulness of their water accountability statutes and regulations. The project, titled *Survey of State Agency Water Loss Reporting Practices* or the "States Survey Project," was successful in garnering valuable information from 46 jurisdictions, including 43 state agencies and 3 regional agencies (Beecher 2002). The results of the survey found that widely varying language existed throughout many regulations and statutes of these agencies. Many organizations defined water losses as some form of *unaccounted-for* water but left the components

Table 1-1 Guidance for the use of proper terminology in the standardized water audit methodology

Non-Preferred Term	Preferred Term	Reason
Unaccounted-for water (UFW)	Non-revenue water (NRW)	All water entering a distribution system can be defined as a component of either authorized consumption or water loss.
Percentage of system input volume to measure water loss performance	Suite of key indicators for water loss as outlined in AWWA audit method in chapter 3 (e.g., gal/service connection/d)	A percentage-based expression obscures the underlying causes of water loss and impedes realistic solutions based on system specifics.

included in this parameter subject to interpretation *and manipulation*. As an example of the latter, some utilities included volumes from known leaks in “accounted-for” water categories, thus underestimating actual leakage volumes, which are a loss. In attempting to gather voluntary data from large water utilities, one state agency found that water utilities that earnestly attempted to audit their supplies reported figures that appeared less flattering than counterparts who reported unrealistically low losses, with no substantiation of their data (McNamee 2002). This type of gamesmanship reflects poorly on the US water industry, which has proven itself up to any challenge, including that of reliable water auditing and loss control. The final report of the States Survey Project was astute in its recommendation that “a better system of accounting is necessary if accountability is to be instilled in water utilities” (Beecher 2002).

The WLCC supports the methods offered in this manual as the “better system of accounting” called for in the States Survey Project report. Since 2003, AWWA has recommended against the use of the imprecise term *unaccounted-for water* because it does not exist in the best practice water audit method, and its use creates more confusion than guidance to water utilities. Instead, the precisely defined term *non-revenue water* should be employed, as given in this guidance. The use of non-preferred and preferred terminology is given in Table 1-1.

The WLCC holds that the methods in this manual are workable, meaningful, and offer the greatest potential to bring about improved accountability and water efficiency in water utilities. The methods can enhance service for water customers, improve the bottom line for water utilities, and better manage water resources for the common good. It is recommended that these methods become the model approach for quantitative management of water resources in North America for water utilities, professional organizations, regulatory agencies, and all stakeholders who support safe and reliable water.

Across North America, several state, provincial, and regional agencies have enacted water auditing requirements applying the methodology first advocated by the AWWA WLCC in 2003. Although the movement toward routine, standardized water auditing is still in the early stages, validated data for hundreds of water utilities have been compiled, allowing water managers, regulators, and policy analysts to gain the first truly representative assessment of the quantitative management of water supplies in North America. This will allow for strategic targeting of loss control efforts by individual water utilities and coherent policy and statutory decisions by water resource managers and regulators. The number of states and provinces enacting new water auditing requirements will undoubtedly grow in coming years, and water utilities must be prepared to assess their water supply management in a more comprehensive manner.

Water accountability and loss control is garnering increasing prominence in water resources management, particularly as limitations in available water resources are occurring in many parts of the world. New water sources will continue to become more difficult and costly to develop, water quality regulations and customer expectations will increase the value of water, and growing populations and economies will need adequate water supplies on a continuous basis. All of these drivers will combine to create an increased focus on water accountability, efficiency, and conservation. By employing the methods included in this manual, water utilities will have the tools to meet these growing challenges.

REFERENCES

Alegre, H., W. Hirner, J. Baptista, and R. Parena. 2000. *Performance Indicators for Water Supply Services*. Manual of Best Practice series. London: IWA Publishing.

AWWA (American Water Works Association). 2014. AWWA Free Water Audit Software, Version 5.0. http://www.awwa.org/home/awwa-news-details/articleid/2641/awwa-free-water-audit-software-version-5-0-now-available.aspx

Beecher, J. 2002. *Survey of State Agency Water Loss Reporting Practices*. Final Report to the Technical and Educational Council of the American Water Works Association. Indianapolis, Ind.: Beecher Policy Research.

Kunkel, G., et al. 2003. Water Loss Control Committee report: Applying worldwide BMPs in water loss control. *Journal AWWA*, 95(8):65–79.

McNamee, A. 2002. Water audits of public water systems: Maryland's experience. In *Proceedings, Technical Session on Promoting Progressive Approaches for Water Loss Control, American Water Works Association, Distribution & Plant Operations Conference*, Nashville, Tenn. Denver, Colo.: AWWA.

WRF (Water Research Foundation). 2014. *Real Loss Component Analysis: A Tool for Economic Water Loss Control*. Denver, Colo.: WRF.

This page intentionally blank.

Chapter 2

Implementation of Water Loss Control Regulatory Approaches in North America

Considerable advancement has occurred in water auditing and loss control methodology and policy since the early 1990s. Water auditing methodology and innovative technologies for water and revenue loss control are explained in great detail in this manual, starting in chapter 3. Since the advent of the best practice methods described herein, many water utilities throughout North America have launched or refined efforts to audit their water supplies and manage losses in a more proactive manner. At the same time, drinking water and water resource agencies have also taken note of the benefits of these approaches.

This chapter discusses the evolution of policy and regulatory developments in water loss control, most of which have occurred since the year 2000. Readers will find the descriptions included in this chapter useful in discerning how the efforts of individual water utilities can collectively promote the long-term stability of a region's water resources when programmatic requirements are put in place via a sound, consensus-based process.

AWWA's Water Loss Control Committee (WLCC) has been very active in both developing tools and methods for effective water loss control and in conducting outreach to educate and promote the use of these methods. The prominent initiatives of the WLCC are described in this chapter. Early in the development of these approaches, AWWA conducted the project that led to the publication of the States Survey Project report on regulatory policies and guidance for water loss control in 2002. The report detailed the findings of an extensive survey of United States state and regional water agencies and found that requirements for water auditing and loss control varied widely and were of mixed degrees of effectiveness. The survey report concluded that "a better system of accounting is needed if accountability is to be established in water utilities" (Beecher 2002).

The WLCC followed the States Survey Project with its 2003 committee report *Applying Worldwide Best Management Practices in Water Loss Control*" (Kunkel et al. 2003), which included recommendations for water utilities to adopt new best management practices for water loss control. Since the publication of these reports, there has been increased recognition of the need for and value of implementing improved practices for effective water loss control. Drinking water utilities gain the benefits of reduced operating costs and increased revenues that can be applied to better sustain water system assets. Valuable water resources are better preserved, while allowing economic growth to continue. Water utility customers benefit from quality water supplies that are reliably provided at affordable rates. Drinking water regulatory agencies are better able to oversee responsible water resources management and incentivize programs where utilities can leverage funding of projects that ensure their sustainability. Bond rating agencies can more favorably rate utility debt issuance, thus lowering the cost of borrowing for capital programs and offsetting upward pressure on water rates. Furthermore, as a result of increased public discourse on the benefits of water use efficiency and sustainability, drinking water regulatory agencies are finding that a consensus-based stakeholder involvement process for policy development is effective and more likely to be readily accepted across the spectrum of stakeholders.

Table 2-1 is a listing of North American regulatory or water resources agencies that (as of 2014) have adopted (or are close to adopting) water auditing and loss control requirements that feature the AWWA Water Audit Methodology as the foundation for accountability. This table lists 10 state agencies, one regional river basin commission, and one Canadian province that have requirements for the routine submittal of water audit data by water utilities in the form of the AWWA Water Audit Methodology. These requirements exist with varying degrees of compliance enforcement measures. Several regulatory agencies have implemented programs on a multiyear, phased approach with the largest water utilities required to comply first. Varying performance thresholds are employed as "triggers" for followup activities in some agencies. These activities can include assistance with leak detection surveys of the water distribution system or robust meter accuracy testing and replacement programs. In some cases, notices of violation can be issued, fines can be imposed, extensions of existing—or granting of new—water supply permits can be withheld, or permitted allocations can be reduced if the performance thresholds are not met. However, in general, the regulatory approaches have keyed largely on data collection and identifying water utilities that appear to have the greatest need for improved water loss management.

This chapter presents what are believed to be the essential elements of water auditing and loss control programs that should be carefully considered by regulatory or water resource agencies when undertaking rulemaking processes or setting regulatory guidance. This discussion also provides examples of recently developed federal, state/provincial, and regional regulatory programs that encourage drinking water utilities to implement best practices for water loss control.

ESSENTIAL ELEMENTS OF THE RULEMAKING PROCESS AND REGULATORY GUIDANCE

Most water utilities can benefit by adopting the practices and tools contained in this manual. It is also recognized that flexibility to employ other approaches can advance the body of knowledge in the drinking water industry. *The AWWA WLCC recommends that water utilities should routinely compile water audit data on an annual basis as a standard business practice. This serves as the fundamental activity to promote efficient management of water in the drinking water sector.* Thus, collection of standardized, validated water audit data should be the starting basis for water utilities voluntarily launching a water loss control program, and

Table 2-1 Water loss requirements of regulatory agencies in North America (2014)

These are state/provincial and regional regulatory agencies with a water loss control program and requirements based on the AWWA Water Audit Methodology*

State/ Province	Agency	Water Audit Data Submission Requirement	Water Audit Methodology in Use	Water Audit Data Collection Format	Performance Target Requirement
California	California Urban Water Conservation Council (CUWCC)	Incentivized (SB 1240 makes this mandatory in 2016)	AWWA	AWWA Free Water Audit Software	Leakage control; by year 5 of program, show improvement or obtain top 20% level, or below benchmark leakage level.
	Department of Water Resources	Mandatory	AWWA	AWWA Free Water Audit Software	Urban water systems required to quantify and report water loss and description of water loss management program measures. No performance targets for urban water systems that are not a signatory utility to CUWCC Memorandum of Understanding.
Delaware, New York, Pennsylvania, New Jersey	Delaware River Basin Commission	Mandatory	AWWA	AWWA Free Water Audit Software	15% Non-revenue water (NRW) used as a benchmark of performance; additional reporting may be required by systems in excess of this value.
Georgia	Department of Natural Resources–Environmental Protection Division, Georgia Environmental Finance Authority	Mandatory	AWWA	AWWA Free Water Audit Software	No performance target, but Georgia offers training and employs a mandatory water audit data validation process funded via State Revolving Funds.
Illinois	Illinois Department of Natural Resources	Mandatory	AWWA		Previously 8% "unaccounted-for water"; however, the State adopted a comprehensive program change to the AWWA Water Audit Methodology with an NRW standard of 12%, declining to 10% in Water Year 2019.
New Mexico	Office of the State Engineer	Incentivized	AWWA	AWWA Free Water Audit Software	Detailed water audits and case studies were assembled for several water utilities.

Table continues next page

Table 2-1 Water loss requirements of regulatory agencies in North America (2014) (continued)

State/ Province	Agency	Water Audit Data Submission Requirement	Water Audit Methodology In Use	Water Audit Data Collection Format	Performance Target Requirement
Pennsylvania	Public Utility Commission	Mandatory	AWWA	AWWA Free Water Audit Software	None.
Tennessee	Office of the Comptroller	Mandatory	AWWA	AWWA Free Water Audit Software	Threshold levels set for graduated Data Validity Score (65–80), and NRW by cost 30%, to 20% by 2020. Water utilities exceeding these thresholds are offered assistance.
Texas	Texas Water Development Board (TWDB)	Mandatory	AWWA	TWDB format	An Infrastructure Leakage Index of 3 for large systems. Real losses of 50 gal/connection/d or 1,600 gal/mi/d for small systems (density dependent), 5.5% apparent loss for all systems.
Washington	Department of Health (DOH)	Mandatory	AWWA modified	DOH format	10% Leakage, three-year average
Wisconsin	Public Service Commission & Department of Natural Resources	Mandatory	AWWA modified	Wisconsin format	25% Water loss for small utilities, 15% water loss for large utilities. Currently investigating use of the AWWA Free Water Audit Software with training and validation.
Quebec	Ministry of Municipal Affairs, Regions & Territorial Occupation	Incentivized	AWWA modified	Quebec format	20% Water loss, <15 m^3/km/d of water mains (6,400 gal/mi/d)

*This is not necessarily a complete listing. Other state and regional agencies may have developed, or intend to develop, water loss control requirements substantially based on the AWWA Water Audit Methodology.

for regulatory agencies to assess water loss management performance. Regulatory agencies may also consider requirements for loss control activities; however, these activities cannot be reliably planned, or tracked, if a sound water auditing structure with valid water audit data is not first in use.

A majority of the agencies listed in Table 2-1 have adopted the AWWA Water Audit Methodology virtually in its entirety as a basis for regulatory requirements. In some cases, the water loss control requirements are imposed as part of a broader water use efficiency context that includes more conventional water conservation programs that are intended to aid in managing water resources in areas experiencing water shortages. In other cases, requirements are intended to specifically address operational concerns or issues of financial viability. Either approach can be effective when the affected water utilities are afforded the opportunity to provide input to the rulemaking process.

The following elements are considered to be important for engaging drinking water utilities in the process of setting objectives of a water loss control regulatory program.

- Stakeholder participation process:
  - The agency proposing rules for water auditing and loss control practices should engage as wide a group of potential stakeholders as possible to participate in the rulemaking process.
  - Stakeholders should be given sufficient time to review proposed language and provide comments and feedback to the agency proposing the rules.
- Statement of desired objectives, policies, and approaches for achieving the objectives:
  - The process should clearly state the applicable water loss policies and definitions, desired objectives, and rationale for use of the practices and tools detailed in this manual, along with the means by which results will be measured. This should include a clear description of the water audit methodology and format to be employed.
  - The outdated and imprecise term *unaccounted-for water* should be replaced with the specifically defined term *non-revenue water*. This is an important modification that promotes meaningful expression of water accountability and water loss management performance.
  - The water utilities to be included under the regulatory program should be clearly identified.
  - This manual describes numerous approaches to the effective control of apparent and real losses. Not all of these approaches are applicable and useful to all water systems, since varying conditions exist among the large number of water utilities in operation today. Thus, rulemaking should take into account specific regional or local conditions that exist for water utilities and determine whether specific approaches detailed in this manual are, or are not, applicable.
  - Strongly consider the establishment of a structured training program to instruct water utility personnel on the water audit process. Effective training will produce more reliable water audit data and ultimately save utility personnel time in the data collection and review process.
- Appropriate application of the best practice water audit performance indicators and Data Validity Score (DVS) of the AWWA Free Water Audit Software:
  - The AWWA Free Water Audit Software is the standard tool recommended for water utilities to compile the annual water audit. It is described in detail in chapter 3 of this manual. The Audit Software includes the array of standardized output-based performance indicators that serve as performance-based metrics to guide water utilities in tracking their performance and making valid comparisons with peer water utilities.
  - In 2010, the AWWA Free Water Audit Software was updated with a system of process-based metrics to give water utilities a sense of the validity of their water audit data as related to the day-to-day practices that they employ. Utility auditors assign a numeric grading value to each input quantity in the water audit, with low values for more questionable data and higher values for well-validated data. The Audit Software then calculates a composite DVS that reflects the overall validity, or trustworthiness, of the water audit data. The DVS is also an indirect measure of the process integrity of the water utility's

practices. Several agencies have keyed on the DVS in particular to promote a focus on the use of recommended best practices in water utility operations.

- Independent review and validation of the water audit data ("auditing the audit") is strongly encouraged to confirm that objective data gradings are assigned and the DVS is representative of water utility performance. Programs that include both training for utility personnel on the water audit process and independent validation of the water audit data have shown the greatest success in producing representative data.
- The water audit performance indicators should be applied only in the manner for which they are intended. Certain indicators are intended to track the year-to-year performance of the water utility and not to make comparisons with other water utilities. Performance indicators for the normalized measure of real (leakage) losses are different for water systems having a low density of service connections and those with a more typical density of connections. The Infrastructure Leakage Index (ILI) is performance indicator designed for comparisons among water utilities and for benchmarking performance. However, the ILI is best suited for utilities with well-validated water audit data and all justifiable pressure management already implemented. The ILI has not been proven valid for very small water utilities; hence, it cannot be applied in all cases.
- There are other options for utilities to use when analyzing these performance indicators to assist in understanding the underlying factors contributing to the water audit results. Water audit data can be segregated into groups of similar system attributes or regional characteristics, such as population, number of customer service connections, average operating pressure, annual precipitation, and temperature range. This type of analysis can allow more precise comparisons, but it is not as relevant for regulatory purposes. AWWA's Water Audit Data Initiative (WADI) collects and validates water audit data annually, and, in 2011, this effort included detailed analysis of data from 21 water utilities. This analysis segregated utilities by system size, with those serving a population of less than 50,000 as one group and systems serving more than 50,000 as a separate group (AWWA 2011). This type of analysis provided greater context for interpretation of the performance indicators of the water utilities in the WADI dataset.

- Appropriate caution in target-setting for loss control interventions:
  - The water audit process is the fundamental water efficiency activity that water utilities should conduct on an annual basis to track their use of water resources. At this time, it is likely best for regulatory or water resources agencies to focus primarily within the practice of water auditing for water utilities and thus promote the collection of reliable, comparable utility data.
  - Several agencies have also set rules for loss reduction, keying on real (leakage) losses, financial management, or other aspects of non-revenue water (NRW). Setting water or revenue loss reduction targets, however, is a complicated undertaking that should be derived only from well-validated water audit data from a large pool of water utilities. To date, however, only a limited pool of well-validated data exists. Regulatory agencies should be well aware of several fundamental concepts of water utility operations before proceeding to establish goals and targets for water loss control. The components, volume, and financial impacts of NRW occurring in a water utility are system-specific characteristics. Setting goals and targets to reduce apparent

and real losses in a water utility is therefore a system-specific endeavor, and it is not generally effective to establish singular output targets for all utilities in a region or state. Managing NRW is akin to the utility rate-setting process: the individual factors and costs of the water utility go into setting a system-specific water rate structure. No one would expect multiple water utilities in a given region to employ the same water rate structure and charge the same rates for water. Thus, loss reduction goals and programs should also be set in a system-specific manner, and it is difficult for regulatory agencies to attempt to set singular loss reduction goals for water utilities.

- Defining compliance/noncompliance provisions of prospective water auditing and loss control rules:
  - Care should be taken when defining remedies for noncompliance with regulatory approaches that are based on the best practices defined in this manual. As previously noted, this publication is a guidance manual and is not written as a regulatory instrument. While a variety of means to audit supplies and control losses are detailed herein, it is not necessary that all water utilities employ all of the loss control interventions. Corrective measures that are based on steps detailed in this manual should be restricted to those that encourage improvement and compliance rather than those that produce financial or other penalties without additional guidance.
- Guidance for compliance with prospective water auditing and loss control rules:
  - The regulatory agency should clearly communicate the schedule for water audit data submittal, and how the information will be compiled and shared. The agency should also identify, as applicable, which types of proposed water utility programs (e.g., water supply and other growth-induced treatment and conveyance projects) are subject to compliance with water audit data submittal requirements.
  - Thresholds for compliance should be based on well-founded rationales that yield actionable information and recognize benefit–cost analysis to evaluate alternative activities for achieving compliance, such as those described in this manual. Such rationales are preferred over arbitrary, less meaningful parameters like universal or percentage-based triggers. The method of calculation for the applicable parameters should be clearly stated.
  - As previously noted, the proposed schedule under which water utilities would begin submitting required information to the regulatory agency should be discussed with the affected utilities, recognizing that smaller systems may need more time to install needed data collection equipment, collect and validate the required data, and assemble the data for submittal.
  - It is important to also identify additional guidance documents that the regulatory agency believes will complement methods detailed in this manual. Agencies should also provide contact information to which water utilities can turn for technical assistance.
- Obtaining financial support for relevant projects:
  - The regulatory agency should clearly communicate the availability of, and requirements to receive, financial support for water auditing or loss control functions or projects undertaken by water utilities. Such efforts might include water auditing training and data validation, leak detection assistance, customer meter testing, and occasionally water pipeline replacement. Agencies should investigate the availability of State Revolving Fund monies as a possible source of such programs' funding for water efficiency purposes.

RECENT RULEMAKING PROCESSES AND REGULATORY PROGRAM DEVELOPMENT

Several states, one regional water management commission, and one Canadian province have promulgated water loss control–related protocols that align with the approaches included in this manual. Typically, these emerging types of programs require water utilities to submit data in the form of the best practice annual water audit structure. This goes well beyond the traditional gathering of basic monthly or annual water supply and consumption data, and noting the difference between these two volumes. In the sections that follow, the structures employed in these agencies are highlighted, and they reflect the momentum that is growing around the implementation of AWWA's best practice methods.

Additional information on evolving regulatory requirements for water loss control is available in *The Water Efficiency and Conservation State Scorecard*, published by the Alliance for Water Efficiency and the Environmental Law Institute (AWE and ELI 2012). This compendium of state agency responses to a 20-question survey provides an indication of how regulatory agencies are incorporating water loss control policies within the broader context of water use efficiency. *The Scorecard* includes responses to a specific question on policies or regulations for water utilities regarding water loss in the utility distribution system, as well as excerpts from certain state regulations for comprehensive water conservation plans that include water loss control program–related provisions.

The US Environmental Protection Agency (USEPA) sets national drinking water regulations in the United States and has extensive regulatory structures in place for clean streams and rivers and for utility drinking water quality. USEPA has taken an interest in water loss control and issued the guidance manual *Control and Mitigation of Drinking Water Losses in Distribution Systems* (2010a). At least one region of the United States (Region 4–Southeast) has included recognition of the need for utilities to have a water loss control plan when coordinating the review process for the permitting of water supply reservoirs (USEPA 2010b). USEPA continues to monitor the progress for implementation of improved water auditing and loss control methods by US water utilities.

A summary of a representative mix of regulatory approaches that is now in place for water loss control policy follows, in alphabetical order.

State of California

The California Urban Water Conservation Council (CUWCC) is a consortium of more than 200 metropolitan water utilities (signatory utilities) and other stakeholders who are dedicated to the promotion of water efficiency. The CUWCC was created to increase efficient water use statewide through partnerships among urban water agencies, public interest organizations, and private entities. The council's goal is to integrate a series of defined urban water conservation best management practices (BMPs) into the planning and management of California's water resources.

Best practices for water loss control programs in California primarily comprise one of four subcategories of the Water Utility Operations component of the Memorandum of Understanding (MOU; last revised on Sept. 16, 2009) issued by the CUWCC. "Foundational" BMP 1.2–*Water Loss Control* and the related BMP 1.3–*Metering With Commodity Rates and Retrofit of Existing Connections* establish a reporting system for the signatory utilities. Under these BMPs, water utilities should annually compile and submit water audits in accordance with the AWWA Water Audit Methodology, using the AWWA Free Water Audit Software. Additionally, utilities should submit reports detailing their progress in installing meters on all new construction and retrofitting of meters to existing service lines (including outdoor irrigation systems but not fire suppression lines). Water utilities should also conduct billing on a volume basis, conduct regular testing and repair of customer meters, and implement a program of regular customer meter replacement.

Background and basis for a revised BMP for water accountability and loss control. The CUWCC is not a regulatory agency. The CUWCC provides annual reports to the California State Water Resources Control Board and the governing bodies of the signatory water utilities on the progress of implementation of the several BMPs relating to water efficiency.

Stakeholder involvement. Membership of the CUWCC includes representatives from the signatory water utilities, public advocacy groups, and other interested stakeholders. Only the first two groups are eligible to serve on the board of directors and to vote on matters relating to the MOU (including modifications to the BMPs) and the organization's bylaws. Nonvoting members of the board of directors include representatives of the other interested stakeholders and representatives of certain state and federal agencies involved with the allotment of California water resources.

Applicability and implementation. BMP 1.2 incorporates the water loss management procedures embodied in AWWA Manual M36, and the signatory water utilities are expected to use the AWWA Free Water Audit Software to compile and submit their standard water audit annually.

The signatory water utilities are assigned the first four years of water audit data collection as a period to gradually improve the quality of their water audit data, with the goal of achieving a DVS of at least 66 by year 4 submittal. Utilities are designated to achieve a DVS of 71 or higher (Level IV of the Water Loss Control Planning Guide worksheet included in the Audit Software) by the fifth year of data submittal. Utilities should follow recommendations on the Audit Software's Grading Matrix worksheet to improve their practices and produce more reliable data.

The CUWCC established a progressive program in that it includes both the water audit data submittal process and a requirement to track and manage real (leakage) losses to achievable low levels. The economic value assigned to real losses recovery is based on the signatory water utility's avoided cost of water as calculated by the CUWCC's adopted Avoided Cost Model, or other signatory water utility's model consistent with the CUWCC's Avoided Cost Model.

Signatory water utilities are required to conduct a leakage component analysis at least once every four years. *Leakage component analysis* is defined as a means to analyze real losses and their causes by quantity and type. The goal is to identify volumes of water loss, the cause of the water loss, and the value of the water loss for each component. Knowing these parameters, the utility has the inputs for the Leakage Component Analysis (LCA) Model that provides information needed to support the economic analysis and selection of intervention tools. The LCA Model is explained in detail in chapter 7 of this manual. This model follows the bursts and background estimates (BABE) model (Lambert 1994), which assesses leakage occurring in a water distribution system by its components of background losses, reported leaks, and unreported leaks. The nature, extent, and value of the leakage losses occurring in a water utility are unique to each utility's water distribution system. The leakage component analysis provides information to set a realistic, achievable level of leakage to target. Signatory water utilities are required under BMP 1.2 to reduce real losses to the extent that it is cost-effective.

A phased implementation schedule was established beginning on July 1, 2009, with the first BMP 1.2 report due by Dec. 1, 2010, for the periods of 2008–2009 and 2009–2010 for those signatories as of Dec. 31, 2008. Subsequent signatories are required to begin implementation no later than July 1 of the year following the year that they executed the MOU. While the signatory water utilities have largely met the data submittal goals, results of these efforts are not yet available.

Signatory water utilities are also required to test source, import, and production meters annually, beginning in the second year of implementation.

Consequences of noncompliance. Because a benchmark performance indicator was to be determined after the first four years of data collection from the signatory water utilities, and voted on by the council by year 6 of the revised MOU implementation schedule, the CUWCC has yet to establish such an indicator and determine the consequences of noncompliance.

The leakage component analysis of real losses is required to be updated every four years. Beginning with the fifth year of implementation and carrying through the tenth year, progress in water loss control performance as measured by the performance indicator “gallons per day per service connection” or “gallons per day per mile of mains,” or another appropriate indicator, must be demonstrated through achievement of

- a score lower than the prior year’s score, or
- a score less than the 3-year running average, or
- a score in the top quintile (20 percent) of all signatory water utilities reporting such performance with a Data Validity Level IV, or
- in year 6 and beyond, reducing real losses to or below the benchmark determined in the CUWCC’s process noted previously.

Signatory water utilities are also required to repair all reported leaks and breaks to the extent they are cost-effective. By the end of the second year of implementation, a record-keeping system for these repairs must be established, including time of report, leak location, type of leaking pipe segment or fitting, and leak running time from report to repair. By the end of the fourth year, the report must include the estimated leakage volume from report to repair and the cost of repair (including pavement restoration costs and paid-out damage claims, if any). Unreported leaks shall also be located and repaired to the extent they are cost-effective. All of the data serve as inputs to the leakage component analysis and allow water utilities to continue to refine and improve their leakage management efforts.

Documentation of the foregoing data must be maintained, including the economic value assigned to the apparent and real losses, miles of mains surveyed for leaks, pressure reduction undertaken for real loss reduction, infrastructure rehabilitation and renewal, volumes of water saved, and costs of intervention(s). Such documentation must be submitted to the CUWCC annually during years 2 through 5 of implementation.

Financial and technical support mechanisms. Training in water auditing and the LCA method was required and offered to the signatory water utilities by AWWA and the CUWCC within the first four-year implementation period. Funding of projects related to improved management of apparent and real water losses has been supported through other state programs, such as the Drinking Water State Revolving Fund, as well as recent federal programs intended to enhance economic recovery.

On Sept. 19, 2014, California amended Section 10631 of the State Water Code to require all urban water systems, including those not signatory to the CUWCC MOU, to quantify and report distribution system water loss using the water system balance methodology developed by AWWA (State of California 2014). Urban water systems are also required to include this information, together with descriptions of water demand management measures (including water loss management), in updates to their urban water management plans beginning with the 2015 plan updates, which are to be submitted by July 1, 2016. There are no water loss performance targets in the amended Section 10631 for water systems that are not a signatory to the CUWCC MOU.

Delaware River Basin Commission

The Delaware River Basin Commission (DRBC) was formed in 1961 when President Kennedy and the governors of Delaware, New Jersey, Pennsylvania, and New York signed concurrent compact legislation into law. The compact's signing marked the first time since the nation's birth that the federal government and a group of states joined together as equal partners in a river basin planning, development, and regulatory agency to oversee a unified approach to managing a river system without regard to political boundaries. The members of this regional body include the four-basin state governors and the division engineer of the US Army Corps of Engineers North Atlantic Division who serves as the federal representative. Commission programs include water quality protection, water supply allocation, regulatory review (permitting), water conservation initiatives, watershed planning, drought management, flood loss reduction, and recreation.

Background and basis for an amendment to DRBC's Water Code. For several decades, the DRBC has employed a comprehensive water efficiency program, which has formed an integral component of its broader strategy to manage water resources throughout the basin. In 2009, the DRBC amended its Comprehensive Plan and Water Code to implement an updated water audit approach to identify and control water loss in the basin. The new approach requires water utilities to prepare and submit an annual water audit conforming to the AWWA Water Audit Methodology and using the AWWA Free Water Audit Software as the data collection tool. The impetus for the rule change was that DRBC determined that then-current methods to account for, track, and reduce physical water losses from public water supply distribution systems in the Delaware River Basin—estimated to be as much as 150 mgd (million gallons per day)—were inadequate. In recognizing such problems and proactively seeking best management solutions, the DRBC is one of a handful of regulatory agencies in the United States that has changed its regulations to reflect the improved approach to water loss accounting made possible by the AWWA Water Audit Methodology. On Sept. 1, 2008, the DRBC announced its intention to revise provisions of its Water Code relating to efficiency for water utilities who serve the public with sources located within the Delaware River Basin. By Resolution No. 2009-01 on Mar. 11, 2009, the DRBC approved amendments to its Water Code and Comprehensive Plan calling for a phased program of water auditing and reporting in accordance with the audit structure established by AWWA (DRBC 2009).

Stakeholder participation. Potential modifications to the DRBC's policies and regulations on water loss control were considered and drafted by the DRBC's Water Management Advisory Committee (WMAC). WMAC is comprised of 20 members representing a wide range of interests in the water resources of the Delaware River Basin. The committee concluded that the AWWA water audit approach offered multiple benefits over the existing regulations through the use of more precise definitions, rational accounting procedures, and a consistent methodology. Upon publication of the Notice of Proposed Amendments in the participating states' legal publications and in the *Federal Register*, a public hearing was held on Sept. 25, 2008, and written comments were accepted through Oct. 3, 2008. The DRBC made minor clarifying revisions and published a detailed comment and response document simultaneously with adoption of the final rule.

Applicability and implementation. The 2009 DRBC rule change required the AWWA reporting format to be used for the 2012 calendar year water audit and annually thereafter. In the interval between the passing of the resolution and the implementation of the new reporting format, the DRBC promoted voluntary use of the new format and focused its efforts on raising awareness of the new approach and requirements through efforts such as:

- presentations and outreach to the regulated community;
- a one-day water audit training workshop held by DRBC in partnership with water utilities in the basin; and
- new DRBC Web pages dedicated to water audits, hosting materials from the workshop, and other supporting information.

The water audit requirement applies to all public water suppliers within the Delaware River Basin who have been issued approvals by the DRBC to withdraw and use in excess of an average of 100,000 gpd (gallons per day) of water during any 30-day period. Through an extensive outreach effort, DRBC notified the regulated community, subject to the new water audit requirement, that the first report would cover the period of calendar year 2012 and would be due to DRBC by Mar. 31, 2013, with subsequent reporting required annually thereafter. An important aspect of the new DRBC water audit program was an emphasis on electronic reporting and processing of water audit reports. As previously noted, the AWWA Free Water Audit Software is the specified tool for water audit data collection and submittal. This method provides for a consistent reporting format and enables the AWWA Water Audit Software Compiler Tool (another tool freely available from the AWWA Web site) to be used to rapidly assemble water audit data for analysis.

Prior to adoption of the new regulations, a 15 percent "unaccounted for water" performance standard was utilized by DRBC. Until a sufficient body of data exists to indicate that a more meaningful measure of system performance can be established, DRBC will look at NRW as a key indicator of system performance.

In addition to compiling the annual water audit, water purveyors (utilities) distributing more than 100,000 gpd are required to develop and undertake a systematic program to monitor and control leakage within their system. Such a program shall, at a minimum, include periodic surveys to identify leakage, enumerate NRW, and determine the current status of system infrastructure, recommendations to monitor and control leakage, and a schedule for the implementation of such recommendations.

Consequences of noncompliance. Each program to monitor and control leakage is subject to review by the applicable state agency where the water system is located and must be updated at a frequency not less than every three years. A more frequent submittal may be required if NRW as a percentage by volume of water supplied exceeds 15 percent.

Financial and technical support mechanisms. The DRBC has hosted workshops describing the revised regulations, including outreach to smaller water systems, and collaboration with state and local water industry organizations and training programs. DRBC staff has also led the development of the AWWA Free Water Audit Software and complementary tools. More information about the DRBC's water audit program can be found on the DRBC Web site at www.state.nj.us/drbc/programs/supply/audits/.

State of Georgia

The State of Georgia's program focuses not only on a rational structure for the program, but also dedicates considerable resources to the training and education of the water utilities, and validation of the water audit data submitted by the water utilities. Its ability to leverage State Revolving Funds to assist these purposes is groundbreaking. According to the *Georgia Water System Audits and Water Loss Control Manual*, published by the Georgia Department of Natural Resources, the Georgia Environmental Protection Division (GA EPD), and the Georgia Association of Water Professionals (GAWP), the primary impetus for adopting a comprehensive water loss control regulatory system was the recognition that demonstrating strong stewardship of the state's water resources would be very beneficial for improving water use efficiency in the face of potential shortages in many regions of the state (GA DNR, GA EPD, and GAWP 2014). Water system audits and water loss control are considered valuable water management strategies that can improve the efficiency of water production and delivery within all water systems in the state.

Background and basis for Georgia's Water Stewardship Act. The State of Georgia moved proactively to create a stronger water efficiency ethic throughout the state by passing the Water Stewardship Act of 2010 (SB 370). The state's water loss control program is embodied in this legislation and is applicable to water systems serving at least 3,300 persons. These water systems must conduct and submit a standardized annual water system audit (according to the AWWA methodology) to GA EPD and implement a water loss control program. The water audit data undergoes an extensive data validation process, is finalized, and the summary results are posted on the GA EPD Web site.

Stakeholder involvement. Stakeholder input was obtained through a series of public comment periods, with technical support provided by the GAWP. The three entities that created the *Georgia Water System Audits and Water Loss Control Manual* also enlisted the assistance of key stakeholders and a number of nationally recognized experts to participate in the creation and review of this publication, which serves as the primary training tool for water utilities in Georgia.

Applicability and implementation. A phased approach was adopted by GA EPD, which required systems serving more than 10,000 individuals to electronically submit their audit by March 2012 for the period Jan. 1, 2011, to Dec. 31, 2011. Systems serving fewer than 10,000 persons but at least 3,300 persons were required to submit their 2012 calendar year audits by March 2013. Annual reporting for all systems serving at least 3,300 persons continues thereafter.

Consequences of noncompliance. It is intended by GA EPD that water withdrawal permits, water treatment plant production increases, and loan issuance by the Drinking Water State Revolving Fund/Georgia Environmental Finance Authority (GEFA) may take into consideration water audit results and the development and implementation of water loss control programs.

Audit results are evaluated by the state, and utilities are required to demonstrate progress using a suite of performance indicators that includes data validity and real and apparent loss per connection per day. Percentages are not used as a performance indicator to track improvement over time. Performance targets are the system-specific Economic Level of Leakage, which, once achieved, are to be maintained.

Financial and technical support mechanisms. GEFA leverages State Revolving Funds for water efficiency purposes, providing funding for training, technical assistance, data validation, and water loss control grants to small systems serving less than 10,000 persons. Grants are awarded depending on the level of water audit data validity, performance indicator values, and the utility's ability to achieve a meaningful reduction in water loss. With these functions in place, Georgia has ensured that water utilities are knowledgeable and active participants in the water audit data collection process and are fully engaged in launching efforts to better control losses. The *Georgia Water System Audits and Water Loss Control Manual* defines and describes best practices for compliance and improving water audit data validity, and provides guidance for use of the AWWA Free Water Audit Software, which is the defined method of data collection for the program. Updated information and technical resources on the Water System Audit and Loss Control Program can be found at the GAWP Web site at www.gawp.org.

A series of workshops is conducted on a periodic basis to provide training to utility personnel on compiling the water audit, review results of the previous round of audit data collection, and assess performance indicator data to better develop improvement programs. These training sessions also key on in-depth practices for managing water loss, updates to the regulatory and administrative requirements and technical tools, and other aspects of evolving technical guidance, such as recent research findings from organizations such as the Water Research Foundation.

Georgia's Water Loss Control Program Successes

The State of Georgia implemented a water loss control program that keys primarily on the collection and validation of utility water audit data. While requiring the use of the AWWA Water Audit Methodology, considerable resources are dedicated to the training and education of the water utilities in the data collection process. An effective collaboration of the Georgia Department of Natural Resources (GA DNR), the Georgia Environmental Protection Division (GA EPD), and the Georgia Association of Water Professionals (GAWP) resulted in several training tools, including the *Georgia Water System Audits and Water Loss Control Manual* (GA DNR, GA EPD, and GAWP 2014).

Training workshops were held across the state prior to the initial data collection, and a comprehensive data validation process was conducted on the submitted water audit data. The above-mentioned agencies worked closely with the Georgia Environmental Finance Authority to leverage State Revolving Funds to pay for consulting services to conduct training and data validation. The validation process includes one-on-one data review and revision as needed with each of the water utilities submitting data.

The State of Georgia has taken a very comprehensive approach in launching its water loss control program and benefits from its growing pool of well-validated data to more reliably identify the extent of losses in water utilities and the appropriate controls to cost-effectively control the losses.

As previously noted, a distinct data validation effort was included in the Georgia program to ensure that all collected data was objectively represented in terms of its validity, but also as an additional educational process for utility personnel to become familiar with the integrity of their data sources and data management processes. To accomplish this, GA EPD implemented a third-party review process of all submitted water audits. For the first year that water audits were submitted by water systems serving 10,000 persons or more, a validation process was performed using contracted services of consultants versed in the water audit validation process. The validation team interviewed the water utility auditors to review their data inputs and the basis for their data grading assignments. Where applicable, water utilities systems submitted revised water audits before GA EPD finalized and then posted the summary water audit data to their Web site. GA EPD is planning to continue this validation process with future water audit submissions prior to posting on the Internet. While the water audit data validation process demands additional resources of time and funding, this process is invaluable to the success of the water audit data collection process, as the assessments and judgments made about the results of the water audit are only as valid as the trustworthiness of the audit data inputs.

State of Illinois

As a result of a 1967 US Supreme Court Decree (amended in 1980), the Illinois Department of Natural Resources (IDNR) administers the allocation of water supply from Lake Michigan to more than 50 water utilities in the Metropolitan Chicago area. The decree and Illinois state law mandate that "all feasible means reasonably available to the State and its municipalities, political subdivisions agencies and instrumentalities shall be employed to conserve and manage the water resources of the region and the use of water therein in accordance with the best modern scientific knowledge and engineering practice" [Level of Lake Michigan Act (615 ILCS 5O/5)]. IDNR's water-needs criteria require these water utilities to indicate their existing sources of supply, water use and population served, projections of future consumption and water supply needs, and to demonstrate their implementation of conservation practices and reduction of NRW.

Background and basis for a rule change. Title 17, Chapter I, Subchapter h, Part 3730, Section 3730.304 of the Illinois Joint Committee on Administrative Rules–Administrative Code describes the water-needs criteria that these water utilities (permittees) must document, which includes descriptions as to the extent of customer metering, expenditures for maintenance and repair of water distribution systems, groundwater conservation levels if applicable, and conventional elements of conservation-related programs (Illinois Joint Committee on Administrative Rules 2015).

Until 2014, with specific regard to water loss management, threshold percentages of "unaccounted-for flows" (UFFs) were also indicated, above which holders of Lake Michigan water allocation permits would be considered in violation and subject to fines and possibly review of their allocation permits. Furthermore, Section 3730.307 mandated that all permittees must reduce or eliminate wasteful water use and reduce UFFs (expressed as a maximum unavoidable leakage [MUL] allowance) to 8 percent of net annual pumpage or less (having previously been required to meet a 12 percent threshold). Permittees must also determine the efficiency of water metering or accounting in their system and, subject to practical difficulties, limit hydrant uses (excluding fire-fighting needs) to 1 percent of net annual pumpage or less. Annual reporting requirements described in Section 3730.309 include summaries of results and recommendations for leak detection surveys performed during the reporting period.

As described throughout this manual, IDNR has recognized that the use of the term *unaccounted-for* water is imprecise, and the sole reliance on simple percentage performance indicators, such as the "unaccounted-for" water percentage, is misleading. Thus, a good opportunity existed to improve beyond the existing requirements of the traditional rule defined above.

Stakeholder participation. In February 2013, IDNR announced proposed changes to its rules for permitting allocations of Lake Michigan water, consistent with the above obligations to "require that all feasible means reasonably available be employed." The initially proposed rules would have modified the protocol for evaluating the water loss control performance of regulated water systems and would have included provisions for managing demand through submetering of new multifamily construction, updating low-flow plumbing fixture specifications to labeled WaterSense products, updating lawn-sprinkling ordinances to require time-of-day restrictions, not on consecutive days, and would recommend that water rates reflect full-cost pricing.

In September 2013, in response to numerous comments received from many water systems that would be affected by the proposed changes and from other stakeholders, IDNR announced that it was considering modifications to its original proposal. IDNR then proposed phased-in compliance while moving its traditional reporting form (LMO-2) submittal process toward completion of a water audit methodology resembling that of the AWWA Water Audit Methodology. The modified rules, if approved, would change the "Unaccounted-For Flow" Standard to a Non-Revenue Water Standard (12 percent in Water Year 2015, decreasing to 10 percent by Water Year 2019), without a MUL allowance.

The proposed rules would also require a valuation of utility water losses based on the water utilities' wholesale cost of water purchased (conservatively assuming that all loss is real loss rather than apparent loss), thus enabling permittees to translate their water loss volume data to a monetary amount and thereby illustrate the value of undertaking infrastructure improvement to their water systems. The modified rules would also require preparation and submittal to IDNR of a water system improvement plan for noncompliant water systems that enables these systems to make necessary improvements over time.

Under the modified rule, implementation of submetering of multifamily service connections would also be included as a recommended, not mandatory, practice. The final proposed rules were submitted for approval by the Joint Committee on Administrative Rules with additional time needed to complete the process and promulgate the revised rules.

Applicability and implementation. All water utilities with or seeking allocations of water supply from Lake Michigan are subject to the described rules. There are no comparable requirements for water utilities in other parts of Illinois. The implementation process under the proposed rules was promulgated on Nov. 18, 2014 (Illinois Joint Committee on Administrative Rules 2014). The State of Illinois has taken strong, positive steps to improve its structures for utility water accountability and loss control and preservation of Lake Michigan's waters.

Consequences of noncompliance. Failure to comply with the requirements of the existing and proposed rules may result in issuance of a notice of violation, fines, and/or reduction of an existing allocation, or a denial of application for an allocation or renewed allocation of water supply from Lake Michigan.

Financial and technical support mechanisms. Financial assistance is available through the Illinois Environmental Protection Agency (IEPA), which administers the state's Public Water Supply Loan Program. Funding through this program was recently expanded through integration with the governor's Clean Water Initiative. Assistance can support projects such as renewal or replacement of water mains. The state does not directly provide technical assistance to water utilities for water loss management. However, IDNR has worked with several organizations, including the Illinois Section of AWWA, IEPA, Chicago Metropolitan Agency for Planning, the Metropolitan Planning Council, and the Center for Neighborhood Technology, to conduct a series of water loss audit workshops and otherwise make available guidance to communities to help them better understand the nature of their particular water loss issues and how their particular infrastructure needs can be clarified and an investment strategy developed. The workshops were held at several locations within the Lake Michigan allocation area throughout the state of Illinois.

State of New Mexico

New Mexico does not have a discrete regulatory system in place for water auditing and reporting, although it has conducted a pilot AWWA water audit for several water utilities in the state. Water auditing and water loss control are promoted by the state through guidance to those water rights applicants who are public water suppliers, for preparation of a water conservation plan that can be used to demonstrate the applicant's stewardship of water resources.

Background and basis for rule changes. Under Title 19, Chapter 25, Part 13 of the New Mexico Administrative Code, and as authorized by Article XVI of the New Mexico State Constitution, the New Mexico Office of the State Engineer (NMOSE) adopts rules and regulations to supervise the physical distribution of water, to prevent waste, and to administer the supply of water by priority date or by alternative administration, as appropriate. Accordingly, subject to court adjudication, NMOSE may deny a permit sought by applicants for rights to such water supplies, within the framework of a system of water master districts, if the applicants do not meet the requirements of these rules and regulations. One of the requirements is for the applicant to demonstrate that the permit will not be contrary to the conservation of water.

Stakeholder participation. In addition to promoting the conservation of water by facilitating the formation and operation of water rights groups, NMOSE provides assistance to applicants who are public water suppliers in the form of a resource guide titled *Water Conservation Planning Guide for Public Water Suppliers* (NMOSE 2013). This planning guide includes extensive discussion of how to apply the AWWA Water Audit Methodology and make use of the AWWA Free Water Audit Software, together with NMOSE's GPCD (gallons per capita per day) Calculator, to assist in the development of a water conservation plan.

Applicability and implementation. In particular for assessment of water loss management performance, the *Water Conservation Planning Guide* recommends that the water audit approach be employed to organize water diversion data and track its path through the distribution system. Users are encouraged to examine the DVS that is generated by the

AWWA Free Water Audit Software before proceeding with water loss control program planning. Provided the underlying data are sufficiently valid, this auditing process determines the volume of NRW and assigns a cost to the components of NRW, particularly apparent and real (leakage) losses. Additionally, water utilities can assess their performance by reviewing the performance indicator values calculated by the Audit Software.

Once the results of the water audit are known, users are advised to establish realistic goals for the water conservation plan, which may comprise short-term actions to improve water audit data validity and achieve early success in reducing NRW. This can be followed by longer-term activities that will achieve further improvements in water loss management.

Consequences of noncompliance. Applications for water rights permits may be denied by NMOSE if the applicant is unable to demonstrate consistency with the principles of water conservation.

Financial and technical support mechanisms. *The Water Conservation Planning Guide* includes several potential sources of funding for projects related to water loss management and water conservation, including the US Bureau of Reclamation and the New Mexico Environment Department. In particular, the New Mexico General Services Department provides statewide price agreements for water meters and installation components. These contracts allow public entities to avoid the public bidding process. Various types of meters are available with a variety of features.

The New Mexico Rural Water Association (NMRWA) is a nonprofit membership organization committed to helping communities provide safe drinking water and wastewater services through onsite technical assistance, specialized training, and legislative support. NMRWA partners with community utilities across the state to create sustainable systems and build local expertise. It provides leadership, technical assistance, and training for utility professionals who serve rural New Mexico families. The NMRWA has published several management and sustainability guides, including *Water Use Auditing: A Guide to Accurately Measure Water Use and Water Loss* (Holmes 2007), and also provides a list of funding sources.

The *Water Conservation Planning Guide* includes detailed instructions for completing a water audit using the AWWA Free Water Audit Software and interpreting the results to establish an improvement program.

Pennsylvania Public Utility Commission

In partnership with the implementation of the water auditing program of the Delaware River Basin Commission (DRBC), the Pennsylvania Public Utility Commission (PAPUC) launched a two-year water audit pilot program in 2009 with five of the largest private water companies in Pennsylvania. (The PAPUC is a financial regulator that has oversight of Pennsylvania's privately held water utilities, but not publicly held utilities.) Water audits were compiled for several individual water systems operated by these companies using the AWWA Free Water Audit Software, and an assessment of the program was conducted in 2011. PAPUC judged the pilot program to be a successful demonstration of the AWWA Water Audit Methodology and moved to make the pilot program a permanent requirement. The following excerpt of the Advance Notice of Proposed Rulemaking Order appeared in the *Pennsylvania Bulletin* on Feb. 9, 2013 (*Pennsylvania Bulletin* 2013).

> On November 10, 2011, the Commission [PAPUC] issued a Tentative Opinion and Order at M-2008-2062697 (2011 Tentative Order) wherein the Commission ordered all Class A water utilities (over $1,000,000 in annual revenues) to implement the Water Audit methodology. The Tentative Opinion and Order became final January 27, 2012 (2012 Order). [A Secretarial Letter finalizing the 2011

Tentative Order was issued on January 27, 2012, at Docket No. M-2008-2062697, after the only comments filed to the 2011 Tentative Order was withdrawn.] Specifically, the Commission concluded:

> Based upon this Commission's tradition of establishing ground-breaking regulatory tools, such as the DSIC or single tariff pricing, we will order the implementation of this Water Audit methodology which will help achieve a number of public interest benefits, such as increased infrastructure reliability, help preserve water resources, limit water leakage, reduce overall company risk, and enhance customer service. We believe that this practice is a better tool than the current unaccounted-for-water method and in the public interest.

To this end, the Commission ordered the five participating water utilities, namely, Aqua Pennsylvania, Inc., Pennsylvania-American Water Company, Superior Water Company, York Water Company and United Water Pennsylvania, Inc., to file annual Water Audit summaries with the Secretary of the Commission for the year ended December 31, 2011, no later than April 30, 2012, and on subsequent years no later than April 30.

In addition to ordering the five participating water utilities to file annual Water Audit summaries by April 30, 2012, the Commission specifically directed in the 2012 Order:

> That all other Class A water utilities (over $1,000,000 in annual revenues) commence to file the annual Water Audit summaries with the Secretary of the Commission for the year ended December 31, 2012, no later than April 30, 2013, and on subsequent years no later than April 30. These other Class A water utilities presently include Columbia Water Company, Newtown Artesian Water Company, CAN DO, Inc.-Water Division, United Water Bethel, Inc., and Audubon Water Company.

Accordingly, the Water Audit methodology has now been adopted by this Commission and all Class A water utilities are now required to file the annual Water Audit summaries with the Secretary of the Commission no later than April 30 of each year.

While the Commission has formally adopted the Water Audit methodology and also has directed all Class A water utilities to file the annual Water Audit summaries no later than April 30th of each year, a remaining question going forward for the Commission and the water industry is whether the Commission should revise its existing regulations regarding unaccounted-for-water at 52 Pa. Code § 65.20, or, whether it is necessary for the Commission to adopt new regulations regarding the Water Audit methodology.

Section 65.20 of the Code states, in pertinent part:

> § 65.20. Water conservation measures—statement of policy.
>
> In rate proceedings of water utilities, the Commission intends to examine specific factors regarding the action or failure to act

> to encourage cost-effective conservation by their customers. Specifically, the Commission will review utilities' efforts to meet the criteria in this section when determining just and reasonable rates and may consider those efforts in other proceedings instituted by the Commission.
>
> Subsection (4) of this section, which specifically addresses unaccounted-for-water, states:
>
> Levels of unaccounted-for-water should be kept within reasonable amounts. Levels above 20% have been considered by the Commission to be excessive…."

Additionally, the Commission, as was requested in the 2012 Order, invited comments from the regulated community (particularly the participants in the pilot project and the other Class A water utilities designated to file their first annual Water Audit by April 30, 2013) and other interested parties on the experienced benefits and costs of the Water Audit methodology.

PAPUC also invited comments as to whether the Water Audit methodology should be extended to the other jurisdictional water utilities. PAPUC has since issued an Advance Notice of Proposed Rulemaking for comment (PAPUC 2013). At the time of publication for this manual, a final decision on the new rulemaking is awaited. PAPUC has taken a progressive stand to require a defensible, best practice methodology to collect water audit data from private water utilities in the Commonwealth of Pennsylvania. AWWA continues to assist PAPUC in its efforts to improve water efficiency.

Province of Quebec, Canada

Quebec's Water Efficiency Strategy (2011) is rooted in the Quebec Water Policy of 2002 (Government of Quebec Province, Canada 2002). It renders the allocation of financial assistance to municipalities for water infrastructure projects contingent upon the adoption of specific measures to conserve water and reduce leakage rates. While water resources are abundant in Quebec, the policy recognizes the importance of efficient management and responsible water use. The goal of the strategy relevant for water loss management is to achieve, by 2017, a reduction of water loss rates to a maximum of 20 percent of water distributed and a maximum of 15 m^3/km/d (cubic metres per kilometre per day) of water main, or approximately 6,400 gal/mi/d (gallons per mile per day). As of early 2014, Quebec stood as the only Canadian province to implement a requirement for reporting of water loss volumes via the compilation of the annual water audits.

Background and basis for new rulemaking. The Water Efficiency Strategy is administered by the Ministere des Affaires municipales, des Regions et de l'Occupation du territoire (Ministry of Municipal Affairs, Regions and Territorial Occupation).

Stakeholder involvement. The various elements contained in the Water Efficiency Strategy were developed through a close collaboration between the provincial government and the participating municipalities. The Province of Quebec's strong interest in the water loss methods being advanced by AWWA led to the creation of French language versions of both the third edition of AWWA Manual M36 and the AWWA Free Water Audit Software (version 4.2).

Applicability and implementation. Each participating municipality must, annually, as of 2012:

- Measure water distributed and complete a water balance using data loggers on flowmeters to determine minimum night flows and estimate water losses. (Note: many municipalities in Quebec do not meter individual water customers, thus the data-logging requirement was implemented as a means to obtain a representative sample of customer consumption.) As of 2016, accuracy must be within 5 percent of true flow with onsite verification of flows at low, intermediate, and high flow rates.
- Complete/update an action plan that includes
  - a proactive leak detection and repair program if water losses exceed the strategy's maximum values,
  - public education programs designed to inform about water efficiency,
  - adoption of a municipal bylaw on water use, and
  - evaluation of the full cost of water service provision.
- Submit a water use report to the Municipal Council.

And, as of 2014: Install meters in the nonresidential sector, and estimate (with an acknowledged uncertainty) residential consumption, if the quantity of water distributed per person is not reduced by 10 percent from 2001 levels or if the strategy's leakage rate limits are exceeded.

And, as of 2017: Implement adequate water pricing, if the quantity of water distributed per person is not reduced by 20 percent from 2001 levels or if the strategy's leakage rate limits are exceeded.

As of late 2013, more than 750 municipalities, representing 99 percent of the population connected to a drinking water system, participated in the strategy. Approximately 400 municipalities, representing 90 percent of the population connected to a drinking water system, had implemented or planned to implement a proactive leak detection program. Approximately 8,000 leaks were repaired by municipalities in 2012. Approximately 30 percent of nonresidential buildings and 10 percent of residential buildings have a water meter that is now read on a regular basis.

Consequences of noncompliance. Participation in the annual reporting program is voluntary. Municipalities who participate are eligible for financial assistance for water infrastructure upgrades from the Ministry of Municipal Affairs, Regions and Territorial Occupation.

Financial and technical support mechanisms. The government has made a commitment to provide conditional financial assistance to municipalities, make revisions to the Building Code to prohibit the sale of inefficient plumbing fixtures, pursue water efficiency programs in government buildings, produce tools to assist municipalities and building owners, and establish three committees (technical, municipal, and ministerial) to monitor and report results of the program.

The cost of eligible equipment and studies may be reimbursed through a grant program. Forms and technical guidance are available to assist municipalities in the preparation of the annual reports to be submitted to the Municipal Council and to the Quebec Ministry of Municipal Affairs. (For more information, see www.mamrot.gouv.qc.ca/grands-dossiers/strategie-quebecoise-deconomie-deau-potable/.)

State of Tennessee

The Tennessee Code Annotated (TCA) includes provisions for a regulatory system for water loss reporting and control adopted by the state legislature in 2007 (Public Chapter 243, HB 743). The regulatory system is administered by the Comptroller of the Treasury–Utility Management Review Board (UMRB) and the Water and Wastewater Financing Board

(WWFB). These entities provide assistance to utility districts, municipal water systems, water authorities, and county water systems, including establishment of guidelines for water loss reporting and control. Similar to a public utility commission, the focus of the UMRB is the financial protection of the water consumer.

Background and basis for new rulemaking. "The Tennessee UMRB supports natural gas, water and wastewater public utility districts by assuring that they are financially self-supporting and by requiring appropriate action by those districts that have financial deficiencies" (Tennessee Comptroller of the Treasury 2015). On Oct. 7, 2010, acting under authorization of TCA Section 7-82-702, a joint meeting of the UMRB and the WWFB established a percentage for excessive water loss at 35 percent using the then-current method of calculation and required a transition in reporting and calculation methods for water loss (Tennessee Association of Utility Districts 2010). Prior to Jan. 1, 2013, subject to amendment of the TCA to allow the UMRB and WWFB to adopt water loss standards, water utilities were required to submit the original calculation method and reporting form for water loss. If the system has excessive water loss, then it must resubmit using the AWWA Water Audit Methodology. On Jan. 1, 2013, the AWWA Water Audit Methodology became the operative protocol. The term *unaccounted-for water* was removed from the TCA and replaced with *water loss* throughout.

Stakeholder participation. A key stakeholder in the development of the Tennessee regulatory system for water loss control is the Tennessee Association of Utility Districts (TAUD, www.taud.org). TAUD recommended adoption of the AWWA Water Audit Methodology for calculating water loss and an implementation strategy for compliance.

Applicability and implementation. Water utilities regulated by the UMRB and WWFB are required to electronically submit annually the completed water audit via the AWWA Free Water Audit Software together with the water utility's audited financial statements. The spreadsheet submittal is in addition to a single Reporting Worksheet that summarizes water treated and purchased, water sold and other authorized uses, and other financial information for revenues as well as electrical and chemical costs.

The audit information submitted using the AWWA Free Water Audit Software includes the DVS determined according to data input gradings entered by the auditor as guided by the Grading Matrix worksheet within the Audit Software. Water utilities must demonstrate that their DVS is

- greater than 65 for audits received between Jan. 1, 2013, and Dec. 31, 2014;
- greater than 70 for audits received between Jan. 1, 2015, and Dec. 31, 2016;
- greater than 75 for audits received between Jan. 1, 2017, and Dec. 31, 2018; and
- greater than 80 for audits received between Jan. 1, 2019, and Dec. 31, 2020.

A concurrent milestone-based requirement applies for demonstration of improved NRW performance. This performance is assessed using the NRW-by-cost performance indicator. The initial threshold for acceptable performance was 30 percent through Dec. 31, 2014. This threshold declines to less than 25 percent through Dec. 31, 2016, and settles at less than 20 percent through Dec. 31, 2020. For this purpose, "Total Annual Cost of Operating the Water System" is defined to include all costs for operation, maintenance, debt service (principal and interest), and depreciation. The thresholds are subject to change by approval of the UMRB and WWFB.

Consequences of noncompliance. Failure by the water utility to submit the required audit information results in a referral to the appropriate board (UMRB or WWFB), as does a reported NRW-by-cost level that exceeds the designated standard and failure to achieve improvement in the DVS by the milestones noted previously. Referrals are primarily required to substantiate the financial viability of the water utility. The referral is made by

Tennessee's System for Water Loss Reporting and Control

Tennessee's water loss control program is administered by the Comptroller of the Treasury–Utility Management Review Board and the Water and Wastewater Financing Board. These boards operate as financial regulators of water systems in Tennessee. As such, the boards hold the interests of water ratepayers and strive to ensure that water utilities provide reliable service at reasonable cost. Tennessee requires use of the AWWA Water Audit Methodology and data collection via the AWWA Free Water Audit Software. In applying assessments of the software's performance indicators, Tennessee has taken a unique approach. Instead of setting a low target level of non-revenue water (NRW) that all water utilities should meet, Tennessee identified high threshold levels of the water audit Data Validity Score and the NRW-by-cost indicator. Water utilities that exist beyond these high threshold levels are referred to the appropriate authorities to help them gain the proper assistance to improve their performance in a focused manner. This avoids a punitive approach toward utilities and ensures that needed attention is directed to the relatively few utilities that may be struggling to maintain acceptable water loss performance.

the Office of the Comptroller within 60 days of the failure to file or a filing where results do not meet the designated performance standard.

It is important to note Tennessee's progressive approach toward water utilities. Instead of setting a low threshold for NRW that all water utilities should meet, Tennessee identified high threshold levels of water audit data validity and NRW by cost. Water utilities that operate with parameters beyond these high threshold levels are referred to the appropriate authorities to help them gain the proper assistance to improve their performance in a focused manner. This avoids a punitive approach toward utilities and ensures that needed attention is directed to the relatively few utilities that may be struggling to maintain acceptable water loss and/or financial performance.

Financial and technical support mechanisms. TAUD has provided several workshops to assist water utilities with gaining knowledge of the applicable state policies and underlying principles of the AWWA Water Audit Methodology, issues that arise in analyzing the data utilized for the audit, and the process for completion of the audit.

Tennessee's Drinking Water State Revolving Fund awards priority points for offering low-interest loans to eligible water loss control–related projects (intended to reduce leakage) on a sliding scale. Higher priority is assigned to projects submitted by water utilities demonstrating poorer water loss performance (between 80 and 20 points for water loss in increments of 20 points for water loss increments of 10 percentage points, correspondingly ranging between 50 percent or greater and 20 percent or greater).

State of Texas

Texas was the first state to implement legislation that included a water auditing requirement and, very recently, has tightened its requirements for water auditing and loss control. As a result of state legislation (House Bill 3338 passed in 2003, and House Bills 857, 1461, and 3605 passed in 2013), utility companies are required to conduct annual water audits to quantify water loss, to inform customers of water audit results, and to use a portion of state assistance funds to conduct conservation that can include water loss control. HB 857 requires water utilities to conduct annual water loss audits. HB 1461 requires customer notification of the audit results. HB 3605 requires utilities that receive board financial assistance to use a portion of that financial assistance to mitigate the utility's system water loss if, based on a water audit filed by the utility, the water loss meets or exceeds a threshold established by rule. The three recent bills were enacted during the year following the worst period of drought in the history of Texas.

The Texas Water Development Board (TWDB) began requiring submittal of standardized water audits using a water audit worksheet to be filed by retail public water utilities beginning in 2005 at five-year intervals. The methodology, guidance, and worksheet were forerunners of the AWWA Free Water Audit Software, embedded data validity scoring matrix, and technical guidance for data entry and calculation of performance indicators. TWDB still employs these internally developed forms, which are similar to—but not the same as—the AWWA tools.

Background and basis for legislative activity. House Bill 3338 was enacted to help conserve the state's water resources by reducing water loss occurring in the systems of drinking water utilities. In response to the legislation, approximately half of the public water utilities serving approximately 84 percent of the population in Texas reported their water loss data. House Bills 857, 1461, and 3605 were enacted to request that utilities receiving any funding from the TWDB need to submit audits annually. Another objective of House Bill 3605 was to develop water loss thresholds. Rules were adopted on Dec. 5, 2014, and published (*Texas Register* 2014). The adopted rules provide the following thresholds (*Texas Register* 2014):

- For a retail public utility with a population more than 10,000:
  - Apparent loss expressed as gallons per connection per day must be less than the allowed apparent loss, consisting of a unique number calculated for each utility.
  - Real loss expressed as gallons per connection per day must be less than three times the unavoidable annual real loss, consisting of a unique number calculated for each utility.
- For a retail public utility with a population less than or equal to 10,000 and a service connection density more than or equal to 32 connections per mile:
  - Apparent loss expressed as gallons per connection per day must be less than the allowed apparent loss, consisting of a unique number calculated for each utility.
  - Real loss expressed as gallons per connection per day must be less than 50 gal/connection/d.
- For a retail public utility with a population less than or equal to 10,000 and a service connection density less than 32 connections per mile:
  - Apparent loss expressed as gallons per connection per day must be less than the allowed apparent loss, consisting of a unique number calculated for each utility.
  - Real loss expressed as gallons per mile per day must be less than 1,600 gal/mi/d.

Stakeholder participation. Although stakeholder participation in the development of the TWDB's *Water Loss Audit Manual for Texas Utilities* (Mathis et al. 2008) was somewhat limited, a subsequent survey on municipal water loss management practices was conducted in 2009 with the objective of achieving a more consistent representation of water use accounting and water loss management. Approximately 300 water systems responded to the survey. The consensus of the responses confirmed the need for consistency of reporting and management, particularly for methods of leak detection, leak repair response, and meter management, as well as assistance to smaller systems in the state. The final rulemaking process that established the above thresholds received comments from the City of Houston, City of Austin, and Texas Rural Water Association, along with two environmental groups.

Applicability and implementation. Any retail water supplier that is financially obligated to the TWDB and retail water suppliers that serve more than 3,300 service connections are required to file an annual water audit with the TWDB. All retail public water suppliers are required to file a water audit every five years (the next audit is due on May 1, 2016, for the 2015 reporting year). The TWDB encourages all retail public water suppliers to prepare an annual audit as a best practice for proactive identification and resolution of water loss management issues.

The standardized approach, technical guidance for data entry and interpretation of results, data validity scoring system, and data entry forms are described in the TWDB's *Water Loss Audit Manual for Texas Utilities* (Mathis et al. 2008). A drawback to the TWDB's approach was the incorporation of a "balancing adjustment" that allowed some water use to be unclassified. This adjustment has been removed in the most recent versions. Also, although the TWDB uses a data grading system, it does not align with the system used in the AWWA Free Water Audit Software; hence, the DVSs of Texas utilities cannot be compared directly with those of the many other state and regional agencies that employ the AWWA tools.

All public drinking water utilities are required to submit a water conservation plan that includes best practices relevant to water loss management. These practices include supply metering with an accuracy of ±5 percent; universal metering of public uses of water, meter testing and repair as well as periodic meter replacement; periodic visual inspections along distribution lines; and audits of customer service lines. Additionally, public drinking water suppliers who serve or will serve—within 10 years from the effective date of the plan—5,000 or more persons must include a program of leak detection, repair, and water loss accounting for the transmission, delivery and distribution system, documentation of water pumpage, delivery, sales, and loss volumes. These plan requirements also apply to the wholesale customers of these systems.

Consequences of noncompliance. The TWDB is a nonregulatory state agency. However, failure to comply with the audit submittal requirements will preclude a water utility from receiving financial assistance for water supply projects.

Financial and technical support mechanisms. The TWDB maintains a robust capability for providing technical guidance to drinking water utilities. This capability includes staff consultation, Web portals with considerable technical guidance (most also available in Spanish), an outreach program that includes workshops for water utilities—the content of which is eligible for licensure credits to water utility operators offered by the Texas Commission on Environmental Quality, free equipment on loan for acoustical sounding devices for leak detection and pinpointing, and ultrasonic flow-measuring devices to verify metered flow rates through source or master meters.

In early 2014, the TWDB discussed publishing a new Water Loss Reduction Implementation Manual that would include details of apparent and real loss management programs, and discussion of benchmarks and ranges of water audit data collected during the audit reporting program. Technical assistance can be accessed through the TWDB's Water Conservation Division. Financial assistance for projects related to water loss control should be available in 2015 through low-interest loan funding from House Bill 4 (2013) where up to $2 billion of the Texas Rainy Day Fund can be used to provide low-interest loans to aid with implementation of the state's 50-year water supply plan.

MOVING FORWARD THROUGH CONTINUOUS IMPROVEMENT

It is evident from the foregoing examples of regulatory and voluntary systems for water auditing and water loss control programs that a nexus exists between conventional water conservation (demand side) activities and actions that can be undertaken by water purveyors or utilities (supply side). Synergies that are likely to arise from continued implementation of such programs will lead to operating cost reduction, revenue recovery, and improved sustainability of water resources for the water utilities that participate.

In many cases, the quality of data submitted to the administering agencies must be improved and validated so that actionable information is generated for use in planning effective water loss control programs. In other cases, the legal authority of some agencies may need strengthening to achieve greater participation, or the latest methodologies need to be adopted to achieve greater consistency in reporting and improved ability to compare performance against other water utilities with similar characteristics.

The AWWA Water Audit Methodology and companion software tools offer water utilities a standardized approach for assessing and reporting water loss performance. Continued dialogue between the drinking water industry, the regulatory community, and interested stakeholders will assist the process to better understand the components of water loss and how to manage them to economic levels. A collaborative rulemaking process can produce benefits for water utilities, their customers, water management agencies, and other involved stakeholders.

REFERENCES

AWE and ELI (Alliance for Water Efficiency and Environmental Law Institute). 2012. *The Water Efficiency and Conservation State Scorecard: An Assessment of Laws and Policies*. www.allianceforwaterefficiency.org/final-scorecard.aspx.

AWWA (American Water Works Association). 2011. Validated Water Audit Data for Reliable Utility Benchmarking. AWWA Water Loss Control Committee. Denver, Colo.: AWWA. http://www.awwa.org/Portals/0/files/resources/water%20knowledge/water%20loss%20control/VALIDATED-WATER-AUDIT-DATA-FOR-RELIABLE-UTILITY-BENCHMARKING.pdf.

Beecher, J. 2002. *Survey of State Agency Water Loss Reporting Practices*. Final Report to the Technical and Educational Council of the American Water Works Association. Indianapolis, Ind.: Beecher Policy Research.

CUWCC (California Urban Water Conservation Council). 2009. Best Management Practice 1, Utility Operations Programs. https://www.cuwcc.org/Resources/Memorandum-of-Understanding/Exhibit-1-BMP-Definitions-Schedules-and-Requirements/BMP-1-Utility-Operations-Programs.

DRBC (Delaware River Basin Commission). 2009. Water Code, DRBC Rule Change: Water System Audits and Water Loss Control. http://www.state.nj.us/drbc/programs/supply/audits/.

GA DNR, GA EPD, and GAWP (Georgia Department of Natural Resources, Georgia Environmental Protection Division, and Georgia Association of Water Professionals). 2014. *Georgia Water System Audits and Water Loss Control Manual*, Version 1.1.

Government of Quebec Province, Canada. 2002. Quebec Water Policy. http://www.mddelcc.gouv.qc.ca/eau/politique/index-en.htm.

Holmes, M. 2007. *Water Use Auditing: A Guide to Accurately Measure Water Use and Water Loss*. New Mexico Rural Water Association, www.nmrwa.org.

Illinois Joint Committee on Administrative Rules. 2014. *The Flinn Report*. https://www.google.com/#q=Illinois+Joint+Committee+on+administrative+rules+November+18%2C+2014.

Illinois Joint Committee on Administrative Rules. 2015. Title 17: Conservation, Chapter I: Department of Natural Resources, Subchapter H: Water Resources, Part 3730 Allocation of Water From Lake Michigan. http://www.ilga.gov/commission/jcar/admincode/017/01703730sections.html.

Kunkel, G., et al. 2003. Water Loss Control Committee report: Applying worldwide BMPs in water loss control. *Journal AWWA*, 95(8):65–79.

Lambert, A. 1994. Accounting for losses: The bursts and background estimates concepts. *Journal of the Institution of Water and Environmental Management*, 8(2):205–214.

Mathis, M., G. Kunkel, and A. Chastain-Howley. 2008. *Water Loss Audit Manual for Texas Utilities*. Report 367. Austin: Texas Water Development Board.

NMOSE (New Mexico Office of the State Engineer). 2013. *Water Conservation Planning Guide for Public Water Suppliers*. Technical Report 53, Version 1. Santa Fe, N.M.: NMOSE.

PAPUC (Pennsylvania Public Utility Commission). 2013. PUC Seeks Comments on Proposed Rulemaking for Regulations Regarding Unaccounted-for Water. Press release. http://www.puc.state.pa.us/about_puc/press_releases.aspx?ShowPR=3107.

Pennsylvania Bulletin. Feb. 9, 2013. Proposed Rulemaking. Pennsylvania Public Utility Commission [52 PA. Code 65]. Advance Notice of Proposed Rulemaking Order; Water Conservation Measures [43 Pa.B 870]. www.pabulletin.com/secure/data/vol43/43-6/231.html.

State of California. 2014. State Water Code: Section 10631. http://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=WAT&sectionNum=10631.

Tennessee Association of Utility Districts. 2010. Email notification, October 24. http://www.taud.org/TempFiles/WaterLoss.htm.

Tennessee Comptroller of the Treasury. 2015. Utility Management Review Board. http://www.comptroller.tn.gov/umrb/index.asp.

Texas Register. Dec. 5, 2014. Adopted Rules. *Texas Register* 39(49):9515–9612. http://www.sos.state.tx.us/texreg/pdf/backview/1205/index.shtml.

USEPA (US Environmental Protection Agency), Office of Water. 2010a. *Control and Mitigation of Drinking Water Losses in Distribution Systems*. EPA 816-R-10-019. Washington, D.C.: USEPA, Office of Water.

USEPA (US Environmental Protection Agency), Region 4. 2010b. *Guidelines on Water Efficiency Measures for Water Supply Projects in the Southeast*. Atlanta, Ga.: USEPA.

Chapter 3

Conducting the Water Audit

This chapter details the best practice International Water Association and American Water Works Association (IWA/AWWA) Water Audit Method published in *Performance Indicators for Water Supply Services* in 2000 for quantifying customer consumption and volumes of real and apparent losses (Alegre et al. 2000). This method allows the operator to reveal the destinations of water supplied throughout the distribution system and to quantify volumes of consumption and loss. AWWA recommends that drinking water utilities employ this method to conduct a water audit. The auditing process occurs at three levels, each adding increasing refinement:

1. *Top-down approach*—the initial desktop process of gathering information from existing records, procedures, data, and other information systems.
2. *Leakage component analysis*—a technique that models leakage volumes based on the nature of leak occurrences and durations. This technique can also be used to model various occurrences of apparent losses by looking at the nature and duration of the occurrence.
3. *Bottom-up approach*—validating the top-down results with actual field measurements such as leakage losses calculated from integrated zonal or district metered area (DMA)* night flows. Similarly, physical inspections of customer properties can uncover apparent losses from defective or vandalized customer meters, or unauthorized consumption. Process flowcharting of customer billing systems can be used to identify systematic billing errors.

The top-down approach is the recommended starting point for water utilities compiling their initial water audit, and it is described in this chapter. Descriptions of bottom-up approaches and leakage component analysis are given in chapter 5 for apparent losses

* A DMA is a small zone of the distribution system, typically encompassing between 1,000 and 3,000 customer service connections, with measured supply input flow of sufficiently small volume that individual leakage events can be quantified, thereby guiding leak detection deployment decisions. See chapters 6 and 7 for details.

Water Auditing: Top-Down vs. Bottom-Up Approach

Mature water systems employ both the top-down and bottom-up approaches to water system auditing to achieve long-term success in data validity and water loss management. So, what are top-down and bottom-up approaches to water system auditing, and how do they work together?

The top-down auditing approach represents a relatively quick assembly of available records and data regarding system parameters, supply, consumption, and loss; the bottom-up auditing approach represents a relatively slow and deliberate extraction of detailed, supporting data from both the office and the field, which improves the top-down audit. Where the top-down approach typically marks the beginning of water accountability for most water systems, the bottom-up approach constitutes a continuum of improvement, taking place over successive years of top-down auditing. Bottom-up auditing complements top-down auditing and ultimately strengthens the overall audit reliability. Where the top-down approach may often require the use of some educated assumptions, bottom-up auditing tests and validates those assumptions, increasing the accuracy and confidence of the audit inputs and outputs. For example, many water systems may not have accuracy test data for their customer meters and will use an assumed value for this input in their first top-down audit, based on knowledge of the existing meter population's age and condition. The bottom-up activity for this input would involve conducting accuracy tests on statistical samples of the meter population to validate the assumed top-down input value.

The bottom-up approach, discussed in greater detail in chapters 5 and 7, can involve an array of activities, including

- flow verification tests for production, import, and export meters;
- field or bench accuracy testing of customer meters;
- detailed analysis of customer consumption history for profiling of meters, customer classes, zero and inactive accounts, consumption by rate code, registered vs. billed consumption, meter right-sizing analysis, and verification of consumption summary report totals;
- detailed analysis of customer account inventory for verification of revenue-dependent field values such as rate code and meter size;
- field investigation of inactive accounts;
- cross-reference of Geographic Information System and Customer Information System databases, for indicators of unauthorized consumption, such as sewer-only customers that have no well and lie within the water service area;
- temporary fire hydrant metering for verification of estimated flow rates used in determining authorized, unmetered consumption volumes;
- utilization of district metered areas for zonal water balance and night flow analysis;
- pressure logging for refinement to average system operating pressure calculations; and
- leak detections surveys, step testing, and real loss component analysis.

It will take three to six years for most water systems to obtain a mature level of validity in their water audit approach. It is necessary that water systems be critical and candid when assessing the data grading for each audit input, as this will largely inform which next-step bottom-up activities will best serve the water system. Similarly, one must consider the sequencing of bottom-up activities in a rational, methodical manner that can be sustained in perpetuity.

If the water auditing process is instituted as a standard, annual business practice—as it should be—a two-fold goal should exist to both compile the top-down audit and incrementally utilize bottom-up audit methods for ongoing improvement to the completeness and quality of the data, which will foster long-term improvement to data validity and water loss management.

and chapter 7 for real (leakage) losses. See the "Water Auditing: Top-Down vs. Bottom-Up Approach" sidebar for an explanation of the distinctions between the top-down and bottom-up approaches.

The water audit addresses the questions "How much water is being lost?" and "How much are these losses costing the water utility?" With relatively modest effort, the top-down method can provide a good preliminary assessment of water loss standing and insight to the quality of available water supply data. The top-down audit also helps to identify components that require further validation. Ultimately, the water auditor can better validate and improve the accuracy of the water audit when it is augmented by leakage component analysis, bottom-up field measurements, or both.

THE WATER AUDIT

The water auditing process is an effective tool available to utilities to quantify consumption and losses that occur in the distribution system and the management processes of the water utility. The auditing process is a revealing undertaking that provides great insight to the auditor on the types and amounts of loss occurring in the utility. Also, launching a water audit often begins the culture change necessary to focus utility employees on water-efficient practices. The top-down water audit is assembled in two steps: (1) quantifying, via measurement or estimation, individual water consumption and water loss components; and (2) undertaking the water balance calculation.

This chapter explains the recommended water audit approach, which includes example data from the fictitious water utility, County Water Company (CWC). Step-by-step instructions are given to compile the water audit using the AWWA Free Water Audit Software (Audit Software), including the required information, how to get that information, how to enter it in the software program, and how the performance indicators are calculated. The Audit Software was created, and is maintained by, the AWWA Water Loss Control Committee and is available for free download from AWWA's Water Loss Control Resource Community Web site (AWWA 2014b), which also includes considerable additional information on water loss control. Select worksheets of the Audit Software are also shown as figures in this chapter. The reader is urged to download the Audit Software from the AWWA Web site and to view it in tandem with reading the discussions in this publication. This will ensure that the reader can adequately view the Audit Software and test its workings while reading the content in this chapter.

THE WATER BALANCE CALCULATION

A preliminary assessment of water loss can be obtained by gathering available records and placing data into the water audit worksheet. The summary data from the water audit is shown in the water balance, which compares the distribution system input volume with the sum of customer consumption and losses (estimated or known). The sum of all components in each column of the water balance are equal, and therefore in balance, as shown in Figure 3-1. The water balance for CWC in the Audit Software is given in Figure 3-2. Most water utilities have readily available data on production, water imported from or exported to, other utilities, and customer consumption. Utilities often have less data available to quantify leakage, meter error, and unauthorized consumption. The water balance provides a guide for how much water is lost as a result of customer metering inaccuracies, systematic data handling errors, and unauthorized consumption (collectively, apparent losses), as well as leakage (real losses).

The two most powerful features of the best practice water audit method are its rational terms and definitions (Table 3-1) and standard set of performance indicators (as shown

<table>
<tr><td rowspan="9">Volume From Own Sources (corrected for known errors)</td><td rowspan="11">System Input Volume</td><td>Water Exported (corrected for known errors)</td><td colspan="3">Billed Water Exported</td><td>Revenue Water</td></tr>
<tr><td rowspan="10">Water Supplied</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="8">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="6">Water Losses</td><td rowspan="3">Apparent Losses</td><td>Customer Metering Inaccuracies</td></tr>
<tr><td>Unauthorized Consumption</td></tr>
<tr><td>Systematic Data Handling Errors</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and Distribution Mains</td></tr>
<tr><td rowspan="2">Water Imported (corrected for known errors)</td><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to the Point of Customer Metering</td></tr>
</table>

Note: All data in volume for the period of reference, typically one year.

Figure 3-1 Water balance

later in Table 3-24). On the broadest level, water system input volume goes to two places: authorized consumption or losses. The water audit method advances the concept that all water should be quantified, via measurement or estimate, as either authorized consumption or losses. Hence, no water is *unaccounted for*.

Since 2003, AWWA has recommended that water utilities, state agencies, and drinking water stakeholders avoid use of the poorly defined and imprecise term *unaccounted-for water* (Kunkel et al. 2003). Stakeholders should instead employ the term *non-revenue water* (NRW) and apply it as specifically defined in Table 3-1.

The performance indicators give a useful assessment of water loss standing from water resources management, financial, and operational perspectives. They are effective in evaluating current standing, for loss reduction target-setting, and for benchmarking with other similar utilities.

COMPILING THE TOP-DOWN WATER AUDIT DATA

This section provides step-by-step instructions for compiling the top-down water audit. Major tasks are listed, as well as individual steps, under these tasks.

Before Starting the Water Audit

At the outset of the water audit, it is important to establish the scope of the audit by determining its key parameters.

Identify the system boundaries. The auditor must clearly define the system boundaries for the audit, noting where water is launched into supply and where it leaves the system. Three distinct water supply configurations are shown in Figures 3-3a through 3-3c. Figure 3-3a illustrates a configuration for an untreated water transmission (wholesale) system. Figure 3-3b shows a treated water distribution (retail) system. Figure 3-3c displays a discreet subsector of a retail distribution system, such as a pressure district or DMA. A water audit can be conducted on any or all of the three configurations. Water audits are most commonly performed on individual treated water distribution systems (Figure 3-3b), and the example given in this chapter follows this configuration. It is important that the

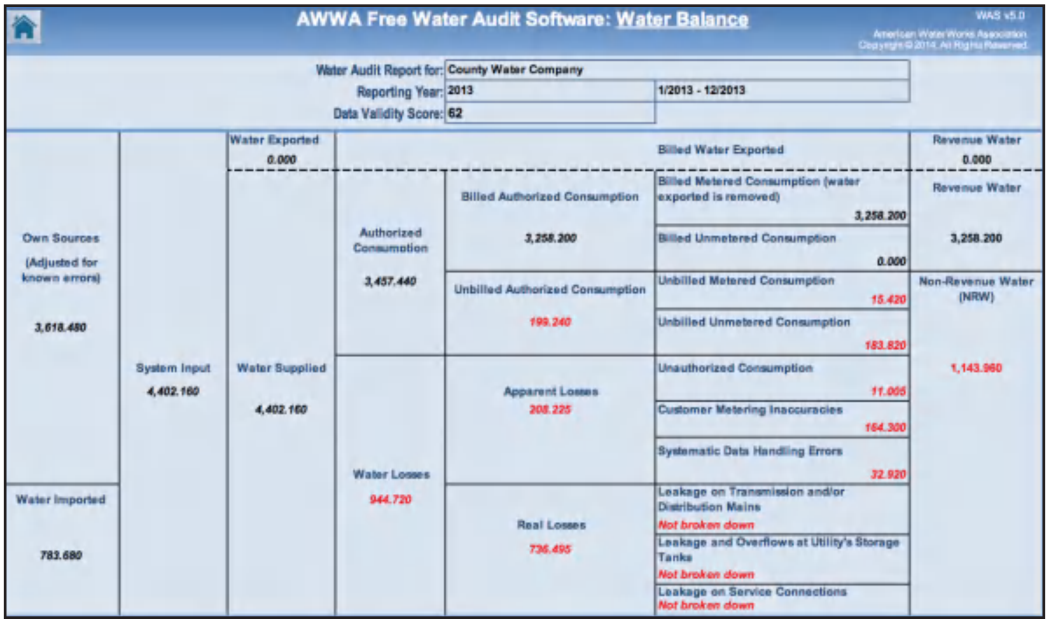


Figure 3-2 Water balance for County Water Company—2013 calendar year using the AWWA Free Water Audit Software

Table 3-1 Water balance terms and definitions

Water Balance Term	Definition
Volume From Own Sources	This is the volume of water withdrawn (abstracted) from water resources (rivers, lakes, streams, wells, etc.) controlled by the water utility, and then treated for potable water distribution.
Water Imported	The Water Imported volume is the bulk water purchased to become part of the Water Supplied volume. Typically, this is water purchased from a neighboring water utility or regional water authority.
System Input Volume	The System Input Volume is the annual volume input to the water supply system. This equals the Volume From Own Sources plus the Water Imported volume.
Water Supplied	The Water Supplied volume is the annual volume of treated water delivered to the retail water distribution system. This equals System Input Volume minus the Water Exported volume.
Water Exported	The Water Exported volume is the bulk water conveyed and sold by the water utility to neighboring water systems that exists outside of their service area.
Authorized Consumption	Authorized Consumption is the annual volume of metered and/or unmetered water taken by registered customers, the water supplier, and others who are authorized to do so.
Water Losses	This is the difference between System Input Volume and Authorized Consumption, consisting of Apparent Losses plus Real Losses.
Apparent Losses	Apparent Losses involve systematic data handling errors (in the customer billing process), all types of customer metering inaccuracies, and unauthorized consumption.
Real Losses	Real Losses are the annual volumes lost through all types of leaks, breaks, and overflows on mains, distribution reservoirs, and service connections up to the point of customer metering.
Revenue Water	Revenue Water pertains to those components of System Input Volume that are billed and produce revenue.
Non-Revenue Water	This is the sum of Unbilled Authorized Consumption, Apparent Losses, and Real Losses. This value can also be derived by calculating the difference between System Input Volume and Billed Authorized Consumption.

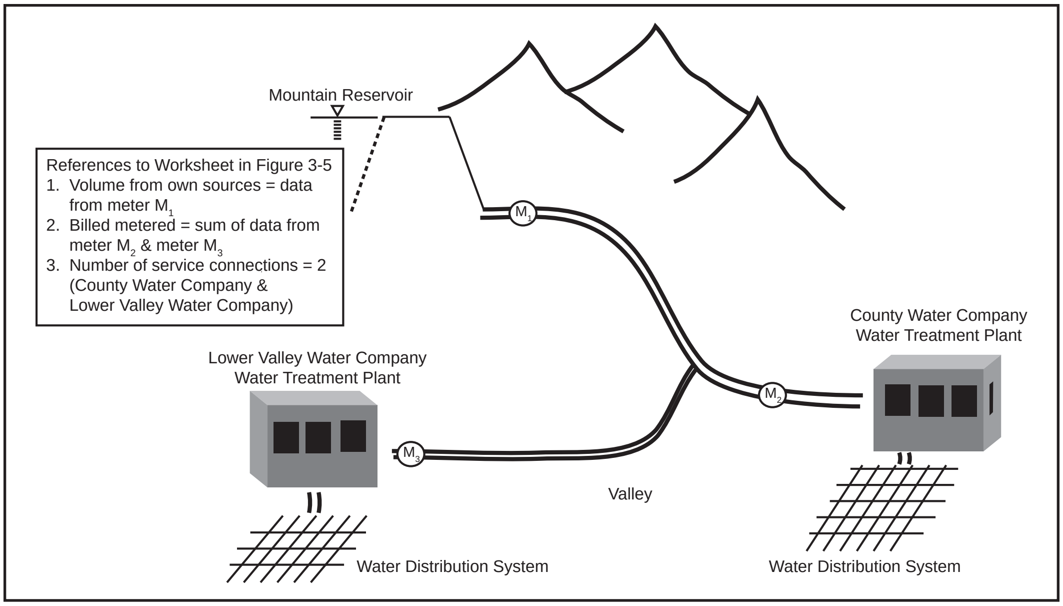


Figure 3-3a Identifying system boundaries for a water audit conducted on a wholesale transmission water supply system

system boundaries be identified to match the justification put forward for compiling the water audit. Appendix C discusses water resources considerations that might justify expanding or isolating the audit to include water transmission systems, water use/loss through water treatment plants, or more detailed evaluations of customer consumption. When identifying the system boundaries, it is important that accurate measurement of the water input is obtainable from existing installed meters, portable meters or other meters that can be used on a temporary basis, or new meters that are proposed for installation at the input location.

The boundary limits should be defined by points of metering of the water supply. Typical metering locations for drinking water supply and distribution are given in Table 3-2. A water audit of the raw or untreated water system (Figure 3-3a) utilizes metering data of the source water withdrawals as the System Input Volume and the water metered at the treatment plant influent or effluent (where the water improves in quality and value) as the end point.

For water audits conducted on treated water distribution systems (shown in Figure 3-3b and the typical example in this manual), the metered flow of finished water leaving the water treatment plant is taken as the starting point for system input and customer metered consumption is the end point.

Set a time period. A water audit is a detailed study over time. One month or even six months is too short a time to give an overall picture of water flow through the system. A 12-month study period is recommended as it is long enough to include seasonal variations and reduces the effects of lag time in customer meter reading. Advanced metering infrastructure (AMI) technology can collect all customer meter readings on a daily (or shorter) basis, thus groups of customer meter data do not lag each other in data collection and the Billed Authorized Consumption volume can be synchronized with the Water Supplied volume in a reliable manner without causing any billing lag.

Most utility records are kept by the calendar or business (fiscal) year; either schedule makes 12 months of data available. The calendar year is illustrated in this chapter.

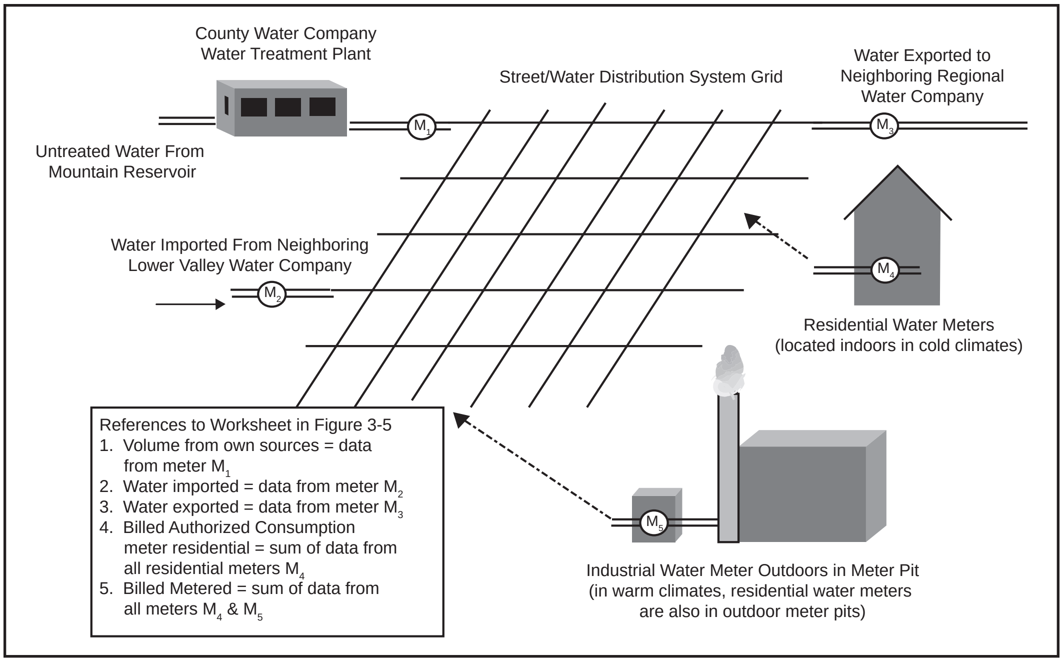


Figure 3-3b Identifying system boundaries for a treated water distribution system

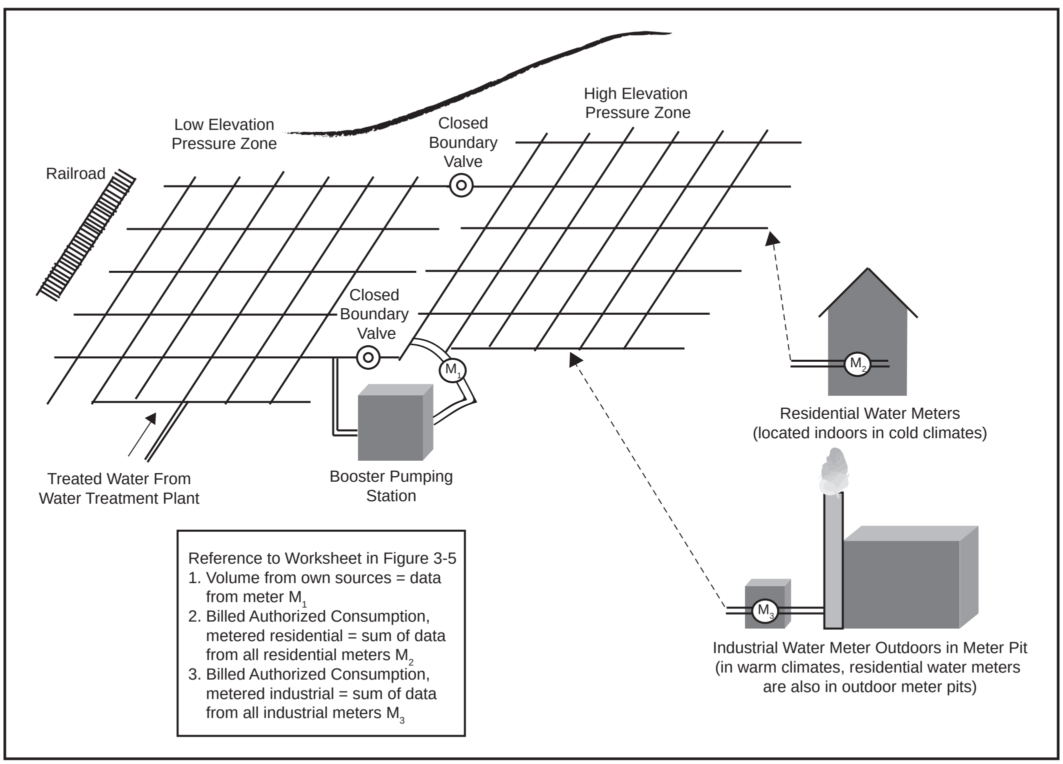


Figure 3-3c Identifying system boundaries for a discrete pressure zone or DMA

Table 3-2 Metering locations in drinking water supply systems

Location	Function
Water source (untreated water)	Measure withdrawal or abstraction of water from rivers, lakes, wells, or other raw water sources
Treatment plant or works	Process metering at water treatment plants; metering may exist at the influent, effluent, and/or locations intermediate in the process
Distribution system input volume	Water supplied at the entry point of water distribution systems; either at treatment plant, treated water reservoir, or well effluent locations
Distribution system pressure zones	Zonal metering into portions of the distribution system being supplied different pressure. Also includes metering at major distribution facilities such as booster pumping stations, tanks, and reservoirs.
District metered area	Discrete areas of several hundred to several thousand properties used to analyze the daily diurnal flow variation and infer leakage rates from minimum-hour flow rates
Customers	Consumption meters at the point of use
Bulk supply	Import/Export meters to measure bulk purchases or sales
Miscellaneous	Capture use of water from fire hydrants, tank trucks, or other intermittent use

The water audit draws upon water supply and consumption data, as well as cost data, leak detection results, meter testing data, investigations of unauthorized consumption, and other data. Most of the data are routinely assembled by water utilities on an annual basis as part of their business year reporting. Thus the water audit is a yearly reporting endeavor. Water audits are not generally compiled on a more frequent basis since most of the data needed for the water audit is quite detailed and usually only assembled and reconciled on a yearly basis. Water utilities, however, can compile a cursory measure of the Water Supplied volume and compare it to the Billed Authorized Consumption volume on a more frequent basis, such as monthly. See Table 8-2 in chapter 8 for an example of such reporting. *However, it is important that such comparisons be conducted using rolling 12-month data for the previous 12-month period.* **Comparing a single-month Water Supplied volume to a single-month Billed Authorized Consumption volume is unreliable and misleading because it fails to take into account seasonal variations, customer meter reading lag issues, and other short-term effects.** Water loss assessments, be they the formally compiled data of the annual water audit or the cursory monthly overview of Water Supplied volume compared to Billed Authorized Consumption volume, should always be conducted using data derived from a 12-month period.

Select the units of measure. The units of measure must also be chosen and standardized so that supply and customer consumption units are the same. In many water utilities, treatment and distribution operations use one unit of measure (e.g., gallons) while metering and billing systems often use a different unit (e.g., cubic feet). Moreover, different multiples are often found in different types of utility records, such as *hundreds* of cubic feet in billing records, *millions* of gallons per day in water production reports, or *thousands* of acre-feet per year in annual financial statements. Although a variety of units are used by North American water utilities (million gallons, acre-feet, cubic feet, megalitres), gallons will be used in the examples in this manual. Because the time period is one year, the unit of measure (million gallons) is presented as a volume for the year. Unit conversion is a common source of error, requiring continual vigilance by the auditor.

Assemble records and data. One of the auditor's greatest challenges is to assemble records and data from a wide variety of operations in the water utility. Information is required on production metering; leak detection and repair; detailed customer metering and billing data; authorized consumption from flushing, fire fighting, and related activities; distribution system pressures; water conservation activities; financial information (water rates and production costs); infrastructure rehabilitation; and a host of related data.

Distribution system maps or geographic information systems (GISs), customer billing systems, maintenance management information systems, and supervisory control and data acquisition (SCADA) systems are some of the information management systems that can be accessed to assemble much of the needed data. In most water utilities, a considerable degree of interdepartmental cooperation is needed to access and assemble the data. Thus it is essential that the auditing process be supported at the outset by the utility's senior management, who should communicate the importance of the water audit and urge active participation from all groups in the water utility.

Establishing procedures and contacts for the routine, annual collection of the data is an important function. The auditor should be cognizant during the auditing process of the caliber of information sources. Who provides the data? What is the format of the data? What is the degree of confidence or validity of the water audit data? If new information sources are uncovered during the auditing process, the new information streams should be documented so that the desired data is available for the water audit in subsequent years. Because similar data is gathered on a yearly basis, routine data collection processes greatly ease the amount of work needed to assemble this information each year after the initial water audit is conducted. Thus the completeness of the water audit, and the validity of its input data, should improve over time.

Through the auditing process, the individual or team responsible for conducting the audit will be required to determine the validity of each audit input, a process referred to as *data grading*. Data grades are strongly dependent on the integrity of both the source of the data and the process by which the audit input value is derived from that data. To assess the validity of each audit input, the auditor must be diligent in the discovery process, including documentation of not only sources of data, but pertinent utility staff interviews regarding practices and procedures as well. The data grading for each input in the audit is selected as a score from 1 to 10, based on specific scoring criteria described in the Grading Matrix worksheet in the Audit Software. Throughout this chapter, guidance is offered about the factors to consider when assessing data quality and assigning data gradings to each of the data inputs of the water audit.

Using the AWWA Free Water Audit Software to Compile the Standard Water Audit

The Audit Software allows the user to easily compile the standard AWWA water audit detailed in this manual. It is standard spreadsheet software that includes 12 worksheets. Three primary worksheets of the Audit Software are shown in Figures 3-4 to 3-6, including the Instructions worksheet, the Reporting Worksheet, and the System Attributes and Performance Indicators worksheet, respectively. Data is input on only the first two of these worksheets. Figures 3-4 to 3-6 include input data and calculated performance indicators for the fictitious County Water Company (CWC), which is the primary water utility example referenced throughout this manual.

Water utilities may desire to create their own spreadsheets or other software to compile the standard water audit, particularly if they would like to include greater detail, such as breaking down the loss components into subcomponents. This could also have advantages since certain subcomponents might be valued at different rates (e.g., residential water rates vs. commercial/industrial water rates for customer metering inaccuracies). However, the Audit Software is easy and straightforward to use, so it is the recommended medium for most water utilities.

The means to compile the water audit is explained in this chapter and referenced in other chapters using CWC data. The Audit Software also includes worksheets (not shown as figures in this chapter) with water audit data of two water utilities: the City of Asheville, N.C., USA (in units of million gallons) and the City of Calgary, Alta., Canada (in metric units).

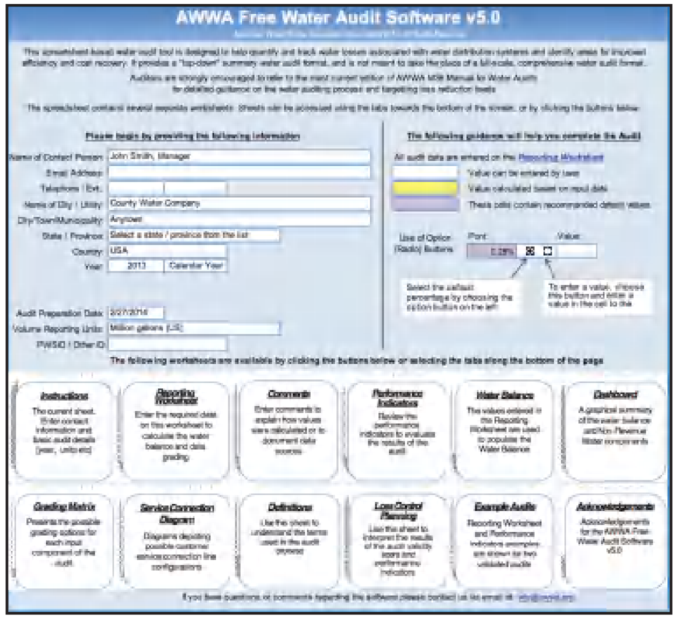


Figure 3-4 AWWA Free Water Audit Software—Instructions Worksheet completed for County Water Company

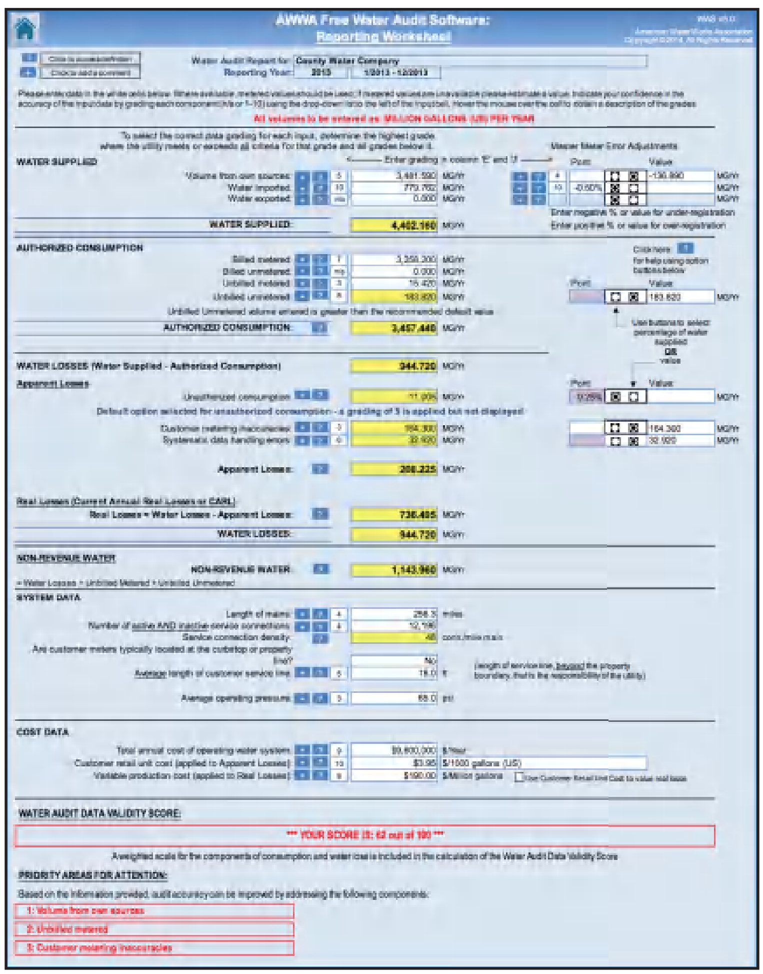


Figure 3-5 AWWA Free Water Audit Software—Reporting Worksheet completed for County Water Company

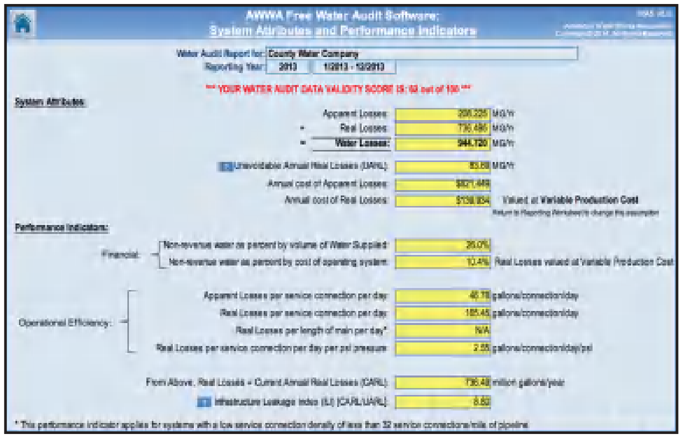


Figure 3-6 AWWA Free Water Audit Software—System Attributes and Performance Indicators Worksheet completed for County Water Company

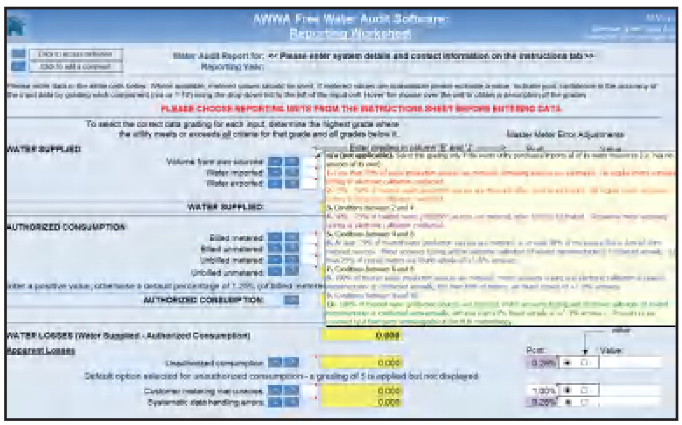


Figure 3-7 AWWA Free Water Audit Software—Reporting Worksheet showing data grading criteria in a hover box for Volume From Own Sources component

Data inputs to the AWWA Free Water Audit Software. As shown in Figure 3-5, the auditor is prompted to enter the primary water audit data into the Reporting Worksheet of the Audit Software. These inputs fall into three categories: volume inputs, system data, and data gradings. *Volume inputs* include the quantities of water supplied, the various components of authorized consumption, the components of apparent losses, and error adjustments for various components. These are the inputs used to create the water balance and they are the primary inputs to the water audit. The *system data inputs* describe the water supply operation and are used to calculate the performance indicators shown in Figure 3-6. *Data gradings* are a user-selected rating of the validity—or trustworthiness—of the individual volumetric and system data inputs. By attaching a grading to each of the volumetric and system data inputs, a composite Data Validity Score (DVS) is calculated by the Audit Software and serves as a measure of the overall validity of the input data of the water audit. The DVS is given at the bottom of the Reporting Worksheet and is based on the cumulative data grading of the audit components and falls within a range of 1–100. Data gradings are input on the Reporting Worksheet in cells that are adjacent to the particular input that they represent. For guidance in selecting the appropriate gradings relative to utility practices, the auditor can refer to the Grading Matrix worksheet in the

Audit Software. Additionally, the auditor can use the hover box feature in the Reporting Worksheet. This feature is shown in Figure 3-7. The user hovers their computer cursor over the respective grading cell and a box appears showing abbreviated definitions of the gradings for the data input component.

Data validity. The top-down audit is highly useful—particularly for water utilities doing a first-time water audit—because it is quick to assemble using readily available data. The water auditor can promptly complete the water audit and assess the values of the performance indicators for the water utility. The disadvantage of the top-down approach is that, for many first-time auditors, the quality and completeness of available data are often questionable. Although the audit can be completed and the performance indicators calculated quickly, how confident can the water utility manager be in those results if it is believed that much of the data entered into the water audit is of marginal quality? This is the question of data validity.

This guidance manual and the Audit Software provide water utilities with a highly robust and reliable structure for water auditing. However, the quality of the outputs (performance indicators) of the water audit is only as reliable as the quality of the data inputs to the water audit.

No water utility has perfect data, and all data are subject to some degree of error. Data of low validity exists if the quantification method applied is cursory (such as use of rough estimates). However, even data that is quantified in a robust manner can be low validity if the quantification is not kept up to date. For example, the length of water mains in the system is an important data input. This value can be of low validity if poorly organized paper records are used to tally the total. Conversely, deriving this length from a well-maintained GIS will produce a value of high validity. However, if the auditor does not access updated GIS data each year (instead applying the same value year after year), the data will become dated and have less validity; particularly if the water system is adding considerable new piping every year and the length of mains is constantly increasing.

If the water auditing process is instituted as a standard, annual business practice—as it should be—a two-fold goal should exist to both compile the water audit and to incrementally use bottom-up activities to improve the quality, completeness, and timeliness of the data (which often results directly in operational improvements and improved loss control).

Several methods have been employed to assess the quality of data in water audits. Some consultants use proprietary water audit software that assigns statistical confidence levels to each component of the water audit. A composite degree of error can then be stated for the audit. The AWWA Free Water Audit Software includes a data grading capability, and the calculation of the composite DVS, to assess the validity of the water audit data. Rather than applying statistics, it uses a process-based approach that also provides specific guidance for water utilities on ways to incrementally improve their data—and their operations. The DVS provides the auditor with context for next steps to improve the accuracy of the audit, as well as next steps for water loss control planning, target-setting, and benchmarking.

Regardless of the data validity assessment method used, it is important that water utilities assess both the water audit outputs and the validity of the input data. The higher the level of confidence or validity of the input data in the water audit, the greater will be the level of confidence in the resultant performance indicators and the development of loss reduction strategies.

Assessing the Data Validity Score of the Audit Software. The Audit Software includes guidance for water utilities to interpret the DVS. The Water Loss Control Planning Guide worksheet features the Water Loss Control Planning Guide, which is shown in Figure 3-8. The guide groups ranges of the DVS based on actions that correspond to the level of validity of the water audit. Five ranges of DVS exist across the full range of 1–100, and these are

AWWA Free Water Audit Software: Determining Water Loss Standing

Water Audit Report for: County Water Company
Reporting Year: 2013 1/2013 - 12/2013
Data Validity Score: 62

Water Loss Control Planning Guide

Functional Focus Area	Water Audit Data Validity Level / Score				
	Level I (0-25)	Level II (26-50)	Level III (51-70)	Level IV (71-90)	Level V (91-100)
Audit Data Collection	Launch auditing and loss control team; address production metering deficiencies	Analyze business process for customer metering and billing functions and water supply operations. Identify data gaps.	Establish/revise policies and procedures for data collection	Refine data collection practices and establish as routine business process	Annual water audit is a reliable gauge of year-to-year water efficiency standing
Short-term loss control	Research information on leak detection programs. Begin flowcharting analysis of customer billing system	Conduct loss assessment investigations on a sample portion of the system: customer meter testing, leak survey, unauthorized consumption, etc.	Establish ongoing mechanisms for customer meter accuracy testing, active leakage control and infrastructure monitoring	Refine, enhance or expand ongoing programs based upon economic justification	Stay abreast of improvements in metering, meter reading, billing, leakage management and infrastructure rehabilitation
Long-term loss control		Begin to assess long-term needs requiring large expenditure: customer meter replacement, water main replacement program, new customer billing system or Automatic Meter Reading (AMR) system.	Begin to assemble economic business case for long-term needs based upon improved data becoming available through the water audit process.	Conduct detailed planning, budgeting and launch of comprehensive improvements for metering, billing or infrastructure management	Continue incremental improvements in short-term and long-term loss control interventions
Target-setting			Establish long-term apparent and real loss reduction goals (+10 year horizon)	Establish mid-range (5 year horizon) apparent and real loss reduction goals	Evaluate and refine loss control goals on a yearly basis
Benchmarking			Preliminary Comparisons - can begin to rely upon the Infrastructure Leakage Index (ILI) for performance comparisons for real losses (see below table)	Performance Benchmarking - ILI is meaningful in comparing real loss standing	Identify Best Practices/ Best in class - the ILI is very reliable as a real loss performance indicator for best in class service

For validity scores of 50 or below, the shaded blocks should not be focus areas until better data validity is achieved.

Figure 3-8 AWWA Free Water Audit Software—Water Loss Control Planning Guide Worksheet completed for County Water Company

labeled as Level I through Level V. Additionally, a list of five functional focus areas are included in the rows of the guide. These focus areas are audit data collection, short-term loss control, long-term loss control, target-setting, and benchmarking.

The structure of the Water Loss Control Planning Guide provides that the higher-level functional focus areas (long-term loss control, target-setting, and benchmarking) should only be conducted once the water audit data has achieved a higher level of validity, of levels III and higher. Note that these activities are not recommended to be pursued by water utilities whose DVS places them in Levels I and II. At these low levels of data validity, the water utility should concentrate heavily on improved data generation and collection, and not risk decision making on higher functional focus areas when the integrity of the data exists at a relatively crude level. The Water Loss Control Planning Guide allows water utilities to reliably focus their attention on the needs that are most pertinent to their current water auditing and operational standing regarding water losses and loss control operations.

The auditor can use the guide to locate the level in which the DVS falls, and then refer to the corresponding guidance for each of the rows in the functional focus areas. The Audit Software highlights the text in the level of the DVS calculated for the individual water audit. Figure 3-8 highlights Level III for the results from CWC since its DVS of 66 falls within the Level III range of 51–70.

Within Level III, the CWC auditor can read down the column for the five functional focus areas to obtain guidance on the most appropriate means to launch or refine specific loss control efforts. Since Level III is in the mid-range of data validity, CWC can assess that its overall water audit data exists with reasonable validity, but efforts should continue to improve its data to a higher level of confidence. Thus, the guidance provided for Level III is to continue to emphasize improving its data validity, further short-term loss control efforts, but only to begin assessing long-term loss control planning, target-setting, and benchmarking with other water utilities.

As water auditing becomes standard practice in the North American drinking water industry and regulatory agencies, the greater will be the need to reliably and transparently state the degree of error existing in the water audit. This will be necessary to make fair comparisons among water utilities. The best course of action is for water utilities to compile regular annual water audits and consistently improve their data via the bottom-up approaches discussed in this chapter and detailed in chapters 5 and 7. For most water utilities, it will take several years of top-down and bottom-up water auditing as a standard business practice before reliable performance benchmarking against other water utilities can or should take place. For this reason, the water utility's main focus should be, initially, to strive for sufficient data validity to establish reliable performance indicators, then benchmark performance against itself for several years, and finally, begin to look at long-term loss control planning and benchmarking with similar utilities.

In addition to the Audit Software, AWWA's Water Loss Control Committee created and maintains a companion spreadsheet tool—the Water Audit Compiler—which is used to quickly assemble and analyze data from multiple water audits. Data from water audits from many utilities can be easily transferred into this spreadsheet, or the water audit data from a single water utility for a multiyear period can be assembled and trends identified. A further description of this tool, as well as sample data, is given in appendix D.

Starting the water audit using the AWWA Free Water Audit Software. On the instructions page, the name of the person compiling the audit (auditor) should be listed, as well as the reference time period that the audit covers, along with the other required information. This is also the page in which the Volume Reporting Units are selected. Instructions on the use of the Audit Software are provided on this worksheet, and links to all of the worksheets in the Audit Software are given here.

All remaining data input occurs on the Reporting Worksheet, including volumes of Water Supplied, Authorized Consumption, Water Losses, System Data, and Cost Data. The auditor also selects an appropriate data grading for the data inputs on the Reporting Worksheet. Once data are entered, performance indicators are calculated and displayed on the System Attributes and Performance Indicators Worksheet. All of these steps are described in detail in the sections (tasks) that follow, and the reader can also reference the Audit Software while reviewing these steps.

Task 1—Quantify the Volume of Water Supplied to the Distribution System

Proceed to the section of the Reporting Worksheet labeled Water Supplied, as shown in Figure 3-5. The Water Supplied volume is calculated automatically by the Audit Software after the individual inputs of Volume From Own Sources, Water Imported, and Water Exported—and their respective Master Meter Error Adjustments—are quantified and input by the auditor. This task demonstrates how much water enters the treated retail water distribution system and where it originates.

Step 1-1. Compile the volume of water from own sources. All water sources should be identified that are owned or managed by the water utility to supply water for treatment and the water that goes into the distribution system. Such sources can include wells, rivers, streams, lakes, reservoirs, or aqueduct turnouts (withdrawal point from an aqueduct). Most water audits (including this example for CWC) are performed on the potable, retail water distribution system (see Figure 3-3b). In this case, the *source* is often the location where treated water enters the distribution system. The finished water supplied from a water treatment plant is a primary example. This also represents the point where the water increases in value by virtue of being treated to meet water quality standards and pressurized for delivery. Ideally, production flowmeters will be located on the effluent piping leaving the water treatment plant. However, this is not always the case, as sometimes flowmeters are located on pipelines conveying untreated (raw) water to the water treatment facility. With flowmeters at the raw water source, an additional adjustment may be needed to account for water used in the water treatment process, lost to leakage, and meter error in the untreated water transmission piping.

The Volume From Own Sources quantity should be metered with routine meter accuracy testing and calibration conducted so that volumes of water taken from all sources are registered accurately. Information about the flowmeters can be compiled in a table similar to Table 3-3. Data from these meters should also be archived in an electronic format that allows for easy retrieval and analysis. Data should be available on a daily, weekly, or monthly basis to compile into an annual volume of water supplied from each source. Water production volumes should be assembled in a table similar to Table 3-4.

Accurately measured source or production flows are critical to the efficient operations of water utilities and wise resource management as overseen by regulatory agencies and other stakeholder groups. Therefore, utility managers and regulators should give high priority to the use of accurate metering at all sources, and reliable compilation and balancing of water production and supply data. All water sources should include flowmeters that are technologically current, accurate, reliable, well-maintained, and—ideally—continuously monitored by a SCADA system or similar monitoring system. Detailed guidance is given in appendix A on production meter management and the means to balance flows across the distribution system, leading to an accurate quantity for the annual Water Supplied volume.

Occasionally one or more water sources of a water utility are unmetered or have meters that are not routinely monitored. Because of the critical importance of the Water Supplied volume in the structure of the water audit, it is strongly recommended that new or replacement source meters be installed as soon as possible, particularly if unmetered sources represent more than 20 percent of the utility's total volume entering the distribution system. If metered data is lacking in this manner on 5 percent or less of the supply, the following approaches can be taken.

- *No meters at a water source.* A portable meter should be used or the flow estimated. Portable meters can be insertion or strap-on types and can be installed on source piping just downstream of the treatment plant effluent or other source. A minimum of 24 hours of continuous metering should be obtained. If portable metering is not feasible, one way to infer an estimate is to utilize treated effluent water pumping records. If the water pump performance characteristics are known, a volume estimate can be derived by multiplying the number of hours that the pump was operated during the year by the average pumping rate. If water is taken from a large reservoir, an estimate of the withdrawal can be formulated by accounting for the amount of drawdown of the reservoir level, adjusted by the amount of inflow from streams and rainfall and losses due to evaporation. Such methods give an approximate volume measurement, and unmetered sources should ultimately be designated for metering.
- *Source water meters have not been routinely calibrated and flow verified for accuracy*. An inspection of the source flowmeter installation should be conducted. The type of metering device that exists should be noted (e.g., Venturi flowmeter, magnetic flowmeter, ultrasonic flowmeter, parshall flume, weir, or stream gauge). Basic information about the measuring device should be noted: type, identification number, frequency of reading, type of recording register, unit of measure (and conversion factor, if necessary), multiplier, date of installation, size of pipe or conduit, frequency of testing, and date of last calibration. Using that information, a table similar to Table 3-3 should be constructed.

A record should be obtained on how much water was produced by each source during the period of the audit. Most meters have some type of register or totaling device.

Table 3-3 Source water measuring devices for County Water Company

Characteristics	Water From Own Sources: Source 1 Aqueduct Turnout 41	Water From Own Sources: Source 2 Well Field	Water Imported: Source 3 City Intertie
Type of measuring device	Venturi	Propeller	Venturi
Identification number (may be serial number)	0000278-A	8759	OC-16
Frequency of reading	Daily	Weekly	Daily
Type of recording register	Dial	Dial	Builder type M
Units registers indicate	100,000 gal	Gal	Cubic feet
Multiplier (if any)	1.0	1.0	100.0
Date of installation	1974	1990	1978
Size of flowmeter	24 in.	8 in.	12 in.
Frequency of testing	Annual	Every 2 years	Every 4 months
Date of last calibration	4/1/2014	8/21/2013	1/15/2014

Table 3-4 Total water supply in million gallons for County Water Company (uncorrected)

2013 by Month	Source 1 Turnout 41	Source 2 Well Field	Subtotal Own Sources (unadjusted)	Source 3 City Intertie (water imported)	Total for All Sources 1, 2, and 3 (unadjusted)
January	0	130.34	130.34	104.27	234.61
February	0	195.51	195.51	65.17	260.68
March	130.83	130.34	261.17	0	261.17
April	160.18	260.68	420.86	0	420.86
May	326.53	97.76	424.29	0	424.29
June	368.62	0	368.62	81.46	450.08
July	372.64	0	372.64	84.72	457.36
August	400.89	0	400.89	89.61	490.50
September	360.72	32.59	393.31	32.59	425.90
October	160.18	32.59	192.77	97.76	290.53
November	160.18	0	160.18	126.42	286.60
December	160.18	0	160.18	97.76	257.94
Annual Total	2,600.95	879.81	3,480.76	779.76	4,260.52
Daily Average, mgd					11.67

Registers may be round-reading or direct-reading. Round-reading registers have a series of small dials with pointers, registering cubic feet, or gallons, in tens, hundreds, thousands, and ten thousands. Direct-reading registers have a large sweep hand for testing and a direct-reading dial that shows total units of volume. If the meter has not been routinely read, tested for accuracy, or its secondary instrumentation calibrated, there should be an effort initiated to test and calibrate the meter and institute routine reading of the meter. Currently, many drinking water utilities link source meters with SCADA systems that convey data in real time to centralized computers, where the flow data is totaled and archived for easy retrieval. See appendix A for further guidance.

Tables 3-3 and 3-4 illustrate the example of CWC with two meters on sources that it owns: "Aqueduct Turnout 41" and "Well Field," as well as water imported (purchased) from a neighboring water utility, "City Intertie." These tables illustrate how source meter and flow data can be arranged and adjusted for the water audit period.

Step 1-2. Adjust figures for total supply. Once a volume is established for each source for the year, the measured amounts should be reviewed and corrected for known systematic or random errors that may exist in the metering data. Figures for the total water supply, based on readings from source meters and measuring devices, are raw data. The raw data must be adjusted for several factors, including

- changes in treated water reservoir and storage levels,
- any other adjustments such as losses that occur before water reaches the distribution system, and
- corrections due to data gaps or data corruption.

Step 1-2A. Adjust reservoir and tank storage. If source meters are located upstream of reservoirs and storage tanks, treated water in storage must be accounted for in the water audit. Generally, water flowing out of storage is replaced; as the replacement water flows from the source into storage, it is measured as supply into the system. If the reservoirs have more water at the end of the study period than at the beginning, the increased storage is measured by the source meters but not delivered to consumers. Such increases in storage should be subtracted from the Volume From Own Sources quantity. Conversely, if there is a net reduction in storage, then the decreased amount of stored water should be added to the Volume From Own Sources quantity. Table 3-5 shows how to compute the change in storage volume using this general approach. Although this method suffices as a concise example of the adjustment for reservoir storage, a more accurate quantification of adjustment due to reservoir and tank storage can be obtained by monitoring storage levels—and making adjustments—on a day-to-day basis. An example of this more accurate method to quantify this adjustment is given in appendix A under the "Example of the Mass Balance Technique" subsection.

It should be noted again that *decreases* in storage are *added* to the supply; storage *increases* are *subtracted* from the supply.

For CWC, this is +825,580 gal or +0.83 mil gal, as shown in Table 3-5.

Large, open reservoirs may require volume adjustments as a result of the effects of evaporation (water lost) and rainfall (water gained), and should be considered by the auditor.

Step 1-2B. Other adjustments. Some water suppliers may be subject to other types of contributions or losses. One example would be losses incurred during the treatment process (filter backwashing, etc.) if the source meter is located at the point of entry to a water treatment plant. In another case, there may be an additional source that enters the water system between the source meter and the finished water system. This could result from infiltration into an open channel. Likewise, losses may be introduced through an unlined or open channel. These additions or losses should be documented by the water auditor.

For CWC, no such adjustments exist, so no adjustment is required.

Table 3-5 Changes in reservoir/tank storage for County Water Company

Reservoir/Tank	Total Volume (gal)	Start Volume (gal)	End Volume (gal)	Change in Volume (gal)
Apple Hill	50,000	32,350	36,270	+3,920
Cedar Ridge	300,000	278,100	240,600	–37,500
Monument Road	1,000,000	978,400	318,400	–660,000
Davis	250,000	187,300	55,300	–132,000
Total change in reservoir storage				–825,580

Step 1-2C. Corrections due to data gaps or data corruption. As discussed in appendix A, gaps in flow recordings may occur because of instrument or SCADA equipment failure. Data archives may also become corrupted periodically. The auditor should attempt to reconstruct the data archive with representative values. This type of surveillance and correction is best accomplished by monitoring the data on a daily basis.

For CWC, no such adjustments are listed in this example.

Step 1-2D. Determine the adjusted Volume From Own Sources quantity due to reservoir/tank storage changes, other adjustments, and data gaps. Only reservoir/tank storage changes have a quantity to enter for this category of adjustments. This adjustment is calculated as follows:

> *The value of "other adjustments" and "data gaps" is zero. Thus, the total adjustments made to the raw Volume From Own Sources quantity from Table 3-4 of 3,480.76 mil gal is calculated by adding the annual volume that was removed from reservoir/tank storage of +0.83 mil gal to result in the adjusted Volume From Own Sources quantity of 3,481.59 mil gal entered in the Reporting Worksheet shown in Figure 3-5.*

Step 1-2E. Determine the appropriate Data Grading value for the Volume From Own Sources quantity. Factors affecting the data grading for the Volume From Own Sources quantity include the percentage of treated water sources that are metered, the frequency of meter accuracy testing and electronic calibration, and management of the flow data. In assessing the management of water supply volumes in CWC, the auditor refers to the Grading Matrix worksheet of the Audit Software. CWC is proactive in metering all three of its water sources. As noted in Table 3-3, CWC conducts regular meter accuracy testing on the flowmeters of its own two sources: Aqueduct Turnout 41 and Well Field. However its Well Field meter is only tested for accuracy every two years. To qualify for a Data Grading of 6 or higher, all source flowmeters must be tested for accuracy at least annually. Thus the CWC auditor objectively selects and enters a Data Grading of 5 into the Audit Software. CWC can quite feasibly increase its data validity in subsequent water audits by increasing the frequency of meter accuracy testing of the Well Field flowmeter to an annual basis. Depending on the accuracy of test results, CWC may be able to elevate its Data Grading to 8 or higher, with minimal additional effort.

Step 1-2F. Calculate the Master Meter Error Adjustment for the Volume From Own Sources quantity. Throughout the water supply industry, a wide variety of flow measuring devices exist, some of which are more suited to untreated or raw water supply and others better suited for the sediment-free potable drinking water. Although most water utility source flows are measured by meters, some are measured by other devices, such as parshall flumes or weirs, particularly if the flow is untreated water being supplied to a water treatment facility. Water supply data (like those used in Table 3-4) are based on readings of these measuring devices that exist with the utility's water supply system. No meter or flow measuring device is 100 percent accurate, and some degree of error always exists. An assessment of the likely degree of error in the measuring devices should be undertaken and included in the water audit as a Master Meter Error Adjustment (MMEA). **An appreciable, nonzero quantity of MMEA must be included in the water audit. If not, the Water Supplied volume will be misrepresented and this distortion will carry throughout the entire water audit, making the quantities of apparent and real losses less certain.** The MMEA should be at least 0.25 percent of the Water Supplied volume. This represents accuracy of 99.75 percent, and most flowmeters in use are less accurate than this level.

To determine the accuracy of the production flowmeters, the results of meter tests should be compared to applicable AWWA standards and guidance manuals. If meter error exceeds the standard for its category, the meter and its related instrumentation should be repaired, recalibrated, or replaced to function within standard limits. If the meter has not been tested for accuracy within the past 12 months, the meter should be tested as soon as possible. See appendix A for detailed discussion of production flowmeter verification practices.

Possible causes of production flowmeter error. Normal wear is not the only cause of inaccurate meter readings. Inspect the flowmeter in its field installation to determine if the flowmeter is the right type and size for the application and that it is installed correctly. See AWWA Manual M33, *Flowmeters in Water Supply* (AWWA 2006), and appendix A for guidance on typical source meter types and applications. The meter should be installed according to manufacturers' recommendations. As feasible, the flowmeter can be removed from service and inspected to see if hard-water encrustation is interfering with the measurement.

Also, it should be verified that the proper registers were selected and installed correctly. Finally, the register should be read to see that the signal from the meter is properly transmitting to the SCADA system. An employee familiar with metering instrumentation should perform the calibration of the instrument and should make a special reading of the source meter, or an employee should accompany the meter reader to verify sample readings. It should be verified that the meter is read and recorded correctly and that the correct conversion factor is used.

Checking Venturi meters. Venturi meters are one of the most common metering devices in use as production flowmeters in the drinking water industry. These meters should only be used for sediment-free water and should periodically be checked for blockages in the throats of the meters or in the sensing lines. The primary device should be regularly tested by comparing it with a measurement taken from a portable insertion-type or strap-on-type meter at an appropriate location downstream on the supply pipeline. Testing the meter with an insertion meter shows whether the installation is adequate for nonturbulent flows. The meter's primary device should be tested at different flow ranges. If pressure deflection for appropriate flows is adjusted without checking the Venturi itself, the meter may still record flows, but it will do so erroneously.

Testing flowmeters for accuracy. Water utilities often conduct flowmeter accuracy testing as well as calibration of related instrumentation such as differential pressure cells connected to Venturi meters. Unfortunately, instrument calibration does not confirm the flow measuring accuracy of the primary metering element. Many utilities conduct regular calibration but do not conduct flowmeter accuracy testing. Regular flowmeter accuracy testing is necessary for water utilities to ascertain the degree of error in the flowmeter and to warrant a high Data Grading in the Audit Software. There are five general ways that production flowmeters may be tested for accuracy, which are listed below in order of effectiveness, with the most effective first:

Table 3-6 Volume of water from own sources in million gallons for County Water Company (adjusted for meter error)

Source	Yearly Total: Uncorrected Metered Volume*	Meter Inaccuracy (%)	Meter Error Calculation: Uncorrected Meter Volume/ Meter Error† — Uncorrected Meter Volume	Meter Error‡	Adjusted Metered Volume§
1. Turnout 41	2,600.95	–3	2,600.95 – (2,600.95/0.97)	–80.44	2, 681.39
2. Well field	879.81	–6	879.81 – (879.81/0.94)	–56.45	936.26
				–136.89	

* Based on Table 3-4.

† A percentage, written as a decimal (95 percent = 0.95).

‡ Negative (–) meter error represents under-registration. Positive (+) meter error represents over-registration.

§ The total corrected meter volume for sources 1 and 2 is 3,617.65 mil gal; note that this is 136.89 mil gal greater than the total supply given for these sources in Table 3-4. This is a way to double-check the arithmetic.

1. Test the meters in place.
2. Conduct a reservoir drop test, if feasible.
3. Compare meter readings with readings of a calibrated meter installed in series with the original meter.
4. Record meter readings for a given flow over a specified time period. Remove the meter and replace it with a calibrated meter. Record readings from the calibrated meter using the same flow rate for the same duration; compare the readings.
5. Test the meter at a meter testing facility.

These methods are discussed in detail in appendix A, and it is recommended that the reader carefully review this information to determine the most appropriate testing options for the flowmeters. Flowmeter accuracy testing may be conducted by trained utility personnel, specialized consultants, meter manufacturers, and meter testing laboratories for meters that can be removed and shipped to the test facility.

The monthly and annual supply data shown in Table 3-4 should be reviewed and the MMEA for the Volume From Own Sources quantified. The MMEA volume can be taken as the difference of the uncorrected metered volume minus the corrected meter volume. The calculation to determine the corrected metered volume is given in Eq. 3-1. The uncorrected metered volume should be divided by the measured accuracy of the meter (a percentage expressed as a decimal) and subtracted from the uncorrected metered volume as follows:

$$\text{uncorrected metered volume} - \frac{\text{uncorrected metered volume}}{\text{percent accuracy}} = \text{MMEA volume} \tag{3-1}$$

Table 3-6 shows how to adjust the supply totals from Table 3-4 to yield the adjusted measurements.

Enter the net Master Meter Error Adjustment for Volume From Own Sources in the Audit Software Reporting Worksheet under the heading "Value," as shown in Figure 3-5. For CWC, this is a quantity of –136.89 mil gal, which represents under-registration of the meter. The auditor has the option of entering a quantity in million gallons/year (as was done in this example) or entering an error percentage if a single master meter error percentage is known to the auditor.

Step 1-2G. Determine the appropriate Data Grading value for the Master Meter Error Adjustment of the Volume From Own Sources quantity. Factors to consider in assigning a Data Grading value for this input include frequency and type of meter recording, and methodology and type of error checking of the data. In assessing the management of production flowmeter data in CWC, the auditor refers to the Grading Matrix worksheet of the Audit Software and finds that the following criteria for a Data Grading of 4 is most representative of its operation. The criterion reads "production meter data is logged automatically in electronic format and reviewed at least on a monthly basis with necessary corrections implemented. Volume From Own Sources tabulations include estimate of daily changes in tanks/storage facilities. Meter data is adjusted when gross data errors occur or occasional meter testing deems this necessary." As noted in Table 3-3, CWC gathers production meter data from Well Field on a weekly basis. To justify a Data Grading of 6 or higher, CWC should begin to collect data from Well Field on an hourly basis. This will require that CWC link the Well Field flowmeter site within its SCADA system, a relatively low-cost improvement.

Step 1-3. Compile the volume of water imported from outside sources or purchased from other water utilities. Tables 3-3 and 3-4 include Source 3, which is an interconnection flowmeter on the City Intertie. This meter registers water purchased by CWC from a neighboring water utility. Interconnections between water utilities are considered custody transfers of water, and the pipelines supplying these flows typically include flowmeters that are carefully maintained and monitored because the metered data provides the basis for billing large water volumes. Both the water utility supplying the water and the system purchasing the water have a strong motivation to keep this bulk measurement accurate because significant costs are at stake for each water utility. For this reason, it is common practice that custody transfer flowmeters are tested for accuracy and calibrated on an annual, or more frequent, interval. As with the data from Volume From Own Sources, the data derived from "import" meters should be carefully managed and adjusted accordingly during the water audit, based on the validation methods similar to those noted in Step 1-2 and described in detail in appendix A.

Enter the Water Imported volume on the Reporting Worksheet shown in Figure 3-5. From Table 3-4, obtain the uncorrected value of 779.76 mil gal for the City Intertie imported volume to CWC and enter it as shown in the Water Imported cell.

Step 1-3A. Determine the appropriate Data Grading value for Water Imported volume. Factors affecting Data Grading for the Water Imported volume include the percentage of imported water sources that are metered, and the frequency and test results of meter accuracy testing and electronic calibration. In assessing the management of production flowmeter data in CWC, the auditor refers to the Grading Matrix worksheet of the Audit Software and finds that the following criteria for a Data Grading of 10 is most representative of its operation. The criterion to assign Data Gradings of 8 and 10 require that all imported water supply pipelines have a permanent flowmeter installed, and this is the case for the City Intertie serving CWC. Also, for gradings of 8 and 10, meter accuracy testing and electronic calibration of related instrumentation must be conducted at least on an annual basis (semi-annually for a 10), with less than 10 percent of test results showing accuracy error over 6 percent for a Data Grading of 8, and less than 10 percent of test results showing an accuracy error over 3 percent for a Data Grading of 10. CWC and its imported water supplier coordinate to conduct meter accuracy testing and flowmeter maintenance every four months. Meter accuracy test results are not listed for the City Intertie in Table 3-3; however, they are known to be a composite of 0.50 percent inaccuracy (99.5 percent accurate) for calendar year 2013. This superior level of testing, maintenance, and accuracy results warrants a Data Grading of 10, which is selected by the water auditor as shown in Figure 3-5.

Step 1-3B. Calculate the Master Meter Error Adjustment for the Water Imported volume. Table 3-3 shows that flows from the City Intertie are measured via a 12-in. Venturi flowmeter that is tested for accuracy every four months. This Venturi installation is well-maintained by the water utility that supplies the water to CWC. Calibration of the instrumentation is also conducted every four months, and the Venturi sensing lines are also tested and cleared as needed at this frequent interval. These actions have resulted in superior meter accuracy test results of a composite 0.50 percent inaccuracy (accuracy of 99.5 percent) for the City Intertie flowmeter.

The Master Meter Error Adjustment for Water Imported volume is entered into the water audit as shown in Table 3-5 under the MMEA "Pcnt" cell for Water Imported. The average inaccuracy of one half of 1 percent, or 0.5 percent, is entered. This inaccuracy value, which translates to –3.92 mil gal, is calculated, but not displayed, by the Audit Software. For all of the MMEA components in the Audit Software, auditors can choose to enter the inaccuracy into the water audit as a volume or percentage. In this case, the auditor for CWC entered the inaccuracy percentage of 0.50 percent.

Step 1-3C. Determine the appropriate Data Grading value for the Master Meter Error Adjustment of the Water Imported volume. Similar to the MMEA for the Volume From Own Sources, factors to consider in assigning a Data Grading value for this input include frequency and type of meter recording, and methodology and type of error checking of the data. In assessing the management of the imported water production flowmeter data in CWC, the auditor refers to the Grading Matrix worksheet of the Audit Software and finds that the following criteria for a Data Grading of 10 is most representative of its operation. CWC and its importer water utility maintain a very high level of rigor in the management, testing, and data archival of the water imported supply, and the highest Data Grading of 10 is warranted for the MMEA volume.

Step 1-4. Compile the Water Exported volume to outside water utilities or jurisdictions. The Water Exported volume is water sold to wholesale customers who are typically charged a wholesale rate that is different than rates charged to the retail customers existing within the service area. Many state regulatory agencies require that the Water Exported volume be reported to them as a quantity separate and distinct from the retail customer billed consumption. For these and other reasons, the Water Exported volume is always quantified separately from Billed Authorized Consumption in the standard water audit. **Be certain not to "double-count" this quantity by including it in both the Water Exported box and the Billed Metered Authorized Consumption box of the water audit Reporting Worksheet. This volume should be included only in the Water Exported box.** The Water Exported volume should be monitored and adjusted with the same scrutiny given to imported water, because the same revenue implications exist. As with the Water Imported volume, a separate entry for MMEA for the Water Exported volume is included on the worksheet in Figure 3-5.

Enter the volume of Water Exported in the appropriate cell in the worksheet shown in Figure 3-5. In this example, CWC exports no water to neighboring water utilities, so no value is entered in this cell.

Step 1-4A. Determine the appropriate Data Grading value for the Water Exported volume. Similar to the Data Grading for the Water Imported volume, the auditor should consider the extent of metering of the exported supply pipeline and meter accuracy test frequency and results. Since CWC does not export any water, the auditor selects the "n/a" (not applicable) option for the Data Grading cell of the Water Exported volume.

Step 1-4B. Determine the Master Meter Error Adjustment of the Water Exported volume. Similar to the MMEA for the Imported Water volume, the auditor should consider the extent of metering of the exported supply pipeline and meter accuracy test frequency and results. The test results should provide data for the auditor to quantify the Exported Water volume for the audit year. Because CWC does not export any water, the CWC auditor does not enter any value for the Exported Water MMEA shown in Figure 3-5.

Step 1-4C. Determine the appropriate Data Grading value for the Master Meter Error Adjustment of the Water Exported volume. Similar to the Data Gradings for the MMEA for the Water Imported volume, the auditor should consider the frequency and type of meter data recording, and methodology and type of error checking of the data in assigning the Data Grading value for the MMEA for the Water Exported volume. Since CWC does not export any water, the auditor selects the "n/a" option for the Data Grading cell of the Water Exported volume MMEA component.

Step 1-5. Calculate the Water Supplied volume into the distribution system. The Water Supplied volume is automatically calculated by the Audit Software after all of the inputs for Volume From Own Sources, Water Imported, and Water Exported are entered into the water audit.

The Water Supplied volume to the distribution system is calculated as the sum of Volume From Own Sources, plus Water Imported, minus Water Exported, and includes the Master Meter Error Adjustments of these three components. The Water Supplied volume for CWC is calculated to be 4,402.16 mil gal for the water audit period of calendar year 2013.

Task 2—Quantify Authorized Consumption

Authorized consumption is any water delivered for consumptive purposes that are authorized or approved by the water utility, thereby providing a benefit to the community. Steps 2-1 through 2-4 describe how to quantify authorized consumption. Steps 2-1 and 2-2 deal with *billed* authorized consumption while Step 2-3 details *unbilled* authorized consumption. Step 2-4 sums all authorized consumption.

Billed authorized consumption represents the collective amounts of water delivered to individual customers that have accounts in a customer billing system. Billed authorized consumption is the basis for revenue generation for the water utility. Billed accounts are customer properties served by permanent customer service connection piping. Most of the water supplied to the distribution system should be attributed to this type of consumption. In North America, most water utilities require customer meters on service connections and bill based on metered consumption on a monthly, bimonthly, or quarterly basis. Metered water can be categorized as residential, industrial, commercial, agricultural, governmental, and other uses. Some water utilities do not require meters for a portion or all of their customers, instead charging a flat billing rate per consumption period, or a charge based on property or other characteristics. Therefore, billed authorized consumption may be metered or unmetered. AWWA recommends that all customers with permanent service connection piping be metered with billing based on measured consumption.

Some utilities also have temporary meters for construction and other uses that should be added to billed authorized consumption totals. These meters are sometimes attached to fire hydrants or allowed to travel with contractors or other service providers to capture water consumption from hydrants. It is most helpful to obtain readings from these meters at the same intervals as other fixed meters, and readings at the beginning and the end of the audit period will be required in any event.

Unbilled authorized consumption describes water taken irregularly in a variety of manners from non-account connections that typically do not supply permanent structures. Withdrawing water from fire hydrants is the most common example of such non-account consumption. Water utilities often allow water to be taken from fire hydrants for fire fighting (their primary purpose), flushing, testing, street cleaning, construction, and other purposes. These uses should include backflow prevention protection, and should be metered to the extent possible, with usage policies in force to protect water quality and public safety. Water utilities often utilize water from the distribution system at their own plants and facilities in uses that include backwash water to clean treatment plant filters, internal building use, and sampling. Sometimes unbilled water supplied to government properties is also included in this category, although it is recommended that all water continuously supplied to permanent structures be metered and tracked in a billed account in the customer billing system. In this way, water consumption is monitored even though the property may be issued a "no charge" bill.

Remember: To be accurate, the water audit period must be consistent across all water audit components. Be sure to use the same 12-month study period and the same units of measure as was used to quantify the Water Supplied volume when evaluating authorized consumption.

Step 2-1. Compile the volume of Billed Metered Consumption. Modern metering, automatic meter reading (AMR), advanced metering infrastructure (AMI), and customer billing management technologies offer outstanding capabilities for water utilities to gather and utilize accurate customer consumption and billing data. It is strongly recommended that water utilities measure individual customer consumption via water meters and use computerized customer billing systems to store customer account data. AMR and AMI systems are being implemented by a growing number of water suppliers because of their cost-effectiveness in gathering metered consumption data and abilities to provide enhanced customer service. For water utilities that utilize these technologies, consumption data is typically accessed via a variety of reports from the customer billing system. Examples of typical reports are shown in Tables 3-7 and 3-8, where consumption is summarized by meter size and customer consumption category, respectively.

Chapters 4 and 5 discuss the sometimes unintended impacts to the integrity of consumption data caused by customer billing system operations. The auditor should develop a sound understanding of the workings of the customer billing system to ascertain the true amount of customer consumption and identify any billing system functions that unduly reduce the actual volume of customer consumption.

Step 2-1A. Maintain customer accounts data. If computerized billing records or reports do not exist, the water auditor must assemble customer account information from available records. Start by identifying all customer users with permanent structures who should have meters. Accounts should be identified by several descriptors such as account number, property street address, meter size, meter serial number, connection size, assessor's parcel number, and the name and address of the property owner as well as any tenants. To track customer consumption patterns and water conservation impacts, it is important to list the consumption category for each account: residential, industrial, commercial, agricultural, governmental, and so on.

Step 2-1B. Maintain customer meter and AMR/AMI data. All active accounts should include the meter identification number, meter size, and meter type. If an AMR or AMI system exists, the AMR device number and meter reading route number should also be included in the customer billing system, along with any other pertinent information. If the AMR or AMI system is compatible, readings should be collected from connected meters at times that coincide with the beginning and end of the water audit.

Step 2-1C. Compile metered consumption volumes for the water audit period. First, assemble the total (uncorrected) water consumption volumes for all accounts and

Table 3-7 Number of customer accounts and metered consumption by meter size for County Water Company: Jan. 1–Dec. 31, 2013

Meter Size (in.)	Number of Accounts	Percent of Total Accounts	Percent of Metered Consumption
⅝	11,480	94.10	71.2
¾	10	0.08	0.1
1	338	2.80	2.8
1½	124	1.00	2.8
2	216	1.80	11.7
3	15	0.12	6.6
4	7	0.05	2.2
6	6	0.05	2.6
Total	12,196	100.00	100.0

connections for each size of meter by month (or other billing period) and for the entire study period, as shown in Table 3-8. The same unit of measure for supply should be used—this may require performing a conversion, for example, from cubic feet to million gallons.

Reference the total value for all billed metered consumption shown in Table 3-8. This is 3,258.0 mil gal and is entered into the Billed Metered Consumption cell on the Reporting Worksheet shown in Figure 3-5.

Step 2-1D. Adjust for lag time in meter readings. Corrections must be made to metered use data when the production meter reading dates and the customer meter reading dates do not coincide with the beginning and ending dates of the water audit period. AMI systems eliminate this issue because customer meter consumption data can be compiled on a daily basis. If the water auditor can employ billed consumption data derived from an AMI system, then the data can be synchronized with the production meter data and the auditor can proceed directly to Step 2-2.

Adjusting for one-meter routes. For this example, a utility studies one calendar year, January 1 through December 31. Source meters are read on the first day of each month and customers' meters are read on the 10th day of each month. The goal is to calculate the amount of water supplied and consumed for the calendar year:

- *Source meters.* No lag time correction is made for source meters, because their reading usually occurs on the days that the water audit period begins and ends. If the last reading (December 31) was a day late (January 1), then the water supplied for January 1 should be subtracted from the total water supply reading.
- *Customer meters.* For utilities that do not use an AMI system, customer meter readings usually do not coincide neatly with the study period; thus a correction must be made. The best way to account for changes in the number of customers and in consumption patterns is to prorate water consumption for the first and last billing periods within the water audit period. The first billing period has only 10 days that actually occur in the water audit period, yet the billing information represents 31 days of consumption. If consumption for December 11 through January 10 is 33.204 mil gal, the amount applicable to the water audit period is

Table 3-8 Total metered water consumption by category for County Water Company (uncorrected)

2013 by Month	Residential (mil gal)	Industrial (mil gal)	Commercial (mil gal)	Metered Agriculture (mil gal)	Total for All Meters (mil gal)
January	146.6	35.8	8.1	0	190.5
February	162.9	35.8	8.1	0	206.8
March	162.9	35.8	8.1	0	206.8
April	179.2	39.1	8.1	24.4	250.8
May	211.8	42.4	8.1	57.0	319.3
June	228.1	48.9	8.1	74.9	360.0
July	260.3	48.9	8.1	57.0	374.3
August	266.5	48.9	8.1	74.9	398.4
September	228.1	45.6	8.1	65.2	347.0
October	162.9	35.8	8.1	0	206.8
November	162.9	35.8	8.1	0	206.8
December	146.6	35.8	8.1	0	190.5
Annual Total	2,318.8	488.6	97.2	353.4	3,258.0
Daily Average, mgd	6.35	1.34	0.27	0.97	8.93

$$33.204 \text{ mil gal} \times \frac{10 \text{ days}}{31 \text{ days}} = 10.711 \text{ mil gal} \quad (3\text{-}2)$$

Thus, 10.711 mil gal of the consumption read on January 10 applies to the water audit period.

At the end of the water audit period, there are 21 days not included in the billing data collected on December 10. Consumption for the last 21 days in December is obtained from the following month's billing (January of the next year). If consumption recorded on January 10 of the next year was 36.66 mil gal, the amount applicable to the water audit period is

$$36.66 \text{ mil gal} \times \frac{21 \text{ days}}{31 \text{ days}} = 24.83 \text{ mil gal} \quad (3\text{-}3)$$

Thus, 24.83 mil gal is added to the consumption read on December 10 of the water audit year.

Adjusting for many-meter routes. The preceding discussion describes the basic method for correcting lag time in meter reading when all customers' meters are read on the same day. That seldom happens, however, in utilities that do not employ an AMI system. Usually meters are assigned to different routes and read on different days. Therefore, a meter lag correction should be used for each meter reading route, particularly if each customer's meter is read on the same day each month. Figure 3-9 gives an example of this situation.

A meter lag correction can involve several steps. In the example shown in Figure 3-9, CWC has three meter routes, each with its own reading date. The water audit period is one calendar year (2013), and the consumption is prorated for each meter route or book.

Meters are read monthly: route A on the 1st of the month, route B on the 10th, and route C on the 20th.

The uncorrected total metered use (from Step 2-1C, Table 3-8) is based on bills issued during the water audit period. However, because of the monthly billing schedule, these bills do not include all water consumed during the year. Some water shown as used in the first billing period (issued in February 2013) actually occurred in December 2012. The last set of bills, issued in November and December 2013, do not include water consumed in December 2013. Two corrections need to be made. First, water consumed in the month preceding the water audit period (December 2012) must be subtracted from consumption figures. Second, water consumed in the final month of the water audit period must be added. The more frequent (monthly as opposed to quarterly) the readings, the smaller the adjustment and the less likely the estimated use will be prone to error.

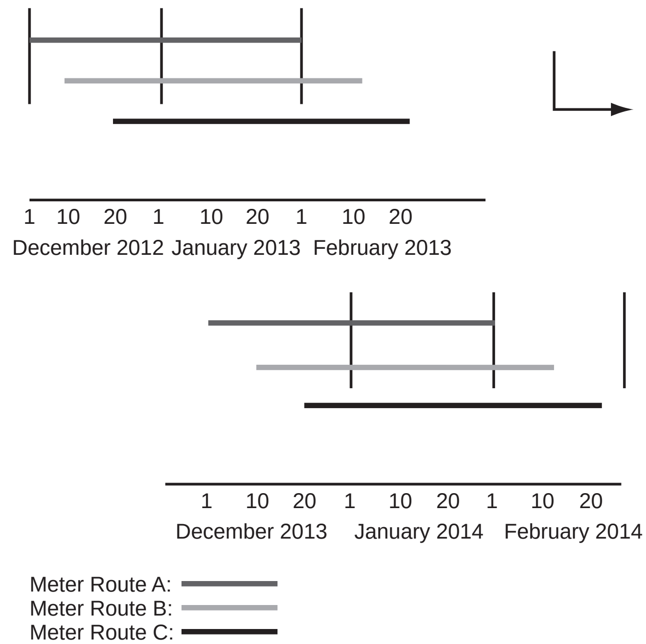
Figure 3-9 shows how to adjust consumption figures for meter lag time. Many utilities combine accounting and billing procedures into a computerized format to make this procedure easier and quicker.

If the proration of water consumption figures to adjust for lag time in meter reading is performed, add the net adjustment of +0.20 mil gal to the Billed Metered Consumption value previously calculated and enter this number into the Reporting Worksheet shown in Figure 3-5. This quantity is 3,258.20 mil gal for CWC.

Step 2-1E. Determine the appropriate Data Grading value for the Billed Metered Consumption. To select a representative Data Grading value for Billed Metered Consumption, the auditor should consider the percentage of customers with volume-based billing from meter readings, meter reading success rate, the type and extent of customer meter testing and replacement, and auditing and type of billing system that is employed in the utility. CWC meters its entire customer population and reads meters manually on a monthly basis. It conducts periodic testing of customer meters, but the testing is limited to a relatively small number of meters and the results of the testing do not drive a meter replacement strategy. Referring to the Grading Matrix worksheet of the Audit Software, the auditor selects a Data Grading of 7 because the practices employed by CWC fall between the criteria of a 6 and an 8.

Step 2-2. Compile the volume of Billed Unmetered Consumption. The majority of North American drinking water utilities have policies to universally meter their customers and bill based on measured consumption. This is standard practice recommended by AWWA. However, not all utilities meter all of their customers; instead some water utilities bill customers a flat fee per billing period. Others meter a portion of their customer accounts. This latter scenario can occur if

- the utility is in transition to a fully metered customer population;
- larger commercial and industrial accounts are metered whereas smaller accounts are not;
- utility policies dictate that certain accounts, such as municipal properties or fire connections, need not be metered; or
- some of the meters are known to be nonfunctional, highly inaccurate, or readings are unobtainable, in which case estimates of consumption are used in place of measured consumption. This position, however, reflects that—by policy—the water utility requires water meters but has difficulty in keeping all meters functional. Generally, for universally metered systems, this number of nonfunctional metering locations is minimal.



The December through January billing period is 62 days long.

Route	Date Read	Sales	Adjustment
A	2/1/2013	4.0 mil gal	31/62 = 2.0 mil gal
B	2/10/2013	3.3 mil gal	21/62 = 1.1 mil gal
C	2/20/2013	3.6 mil gal	11/62 = 0.6 mil gal

Total adjustment to eliminate 2012 consumption from the water audit period equals –3.7 mil gal. This amount appears on the February billing, but the water was consumed during the previous December.

Route	Date Read	Sales	Adjustment
A	2/1/2014	4.2 mil gal	31/62 = 2.1 mil gal
B	2/10/2014	3.3 mil gal	21/62 = 1.1 mil gal
C	2/20/2014	3.9 mil gal	11/62 = 0.7 mil gal

Total adjustment to add December 2013 sales to the water audit period equals +3.9 mil gal. This amount did not appear on the final bill for the year; it is prorated from the bill on which it appears.

Net adjustment..+0.20 mil gal

Figure 3-9 Detailed meter lag correction

In a system that is completely or largely unmetered, the water auditor must devise an estimate of the water consumed by the customer population. Several ways exist to develop reasonable estimates. For instance, water meters could be installed in a small, representative sample of accounts (50–100) based on consumption category or meter size. Data from these meters could be used to develop average consumption trends that could be inferred for the entire population in each category such as residential, industrial, and so forth. Any estimating process that is developed should be fully documented and based on current conditions. Estimation invariably interjects a degree of error into the measure of customer consumption. For this reason, it is highly recommended that all customers be properly metered, routinely read, and archived, thereby keeping Billed Unmetered Consumption at zero or a minimal quantity.

Include the total estimate of Billed Unmetered Consumption in the Reporting Worksheet shown in Figure 3-5. For CWC, this value is zero since the company meters and regularly reads all accounts, so this cell is left blank.

Step 2-2A. Determine the appropriate Data Grading value for the Billed Unmetered Consumption. To select a representative Data Grading value for Billed Unmetered Consumption, the auditor should consider the status of utility metering policies, percentage of billed accounts that are unmetered, and method for estimating unmetered customers' consumption. CWC meters its entire customer population and reads meters manually on a monthly basis, and the volume entered into the water audit for this component is zero. Hence, no Data Grading value is needed for this component and the auditor should select n/a in the Data Grading dropdown box for this component.

Step 2-3. Compile the volume of Unbilled Consumption. As discussed previously, unbilled authorized consumption describes water taken irregularly in a variety of manners from non-account connections that do not typically supply permanent structures. Water utilities often allow water to be taken from fire hydrants for fire fighting (their primary purpose), flushing, testing, street cleaning, and other public purposes. Rarely is such consumption metered or directly billed, although sometimes revenue is recovered via flat fees paid by fire departments or other users. Unfortunately, many water utilities do not employ clearly written policies that include procedures for safely supplying such unbilled water consumption. Similarly, good accounting often does not exist for the types and volumes of such consumption occurring throughout the year. It is recommended that the auditing process review utility policies and practices and improve them as needed to expand the use of temporary/portable meters where practical, to shift such consumption into "billed authorized consumption." Where this is not possible, the utility should ensure that such water consumption is not unsafe or wasteful and can be accounted for to the extent practical.

It should also be recognized that Unbilled Unmetered Consumption is usually a small portion of the volume of Water Supplied. Based on the findings of numerous water audits worldwide, the auditor may choose to use the default value in the Audit Software for Unbilled Unmetered Consumption. To quickly quantify this category, the default value can be used rather than attempting to quantify numerous minor water uses that are authorized by the utility. Generally, the auditor's time will be better served if dedicated to the quantification and control of real and apparent losses. However, under conditions such as severe drought, publicly visible use of water for flushing or other operations could generate negative public perceptions for the water utility. In such cases, auditing should review all instances of unbilled authorized consumption and ensure that they are efficiently managed.

Step 2-3A. Compile the volume of Unbilled Metered Consumption. Any unbilled consumption that is metered can be quantified by obtaining meter readings at the beginning and end of the consumption period(s) throughout the year of the water audit. If a permanent meter exists and supplies a permanent structure (such as a municipal building or a water treatment plant), it is best if the property is eventually assigned an account in the customer billing system and is read and billed regularly—even if the billing charge is minimal or zero. However, it is important to track this consumption separately from water that is billed. Since its use lacks a price signal, waste can go undetected without further scrutiny. Metered properties should exist in the customer billing system to the greatest extent possible, whether the use is billed or unbilled.

Include the total of all Unbilled Metered Consumption documented on the Reporting Worksheet shown in Figure 3-5. For illustration, the auditor of CWC obtained meter readings on a sporadic basis for known unbilled metered water users and tabulated a total of 15.42 mil gal for Unbilled Metered Consumption for the audit year.

Step 2-3B. Determine the appropriate Data Grading value for the Unbilled Metered Consumption. To select a representative Data Grading value for Unbilled Metered Consumption, the auditor should consider the status of utility policies and unbilled customer meter reading and maintenance practices. CWC meters its entire customer population and reads billed metered accounts manually on a monthly basis. However, an unknown number of unbilled metered water users exists. CWC has documentation on several of the high-profile water users, such as the water treatment plant, the wastewater treatment plant, and the municipal office building. For these accounts, meter readings were gathered on a quarterly basis throughout the audit year.

Unfortunately, CWC is also aware that an unknown number of other metered water users exists including at maintenance sheds, park and playground facilities, the municipal airport, and police and fire stations. Written policy documents permitting such water-using facilities to go unbilled are sketchy and very dated. Because CWC is aware that it has not accounted for all unbilled metered water consumption in its system, and because its policy is not current and comprehensive, a Data Grading of 3 was selected by the auditor and this was entered into the Data Grading dropdown box for this component. CWC has a good opportunity to improve its management of unbilled metered water users. Initially, it could identify the likely top ten water-using facilities among this group and establish accounts for them in the customer billing system. These accounts should be included for regular meter reading and billing, even though CWC policy may require a charge of zero. Regular meter reading and billing will place these accounts into the Billed Metered category and their water use can be tracked. This will give CWC information to detect high water use that might stem from internal plumbing leaks. For the smaller-volume water users in the Unbilled Metered status, CWC can gradually conduct inspections to identify more fully this population and begin to obtain regular meter readings. The consumption derived from these readings can be included in the annual water audit, and CWC will warrant a higher Data Grading value for this component.

Step 2-3C. Compile the volume of Unbilled Unmetered Consumption. The most common occurrences of unbilled unmetered consumption include

- fire fighting and training;
- flushing water mains, storm inlets, culverts, and sewers;
- street cleaning;
- landscaping/irrigation in public areas, landscaped highway medians, and similar areas;
- decorative water facilities;
- swimming pools;
- construction sites: water for mixing concrete, dust control, trench setting, others; and
- water consumption at public buildings not included in the customer billing system.

Certain such uses of water, such as fire flow tests conducted by the water utility, are measured by using portable instruments. In such cases, the flow should be averaged over the period of time that the fire hydrant was opened. Volumes of water from such tests should be totaled for the entire water audit period.

Water consumed in water supply operations, such as water quality testing, filling tanks and reservoirs, and loading water mains, would also fall into this category. If drawn from after the finished water meter, process water at treatment plants should be metered and exist in a billed account because water treatment plants are permanent structures.

Often, however, such a use will be unmetered and an estimate of its annual volume should be included in this category of the water audit.

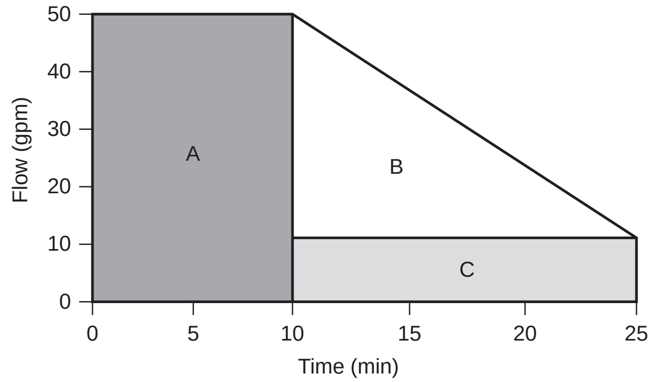
In most water utilities, a variety of unmetered, unbilled authorized consumption exists. In medium to large systems, such occurrences can be numerous, yet their total consumption is still likely to be a small portion of the volume of water supplied to the distribution system. For expediency, and to avoid tedious collection of data on many small uses of water, the auditor may choose to use the default value of 1.25 percent of the Water Supplied volume to quantify this category of consumption.

For reference, the auditor for CWC selected the default value in the Audit Software. In this case, 1.25 percent of the Water Supplied volume, or (4,402.16 mil gal) × (0.0125) = 55.03 mil gal. However, the auditor suspects that the Unbilled Unmetered Consumption is greater than the value that the default percentage gives and therefore decides to perform an analysis of this consumption, as described in the following section.

As in the above case of CWC, if the auditor believes that this consumption is notably greater or less than the default value, he or she can work to obtain detailed estimates of these components. This work can be time-consuming, and the auditor should use good judgment to determine whether the extra effort to analyze many undocumented occurrences of consumption is likely to lead to a consumption quantity notably different from the default value. In many cases, the extra effort to document this consumption is not worthwhile. It is recommended that the default value be applied unless the auditor has documented evidence of Unbilled Unmetered Consumption notably greater or lesser than this amount.

To obtain reasonable estimates of Unbilled Unmetered Consumption, the auditor can apply the most appropriate of the three estimating methods described in the following list. Recognize that these methods are a form of component analysis, the quantification technique that is applied for leakage component analysis in chapter 7 and can be applied to quantify components of apparent loss.

1. *Batch procedure.* When water is transported in a tank truck or container of some sort, the batch procedure should be used. The volume of the tank or other container should be multiplied by the number of times it is filled from the distribution system. This yields the volume of water delivered from the distribution system. Careful record keeping is necessary for accurate estimates.
2. *Discharge procedure.* When water is applied directly from a pipe, as in a sprinkler system, the discharge procedure should be used. The rate of water discharge is multiplied by the total time it flows. This yields the volume of water delivered. The discharge rate may vary and the application period will vary in length and frequency, as shown in Figure 3-10. In such cases, the discharge is calculated as the area of the shapes in the graphic. Again, careful record keeping is necessary for accurate estimates.
3. *Comparison procedure.* For some facilities and areas, such as schools, swimming pools, construction sites, and golf courses, consumption figures may be adapted from similar facilities, provided that they are alike in size, hours of operation, type of use, landscaping, and most other details. Any differences must be accounted for. For example, at a construction site, work habits are important. If the crew at a metered site turns off water between uses while the crew at an unmetered site lets the water run continuously, the consumption figures will have to be adjusted considerably.



The discharge flow was constant for 10 min at 50 gpm, then uniformly reduced to 10 gpm over the next 15 min, and then was shut off.

Volume A = 50 × 10 = 500 gal
Volume B = 0.5 × (50 – 10) × (25 – 10) = 300 gal
Volume C = 10 × (25 – 10) = 150 gal

Total Volume = 950 gal

Figure 3-10 Calculation of water volume from variable-rate discharge

Additional guidance on estimating likely occurrences of Unbilled Unmetered Consumption is given in the following step.

Step 2-3C1. Fire fighting and training. This includes water taken from fire hydrants, fire-sprinkler systems, and other unmetered water drawn for such uses from the water distribution system. It may be used for fire suppression, testing fire equipment, or flushing sprinkler systems that are performed by public safety crews. It also includes water for firefighter training, airport fire-fighting personnel, and other public safety employees and volunteers. This category does not include fire-fighting water withdrawn from ponds, rivers, or any water sources not connected to a piped water distribution system. It also excludes water used in separate, nonpotable fire water distribution systems that are not considered under the water audit.

Usually the water utility must rely on fire department records of hydrant operations during fire events or training operations. The water utility must coordinate with the fire department to establish reliable reporting procedures requiring documentation of water quantities used in fire-related operations. Additional coordination is required of water utilities whose service area includes multiple fire departments.

Again, a cautionary note is offered to the auditor. Water used for fire fighting and training is typically a small component in the annual water audit, and a reasonable estimate of this consumption can be included in the use of the default value described previously under Step 2-3C. If the auditor has strong reason to believe that this consumption is significantly greater or less than that quantified by the default value, work can be conducted to obtain detailed estimates of these components. Establishing procedures for reporting fire volumes can be very time-consuming, and the utility manager must ultimately rely on the efforts of fire department personnel to obtain reliable data. Therefore, the auditor should use good judgment to determine whether the extra effort to collect actual fire-related consumption data is likely to lead to a consumption level markedly different from the default value.

If the auditor believes that fire-fighting water volumes must be tracked in detail, the following methods can be employed. To estimate water volumes consumed in fire-fighting activities, fire department records should be checked for training, flushing, and fire suppression. Many fire departments use more water for training than for fighting fires. Where flowmeters on standby fire systems show water use, the maintenance superintendent of the building may have fire or test records. In some municipalities, fire departments also conduct routine inspections of fire hydrants, usually flushing the hydrant in the process. A measure or estimate of this water consumption should also be gathered.

Many fire departments issue a run report after a unit responds to a call. A survey of all run reports from the water audit period in the water service area should identify the number of fire hydrants open, their duration, and estimated flow rate. A good estimate of the water volume used by the fire department can then be quantified by applying the discharge procedure described previously. Calls to locations where the water used came from water supplies not connected to the distribution system should be eliminated.

Estimates of other fire-fighting uses, such as sprinkler systems (including their testing), require calculations of the flow of the system and the duration of operation. For this calculation, the discharge procedure is used. To acquire the raw data needed for the calculation, meters should be surveyed and inspected at schools, stores, apartments, industrial sites, lumberyards, warehouses, and other similar locations. The more complete the survey, the more accurately the final estimate will reflect water used in testing, and in leaky or incorrectly connected sprinkler systems. However, the auditor should be mindful to ascertain that the time to conduct such a detailed survey is well justified.

In the example of CWC, there are four fire companies located within its water service area. None of them make run reports. However, their logs show a total of 10 structural fires and a five-day wildfire (for which water was airlifted from an open reservoir), plus eight days (48 work hours) of training in which water was used. Estimates of water consumption are 6.5 mil gal for fire fighting and 3.2 mil gal for training. Water used for fighting the wildfire is not included because it was not drawn from the treated water distribution system.

For this subcomponent of Unbilled Unmetered Consumption for CWC for the audit year, add fire fighting and related consumption to determine the total consumption for fire fighting and training. Enter the sum of 9.7 mil gal as item 2-3C1 in Table 3-9.

Step 2-3C2. Flushing water mains, storm inlets, culverts, and sewers. Many water utilities operate flushing programs to maintain good water quality in the distribution system. Water flow rates from these flushing operations should be measured with portable instruments, such as a Pitot blade, or estimated and applied over the period of time that the flushing occurs using the discharge procedure. Quantifying water used in flushing operations not only improves accountability but also helps utilities balance water quality needs with any water resource limitations that may confront the water utility, particularly during drought or shortage conditions. Also, flushing is often used to clean or maintain storm inlets, storm sewers and culverts, or sanitary sewers. Procedures should be employed to quantify and document this water consumption.

CWC's manager estimates that the amount of water used to flush water mains, storm inlets, and sewers is 2.55 mil gal. Enter this amount as item 2-3C2 in Table 3-9.

Step 2-3C3. Street cleaning. Water is often used to clean roadways, walkways, boat ramps, bus stops, parking areas, bike paths, and similar areas. The water may be released directly from fire hydrants for which case logs should be kept indicating estimated flow and cleaning duration that may be used to calculate volumes used in street cleaning. Water may also be sprayed from trucks, sweepers, or other equipment. Knowing the volume of tanks on such equipment and the number of fillings will allow calculation of a reliable

Table 3-9 Sum of individual estimates of unbilled unmetered consumption

Item Number	Item Description	Volume (mil gal)
2-3C1	Fire fighting and training	9.70
2-3C2	Flushing water mains, storm inlets, culverts, and sewers	2.55
2-3C3	Street cleaning	1.75
2-3C4	Landscaping irrigation in large public areas	162.89
2-3C5	Decorative water facilities	1.75
2-3C6	Swimming pools	0.42
2-3C7	Construction sites	0.56
2-3C8	Water quality and other testing	1.20
2-3C9	Water consumption at public buildings not included in the customer billing system	2.15
2-3C10	Other	0.85
	Total unbilled unmetered consumption	183.82

Table 3-10 Estimate of water volumes used by tank trucks for street cleaning

Vehicle	Capacity (gal)	Number of Refills per Day	Number of Days Used per Year	Volume per Vehicle per Year (gal)
A	200	× 5	× 200	= 200,000
B	500	× 10	× 150	= 750,000
C	2,000	× 2	× 200	= 800,000
Total annual consumption				1,750,000

measure of water consumed in such practices via the batch procedure. Table 3-10 shows how to calculate total street cleaning estimates in this manner.

The manager for CWC estimates the amount of water consumed in street cleaning to be 1.75 mil gal. Enter the sum of 1.75 mil gal as item 2-3C3 in Table 3-9.

Step 2-3C4. Landscaping irrigation in public areas. This water is used to irrigate parks, golf courses, cemeteries, playgrounds, community gardens, highway median strips, and similar areas. For landscaped areas watered by tank trucks, the batch procedure should be used for estimating the volume. For unmetered sprinkler systems, the discharge method can be used. Essential factors are (1) the discharge rate at each supply pipe to an irrigated area, and (2) the total amount of time water is supplied to each area. Time- or moisture-controlled irrigation systems make the calculation easier, and some irrigation systems may measure and record the flow and volume over a given time. When determining the amount of time water is applied, the total time the service is discharging should be used, rather than the period for one zone. Note: water reuse systems are being installed in a growing number of communities and often supply irrigation water for large green spaces such as golf courses. The auditor should be mindful to exclude from the audit any water that was supplied via a system other than the potable water distribution system, such as reuse water. Figure 3-11 demonstrates how to estimate the volume used for landscape irrigation.

The auditor for CWC estimates the amount of water consumed in public landscaping irrigation to be 162.89 mil gal. Enter this value as item 2-3C4 in Table 3-9.

Step 2-3C5. Decorative water facilities. This water is used for filling, cleaning, and maintaining water quality in pools, fountains, and other decorative facilities. The major causes of water loss from open-air, standing bodies of water are evaporation, water drained from a pool during maintenance, water used for cleaning, bleed-off water used to maintain chemical balance of the water, and leaks. Because decorative water facilities are typically fixed structures, the best way to account for water supplied to these facilities is to meter the water supply connection piping and gather routine meter readings. This would place these facilities in either the Billed Metered (if an account in the customer billing system is created) or Unbilled Metered Consumption category. Otherwise the following estimation methods can be used.

Evaporation can be appreciative in large, standing bodies of water. In the case of small pools and fountains, no calculation for evaporative loss is necessary. For large outdoor pools and uncovered finished water reservoirs, evaporative losses should be determined. The auditor should determine the pan evaporation rate from weather reporting stations within or near the utility service area and consult an appropriate text on evaporation, conservation, or irrigation to obtain a method for this calculation. If the effects of evaporation are taken into account for a large, open reservoir, measures of appreciable rainfall providing water to the reservoir over the course of the water audit period should also be calculated. An appropriate textbook on hydrology should be consulted to determine this calculation.

Pool drainage. To estimate water loss from pool drainage, the following equation should be used:

$$V \times F = V_w \tag{3-4}$$

Where:

V = volume of pool at the time it is drained
F = frequency of pool draining
V_w = volume of water loss due to drainage

Bleed-off water. The volume of any bleed-off water can also be calculated similarly to the previous equation:

$$Q_b \times T = V_b \tag{3-5}$$

Where:

Q_b = average bleed-off flow rate (volume/time, e.g., gpd)
T = total time that bleed-off is operated during the audit period (e.g., days)
V_b = volume of water loss due to bleed-off

Cleaning. To estimate the water lost in cleaning, maintenance workers should be consulted about pool volumes and the frequency of cleaning and flushing. For an unmetered source, ask how much time is required for maintenance work after the pool is drained. Also, it should be determined whether the hose or refill pipe is left running during that time. Flow rates should be determined for the appropriate outlet, refill pipe, or hose, and the volume used should be calculated. If the source is a hose bib from a metered facility,

Example Estimate of Landscape Watering in a Public Area

A single 2-in. service provides irrigation water to 4½-acre Sunnyslope Park at the rate of 160 gpm. Each of three laterals provides equal amounts of water and is controlled by a common timer.

Lateral A operates from 1:00 a.m. to 3:00 a.m. Lateral B operates from 3:00 a.m. to 5:00 a.m. Lateral C operates from 5:00 a.m. to 7:00 a.m. The system irrigates according to the following schedule:

May and September	Every third day
June	Every second day
July and August	Daily

How much water is applied from May through September? The following shows how this is estimated:

The service supplies 160 gpm or 9,600 gph (160 × 60). It operates 6 hours each day the park is watered. During those 6 hours, 9,600 gph × 6 hr = 57,600 gal of water applied.

The number of watering days must now be calculated:

Month	Days in Month	Frequency of Watering	Number of Days Watered
May	31	Every third day	11
June	30	Every second day	15
July	31	All days	31
August	31	All days	31
September	30	Every third day	11
		Total	99

The total amount of water applied during the five-month period is

57,600 gpd × 99 days = 5,702,400 gal
= 762,353 ft^3
= 5.7 mil gal*

* The final answer must be given in the audit's official unit of measure.

Figure 3-11 Estimating landscape irrigation

no further calculation is needed because the consumption will be included in the billed account data.

Leaks. To estimate leakage, the inlet supply should be closed for 24 hours, and any decline in the water level of the pool should be measured. Knowing the dimensions of the pool, the drop in level should be converted to a volume. The average amount that should be lost to evaporation (if any) is subtracted from the normal water volume. The difference is leakage. Water lost to evaporation, drainage, cleaning, and leaks should be added. The losses by type of facilities (e.g., parks, buildings) should be added within the service area.

The manager for CWC estimates the amount of water consumed in managing decorative water facilities to be 1.75 mil gal. Enter the sum of 1.75 mil gal as item 2-3C5 in Table 3-9.

Step 2-3C6. Swimming pools. Swimming pools require considerable water to maintain volume and water quality, including cleaning filters, as well as maintenance water to clean decks and walkways, and to operate sanitary and drinking water facilities associated with swimming pools. Concessionaires may also be served from a branch supply connection pipe from the pool water supply. Many swimming pools are served via metered supply connections, and this is the recommended practice for pools and related water appurtenances. In such cases, their consumption is already counted as part of Metered Billed Authorized Consumption.

If supply lines to swimming pools are unmetered, the consumption should be estimated from information provided by operations and maintenance staff, carefully noting the volume of the pool and number of fillings. Generally, the batch procedure can be applied. Comparing water consumption with metered pools of similar size and function is also a viable approach. In addition to the recommendation to establish metering on pool supply lines, it is strongly recommended to monitor pool structures, linings, and plumbing for leaks. It is common to hear of public swimming pools being filled continuously throughout the warm weather season with no overflow of the pool as a result of heavy leakage that is left unchecked. Leakage volumes can be estimated in the same manner as described for decorative water facilities.

The manager for CWC estimates the amount of water consumed in swimming pool management to be 0.42 mil gal. Enter this sum as item 2-3C6 in Table 3-9.

Step 2-3C7. Construction sites. Water is often delivered through fire hydrants to tank trucks for road dust control, site preparation, landscaping, temporary domestic use, and materials processing (e.g., mixing concrete). Fire hydrants may also be permitted to supply new building construction sites until such time that permanent water service connections are installed. Meters can be required for such use to obtain the volumes consumed during this work, either mounted on hydrants or on the trucks themselves. In many cases, metered construction water is billed to the contractor so these volumes should be included under *Billed* Metered Consumption.

In the absence of meters, one way to estimate total use is to obtain consumption data from metered construction sites for similar projects. Data might also be obtained from regulatory water agencies. Since unmetered water is more likely to be left running, water use practices at such sites should be compared with the practices at metered sites and compensated for the difference. Bulk water stations are installations similar to gasoline fueling stations, whereby bulk water purchasers can fill their tank trucks at designated sites, generally where they can pay for the water via credit card. These approaches should be considered to assist accountability, efficiency, and positive revenue stream for the water utility (see the “Fire Hydrant Usage Policy” sidebar).

The auditor for CWC estimates the amount of water consumed at construction sites to be 0.56 mil gal. Enter this amount as item 2-3C7 in Table 3-9.

Step 2-3C8. Water quality and other testing. This water is used to test distribution system output to meet public health standards and to test meters and new mains. Operations to disinfect new water mains, or repairs in existing water mains, can use reasonable quantities of water for filling and flushing. Water consumption can be estimated by contacting operations staff to determine testing frequency as well as duration and volumes of water used. Amounts probably vary with each user.

The auditor for CWC estimates the amount of water consumed during water quality and other testing to be 1.2 mil gal. Enter this amount as item 2-3C8 in Table 3-9.

Step 2-3C9. Water consumption at public buildings not included in the customer billing system. It is recommended that water service connections to all permanent structures be metered and included with an account in the water utility customer billing system. Many municipal water utilities have policies *not* to charge their own municipal and

Fire Hydrant Usage Policy: Does the Utility Have Control of Its Fire Hydrants?

An important question for water utility managers: Are your fire hydrants under control?

The primary purposes of fire hydrants are fire fighting and water distribution system testing and maintenance, including flushing water mains. In many water utilities, however, the use of fire hydrants—for both authorized and unauthorized purposes—goes far beyond these basic functions. Unauthorized consumption from fire hydrants, which is classified under Apparent Losses, occurs when hydrants are illegally used to fill tank trucks for landscaping or construction purposes, to wash cars, or for recreational purposes such as for personal cooling in hot weather. Many water utilities have policies that permit water to be drawn from fire hydrants for a variety of community-spirited purposes. This water typically falls under Unbilled Unmetered Consumption in the water audit and includes street cleaning, filling public swimming pools, providing transient supplies (such as nonpotable supply to a traveling circus), watering community gardens, and for use in constructions sites. Some allow hot weather cooling relief from fire hydrants using spray caps. These varied uses of fire hydrants pose potential problems for water utilities and customers, including the following:

- Water taken from fire hydrants is often unmetered. The more hydrants that are opened, the greater the amount of water that must be estimated in the water audit.
- Water taken continuously from fire hydrants should include backflow protection to prevent contaminants from entering the distribution system during a negative pressure event. Often no backflow protection is used.
- Water drawn from a fire hydrant could pose a health risk if used for human consumption because water quality degradation can occur as the water passes through the barrel of the hydrant.
- Using the spray of a fire hydrant to cool off is a significant safety risk because fire hydrants are usually configured to face the street. The public (often children) can be pushed by water under high pressure into the roadway to compete with vehicular traffic.
- Widespread unauthorized openings of fire hydrants can result in greatly reduced pressure in the distribution system, crippling fire-fighting capability and greatly increasing the risk of backflow contamination.
- Allowing multiple uses of fire hydrants sends a poor public relations message that water is free for the taking to those who can manage to open a hydrant. This is a precarious position particularly because of the need to secure drinking water systems.

For the reasons previously stated, it is recommended that water utilities keep the number of permitted uses of fire hydrants to a minimum. Utility managers should maintain strong control of fire hydrants and resist requests for sundry uses of hydrants. It is important that utility managers establish a sound policy for fire hydrant usage that is supported by fire departments and political leaders. Procedures for permitting and tracking allowable uses should be put in place and enforced. Many water utilities are establishing bulk water sales stations to supply tank trucks rather than allowing the use of fire hydrants. This is one step of a good policy on fire hydrant use. Water utility managers should work to educate public officials, contractors, customers, the media, and other stakeholders on the need to maintain strict utility control over fire hydrants.

government buildings. However, establishing accounts in the billing system and regularly reading meters ensures that water consumption is measured and archived. This is essential to provide accountability and tracking to confirm conservation improvements and detect leaks or other wasteful consumption.

Unfortunately, many water utilities do not meter or track consumption at public buildings. Typical facilities can include municipal offices, schools, government buildings, institutional buildings, water and wastewater buildings (treatment plants and pumping stations), park buildings, and recreational facilities. Consumption can be estimated by comparing the unmetered buildings to metered buildings of similar size and type. Water consumption at water or wastewater treatment plants—which require considerable volumes of water in their operations—can be estimated by assessing water-using processes such as filter backwashing and chemical process applications. By noting the pumping rates through individual processes and their duration of operation, reasonable estimates can be obtained. However, these steps should only be taken for water that has been treated and has entered the distribution system through the treatment plant's production meters, unless the system boundary for the audit has been drawn to include such facilities.

The manager for CWC estimates the amount of water consumed at public buildings to be 2.15 mil gal. Enter this amount as item 2-3C9 in Table 3-9.

Step 2-3C10. Other. This water involves any unmetered but verifiable use that may not fit into any of the categories previously described. In this case, the best means for estimating the total volume used should be determined and included in the "Other" category. Notes describing these uses and the means to quantify them can be typed into the Comments Worksheet in the Audit Software.

The manager for CWC estimates the amount of water consumed at a variety of miscellaneous uses to be 0.85 mil gal. Enter this amount as item 2-3C10 in Table 3-9.

Step 2-3C11. Sum of all components of Unbilled Unmetered Consumption. Each of the individual estimates obtained under Steps 2-3C1 through 2-3C10, as shown in Table 3-9, should be added.

The total estimate of Unbilled Unmetered Consumption is 183.82 mil gal. Because this amount is greater than the default calculation of 55.03 mil gal, the auditor selects the radio button to the right of the Unbilled Unmetered Consumption row of the Reporting Worksheet in Figure 3-5 and enters 183.82 mil gal in the cell under the "Value" heading.

The following are several insights regarding Unbilled Unmetered Consumption. Again, careful policy considerations should be employed regarding water withdrawn from fire hydrants (see the "Fire Hydrant Usage Policy" sidebar). Also, the utility should strive to determine how Unbilled Unmetered Consumption instances can eventually become metered and billed accounts. Over time, water utility managers should attempt to establish permanent metering at unmetered sites, particularly if they are permanent structures or facilities, such as municipal buildings, public parks, or irrigation within street rights-of-way. Finally, while these types of consumption may not provide revenue to the water utility, they should have regular meter readings and be "billed" even if the billing charge is zero. In this way, water consumption will be tracked to ensure that it is not wasteful. There should be consideration for how water efficiency improvements (the need for which often becomes evident once meters are installed) could be implemented to ensure that no more water is going toward these uses than needed.

Step 2-3D. Determine the appropriate Data Grading value for the Unbilled Unmetered Consumption. To select a representative Data Grading value for Unbilled Unmetered Consumption, the auditor has two options. If the auditor employs the use of the default value of 1.25 percent of the Water Supplied volume, then a Data Grading of 5 is automatically assigned by the Audit Software. However, if the auditor rigorously quantifies the subcomponents of Unbilled Unmetered Consumption (as done previously in Steps 2-3C1 through 2-3C10), then he or she should consider the status of utility policies allowing water uses in unmetered fashion, the extent of the documentation for the existence of these uses, and the reliability of the quantification methods used to estimate the unmetered consumption. The criteria listed in the Grading Matrix worksheet of the Audit Software should be consulted. Since CWC conducted a rigorous evaluation of its Unbilled Unmetered subcomponents, the default value was not employed. As described previously in Step 2-3C, CWC has a reasonably strong policy and records around those uses in its system that are both unmetered and unbilled. It undertook to reliably quantify the various subcomponents via the batch, discharge, or comparison procedure. Comparing these actions to the Grading Matrix worksheet criteria, the CWC auditor assigned a Data Grading of 8 for the component of Unbilled Unmetered Consumption.

Step 2-4. Calculate the Authorized Consumption volume for the audit year. The Authorized Consumption volume is calculated by the Audit Software as the sum of the four subcomponents of Billed Metered Consumption, Billed Unmetered Consumption, Unbilled Metered Consumption, and Unbilled Unmetered Consumption.

The worksheet in Figure 3-5 calculates the volume of Authorized Consumption to be 3,258.20 + 0.0 + 15.42 + 183.82 = 3,457.44 mil gal.

Task 3—Calculate Water Losses and Quantify Apparent and Real Losses

Water losses are made up of apparent and real losses and are calculated for the audit year as described in Step 3-1. Apparent Losses are quantified as described in Step 3-2. The Real Losses quantity is calculated as the remaining loss volume by the Audit Software, and this is described in Step 3-3. A rigorous means of directly quantifying real losses is described in the "Leakage Component Analysis" section in chapter 7.

Step 3-1. Calculate total water losses. Water Losses are calculated and shown in Figure 3-5 as the Water Supplied volume minus the Authorized Consumption volume.

The worksheet in Figure 3-5 calculates the volume of water losses as: Water Losses = Water Supplied – Authorized Consumption. For CWC, Water Losses = 4,402.16 – 3,457.44 = 944.72 mil gal.

Step 3-2. Quantify apparent losses. *Apparent losses* are the nonphysical losses that occur when water is successfully delivered to the customer but is not measured or recorded accurately. Apparent losses have several undesirable effects on utility operations. They distort customer consumption data and cost water utilities revenue when accounts are underbilled. Conversely, reductions in apparent losses tend to increase water system revenue from a given water rate structure and improve equity among customers. Apparent losses are comprised of

- systematic data handling errors,
- customer metering inaccuracies, and
- unauthorized consumption.

The top-down approach relies on the auditor to devise estimates or measures of apparent losses to include in the water audit. Methods to quantify apparent losses are given in the following steps.

Step 3-2A. Quantify systematic data handling errors. For water utilities that meter customer consumption, integrity must exist not just with the accuracy of the water meter but also with the process to read, transmit, archive, and report customer consumption totals as derived from the meter population. An error at any point in this process potentially represents an apparent loss by distorting the ultimate documented value of customer consumption, causing a portion of the consumption to be understated and possibly missing a portion of revenue. Systematic data handling errors can therefore occur anywhere from the time that the meter reading is registered to the final reporting and use of the consumption data. Systematic data handling errors can occur in two broad manners: systematic data transfer errors and systematic data analysis errors. The means to quantify losses in these classes of error are discussed in the next steps. The reader is directed to chapter 4 for additional information on systematic data handling errors.

Step 3-2A1. Systematic data transfer errors—Customer meter reading. Considerable error can occur in the customer meter reading process. Meters are typically read in two manners: manual meter reading, or automatic meter reading via an AMR or AMI system. Manual meter reading, with meter reading personnel visiting individual meters to collect readings, is the traditional approach and is still used by many water utilities in North America. In many systems, however, manual reading is being supplanted by AMR/AMI systems.

AMR is usually more accurate, less labor intensive, safer, and often (but not always) more cost-effective than manual meter reading. AMR/AMI systems have a strong history in the electric and gas utility industries, with implementation in the water industry growing rapidly since the late 1990s. Many successful case studies in water utility AMR/AMI systems have been documented, an example of which is given in the "Benefits of AMR/AMI Systems" sidebar. AMR/AMI systems have greatly reduced the accessibility and safety problems that have plagued manual meter reading programs. These systems transmit the current meter reading to a device or communications network outside of the building or meter pit in which the meter is located. With mobile AMR systems, readings can be collected by meter readers with handheld devices or, more economically, via vehicles patrolling scheduled meter reading routes in which multiple readings are gathered almost simultaneously. Fixed communication networks with AMI systems have emerged as the more comprehensive and effective means of data collection. Fixed AMI networks typically include permanently installed data collector units, or another communication mode such as cellular, covering the service area. While the traditional AMR systems gather single meter readings every 30, 60, or 90 days, AMI systems generate detailed customer consumption profiles by obtaining readings as frequently as every 15 minutes. By collecting more granular data in this manner, AMI systems can utilize capabilities to reduce and more quickly resolve customer billing complaints, quickly identify plumbing leaks, and assist water conservation and loss control efforts. Thus, AMI systems also bring about significant customer relations benefits. In addition to the above capabilities, AMI includes functions such as tamper detection, leak detection, and reverse flow detection; and more end-point capabilities are likely to be developed as these systems see wider use in the industry.

While AMR is less susceptible to data transfer error than manual meter reading, both forms of meter reading can incur errors. Meter reading attempts can fail for many reasons. Manual meter reading has encountered a growing number of pitfalls, particularly in gaining access to meters located inside customer premises, the typical location of water meters in colder climates of North America. Many properties have no one at home during business hours to let a meter reader into the house. Indoor water meters are often located in hard-to-reach corners of basements, boiler rooms, or other subterranean areas. Often, owners store items that block access to the meters. Outdoor meters in meter pits can have access difficulties, such as flooding and snow cover in colder climates. Meter readers entering private properties often encounter safety risks from aggressive dogs, dark or poorly maintained spaces, or hostile customers. For these reasons, manual meter reading success rates have declined in recent years for many water utilities. AMR/AMI meter reading can fail due to a malfunction of the AMR device from causes such as battery failure. Billing system analysts should evaluate billing data to detect accounts with successive cycles of "zero consumption" to identify potential AMR failure or possible tampering of metering

Benefits of Automatic Meter Reading and Advanced Metering Infrastructure Systems

Prior to the start of AMR installation in 1997, Philadelphia's Water Department and Water Revenue Bureau encountered such poor meter reading success that only one of every seven water bills issued was based on an actual meter reading; six were based on estimates. With the installation of more than 425,000 residential AMR units by 2000, the city witnessed a meter reading success rate of over 98 percent in its monthly billing process. A system of mostly estimates was replaced with a system of mostly actual meter readings. This has greatly improved the confidence of customer consumption data, lessened the number of customer billing complaints, and aided the detection of systematic data handling errors and unauthorized consumption in the City of Philadelphia.

Since the late 1990s, many North American water utilities have installed AMR or AMI systems. DC Water, providing service to the District of Columbia, was one of the first large-scale AMI systems and was installed in 2003. In addition, to improving customer meter reading and billing operations, its AMI system has helped bring about a much improved environment keyed on customer engagement and service.

Many large and medium-sized water utilities have moved to AMR systems given that this approach is usually more cost-effective for systems that must read 10,000 or more customer meters on a regular basis. For small North American water utilities that read only several hundred or several thousand meters once every 60 or 90 days, a productive business case for AMR/AMI systems may not exist based solely on meter reading success. AMI systems, however, now offer a host of other benefits, including improved customer relations, leak detection, and more efficient water supply operations. Hence, water utilities of all sizes have the opportunity to investigate improvements in their operations by employing an AMR/AMI system.

or meter reading equipment. Modern AMR/AMI systems typically feature self-diagnostic alerts to the utility when meter reading devices fail, communication links are interrupted, or for other system disruptions.

When a meter reading attempt is unsuccessful in obtaining an actual meter reading, most water utilities bill customers based on an estimated volume that reflects the customer's consumption based on their recent past history. While this is a reasonable approach, multiple cycles of meter readings without an actual reading greatly increase the prospect of inaccurate estimates. Over periods of time, buildings are sold and new owners with vastly different water consumption habits may be the permanent occupants. An estimate generated for a household of two persons may be fine until the house is sold to a family of seven. Water consumption could triple, but understated billings based on the outdated estimate could continue for some time. When an actual meter reading is eventually obtained, a large billing adjustment will confront the new property owner, a scenario that commonly creates customer ill will toward the water utility. Clearly, obtaining routine, accurate meter readings is key in maintaining sound oversight of customer consumption patterns, and maintaining stable billing and good customer relations.

The water auditor should review records to gain a general sense of the meter reading success rate for both residential and industrial/commercial categories of accounts. The number of estimates assigned should also be tracked, and an approximation of the error due to poor estimation should be attempted. Accounts that register zero consumption for several successive meter reading cycles should be sampled and investigated to determine if the zero consumption is valid (which should only occur in unoccupied or underutilized buildings) or whether AMR/AMI failure or tampering has occurred. Other sources of systematic data transfer errors can exist in any given water utility. Depending on the time and resources available to the auditor, investigations can be conducted to assess any errors that are unique to the utility. The auditor should attempt to quantify the major components of apparent loss due to data transfer error and include them in the water audit.

The quantity attributed to data transfer errors for CWC is related to several meter data collection functions including meter reading error, estimating error, and computer programming error. The auditor estimates the total of errors identified in these areas to be 12.57 mil gal. This quantity must be added to the quantity of systematic data analysis errors to include as the combined Systematic Data Handling Errors component in the Reporting Worksheet of the Audit Software shown in Figure 3-5.

Step 3-2A2. Systematic data analysis errors. Typically meter readings are transferred to customer billing systems where they are used to calculate the volume of customer consumption that has occurred since the previous reading. In the United States, consumption is most often recorded in units of cubic feet or thousand gallons. Billing systems often include programming algorithms that assign estimates of consumption if an actual meter reading cannot be obtained. These algorithms often base the estimate on the recent trend of customer consumption, or they may use another method. If a poor or outdated estimation algorithm exists in the customer billing system, underestimation or overestimation of customer consumption can occur, either of which could distort consumption data needed for operational purposes. The water auditor should understand the method used to estimate consumption and consider programming refinements if it is determined that the existing method creates inaccuracies. A quantity representing the amount of missed customer consumption as a result of this occurrence should be included in the water audit.

A significant error can also occur by billing adjustments that distort consumption data that is registered by water meters and collected in the customer billing system. An important question is: Are billing adjustments triggered by modifying actual consumption volumes? As described in the "Using the Customer Billing System" sidebar and example discussed in the "Hypothetical Example" section that follows, billing systems designed with the intention of good revenue collection may corrupt the operational integrity of customer consumption volumes when generating a credit.

Distortions in customer consumption as a result of billing adjustments can occur when billing systems do not distinguish between *registered* consumption (from meter readings) and *billed* consumption listed on the customer bill and archived in the billing records. Billed consumption can differ from registered consumption when the customer is due a monetary credit. If the billing system creates the credit (negative revenue to the utility) by creating negative consumption values, actual consumption data becomes distorted. Billing systems that include separate fields for registered and billed consumption avoid this problem. Financial managers can track data stored in the billed consumption field, while engineers can separately track the registered consumption.

In determining the amount of data analysis error occurring in billing system operations, the water auditor should determine how billing adjustments are calculated. If adjustments are triggered by changes in consumption, then an approximation of the number of adjustments—both overstating and understating actual consumption—should be attempted.

The quantity attributed to systematic data analysis errors for CWC is estimated to be 8.72 mil gal. This number must be added to the remaining systematic type errors before entering the total on the Reporting Worksheet shown in Figure 3-5.

Hypothetical example. Table 3-11 gives an example of a hypothetical residential customer account that incurred estimates for a 23-month period, during which time the property was temporarily vacant and then sold to a new owner who consumes less water than his predecessors. Beginning in October 2010, the water utility was unable to obtain a reliable meter reading at this property. This may have been caused by blocked access to the

Using the Customer Billing System to Extract Customer Water Consumption

The customer billing system is a standard feature of most drinking water utilities. Revenue is generated via billings to customers, typically on a monthly, bimonthly, or quarterly basis. For utilities that meter their customers, the billing system stores customer account data as well as routine customer meter readings from which consumption volumes are calculated. These systems historically have been designed with a primarily *financial* purpose—to generate bills that result in revenue collection.

It has become evident in recent years that the value of customer consumption data goes beyond serving as the basis for billings. Customer consumption data is also relied on for a variety of *engineering* purposes. Consumption data is needed to evaluate water conservation practices. It is required to realistically size customer meters and service connection piping on an individual basis, and to size water supply infrastructure on a community basis. Consumption data is necessary to develop accurate hydraulic models. It is also needed to assist water loss control programs, by separating components of authorized consumption from components of loss. Unfortunately, many billing systems were designed with only the financial function in mind, and water utilities that now also use billing system data for engineering purposes may be doing so without knowing whether adequate controls exist to ensure the engineering integrity of customer consumption data.

It is important that water utility managers understand the workings of the customer billing system with regard to consumption data integrity. Many billing systems—although configured with sound billing intentions—may unknowingly corrupt the engineering integrity of water consumption data. Some systems, when generating a credit to the customer, back-calculate the adjustment by changing the actual meter readings or consumption. A monetary credit to the customer is thereby triggered by reducing, eliminating, or creating negative consumption values for the period in question. Frequent adjustments in this manner can greatly distort the true amount of consumption for individual customers or whole communities. Other programming features in customer billing systems—though created with good financial intention—might unintentionally corrupt consumption data in an engineering sense.

It is recommended that sufficient controls be designed into the customer billing system if the system is to be used for both billing (financial) and operational (engineering) purposes. This will protect customer consumption data integrity while providing proper billing functions. The primary function of most existing customer billing systems is to accurately account for the revenue received by the utility for services rendered to individual customers. Utility operators embarking on conservation, hydraulic modeling, or water loss control programs should undertake a careful review of the billing system function and configuration to ascertain that the actual consumption amounts are not unintentionally modified by billing operations, and that the customer consumption amounts recorded as output of the billing system are unchanged from the data generated by customer water meters. The utility should undertake a flowcharting exercise of the billing process to identify any impacts to customer consumption integrity, as well as to identify any apparent loss components from the data handling process. If consumption data is found to be unduly modified by billing operations, the utility manager should consider reprogramming the billing system to record both the registered consumption and billed consumption as separate fields, thus ensuring that the accuracy of billing functions and customer consumption data are preserved. Until this process is implemented, an estimate of the impact of such adjustment activity should be included as a component of the apparent losses.

meter, a failure of AMR equipment, or another cause. Unfortunately, the water utility was unable to correct this condition and obtain an accurate meter reading until August 2012. During this period without meter readings, the water utility assigned an estimate of the consumption based on the customer's recent history—in this case, 885 ft^3/month. This estimate, shown in Column D, closely matched the actual consumption (shown in Column G for illustrative purposes) until April 2011, when the property was vacated and placed for sale. The property was vacant until August 2011 and experienced minimal water consumption during periodic caretaker visits from April to August 2011. Upon sale to a new

Table 3-11 Distorted customer consumption data due to customer billing adjustments triggered by the use of negative consumption values (example data for a ⅝-in. residential meter account)

A Year	B Month	C Meter Reading (estimates shown in gray)	D Billed Consumption (current minus previous meter reading; estimated consumption shown in gray) (ft³)	E Cumulative Billed Water Consumption (per year) (ft³)	F Actual Meter Reading	G Actual Consumption (ft³)	H Cumulative Actual Consumption (ft³)
2009	Dec	15004			15004		
2010	Jan	15838	834	834	15838	834	834
	Feb	16654	816	1,650	16654	816	1,650
	Mar	17496	842	2,492	17496	842	2,492
	Apr	18304	808	3,300	18304	808	3,300
	May	19220	916	4,216	19220	916	4,216
	Jun	20162	942	5,158	20162	942	5,158
	Jul	21130	968	6,126	21130	968	6,126
	Aug	22105	975	7,101	22105	975	7,101
	Sep	23007	902	8,003	23007	902	8,003
	Oct	23892	885	8,888	23867	860	8,863
	Nov	24777	885	9,773	24722	855	9,718
	Dec	25662	885	10,658	25535	813	10,531
2011	Jan	26547	885	885	26360	825	825
	Feb	27432	885	1,770	27184	824	1,649
	Mar	28317	885	2,655	28021	837	2,486
	Apr	29202	885	3,540	28433	412	2,898
	May	30087	885	4,425	28513	80	2,978
	Jun	30972	885	5,310	28578	65	3,043
	Jul	31857	885	6,195	28633	55	3,098
	Aug	32742	885	7,080	29255	622	3,720
	Sep	33627	885	7,965	30059	804	4,524
	Oct	34512	885	8,850	30836	777	5,301
	Nov	35397	885	9,735	31592	756	6,057
	Dec	36282	885	10,620	32315	723	6,780
2012	Jan	37167	885	885	33032	717	717
	Feb	38052	885	1,770	33740	708	1,425
	Mar	38937	885	2,655	34462	722	2,147
	Apr	39822	885	3,540	35150	688	2,835
	May	40707	885	4,425	35884	734	3,569
	Jun	41592	885	5,310	36686	802	4,371
	Jul	42477	885	6,195	37520	834	5,205
	Aug	38345	–4,132	2,063	38345	825	6,030
	Sep	39113	768	2,831	39113	768	6,798
	Oct	39811	698	3,529	39811	698	7,496
	Nov	40515	704	4,233	40515	704	8,200
	Dec	41230	715	4,948	41230	715	8,915
2013	Jan	41951	721	721	41951	721	721

owner in August 2011, a regular pattern of water consumption resumed but at a slightly lower rate than that of the previous owner.

Between April 2011 and August 2012 (17 months), the assigned estimate (885 ft^3) notably overestimated the consumption for this account. When the water utility was once again able to gain an accurate meter reading, it found that its estimate of the July 2012 meter reading (42477) was overstated by a total of 4,132 ft^3 since the last accurate meter reading in September 2010. This resulting cumulative overestimation error was compounded by the

- lengthy duration (23 months) of the period with no meter readings,
- four-month period of vacancy of the property, and
- lower water consumption habits of the new property owner.

When an accurate meter reading was obtained in August 2012, an adjustment of negative 4,132 ft^3 was necessary and a credit due to the customer in the dollar amount commensurate with the volume of adjusted consumption.

How the customer billing system awards this credit has bearing on both the billing (financial) and registered (engineering) functions of the system. While money can flow to and from the drinking water utility—via charges and credits, respectively—water flows in only one direction, being supplied *by* the utility *to* the customer. If the billing system contains only a single field for customer consumption, the billed consumption value for August 2012 is *negative* 4,132 ft^3.

While a negative consumption number is acceptable for use for billing (financial) reasons because it translates into a monetary credit, a negative consumption number is unacceptable for operational (engineering) purposes because the actual consumption for the month of August 2012 was 825 ft^3 (Column G), not negative 4,132 ft^3 as shown in Column D.

The distortion of the consumption data is further reflected in the estimated vs. actual consumption based on yearly periods. Water utility analysts reviewing the account data shown in Table 3-11 for conservation or loss control purposes would be in error by 3,840 ft^3 (10,620 – 6,780) over the actual consumption in 2011. Conversely, the analysis would be understated for this account by 3,967 ft^3 (8,915 – 4,948) in 2012. Some may reason that the periods of estimation and adjustment ultimately balance with no net difference over the long term; therefore, using a single consumption value is acceptable. However, many analytical and reporting functions are performed over the course of a calendar or business year. If a given account has been poorly estimated for many years, the use of a huge multiyear adjustment in the last year will greatly distort the consumption for that final year. Additionally, in any given drinking water utility, many hundreds or thousands of accounts could utilize estimates for varying periods of time. Reliably estimating the net impact of the aggregate overestimation or underestimation of these accounts in a given year is unnecessarily complex. Clearly, while a negative consumption value can be acceptable for billing (financial) purposes, it is quite harmful to the integrity of the data for operational (engineering) purposes.

For the reasons previously explained, it is recommended that water utility customer billing systems include two fields for customer consumption: one for *registered* consumption and a separate field for *billed* consumption. Using the same data from the example in Table 3-11, the form of the data with separate fields is shown in Table 3-12.

Table 3-12 includes separate columns for billed consumption (Column D) and registered consumption (Column G). When actual meter readings resumed in August 2012, the consumption adjustment of negative 4,132 ft^3 appears as billed consumption in Column D and is used to generate the monetary credit to the customer. However, Column G reflects the revised estimate of consumption for the prior 30-day period, which is based on the

Table 3-12 Utilizing separate fields for registered and billed consumption in the customer billing system (example data for a ⅝-in. residential water meter account; see Table 3-11)

A Year	B Month	C Meter Reading (estimates shown in gray)	D Billed Consumption (current minus previous meter reading, estimated consumption shown in gray) (ft³)	E Cumulative Billed Water Consumption (per year) (ft³)	F Actual Meter Reading	G Registered (actual) Consumption (ft³)	H Cumulative Registered (actual) Consumption (ft³)
2009	Dec	15004			15004		
2010	Jan	15838	834	834	15838	834	834
	Feb	16654	816	1,650	16654	816	1,650
	Mar	17496	842	2,492	17496	842	2,492
	Apr	18304	808	3,300	18304	808	3,300
	May	19220	916	4,216	19220	916	4,216
	Jun	20162	942	5,158	20162	942	5,518
	Jul	21130	968	6,126	21130	968	6,126
	Aug	22105	975	7,101	22105	975	7,101
	Sep	23007	902	8,003	23007	902	8,003
	Oct	23892	885	8,888	Unknown, No Readings	885	8,888
	Nov	24777	885	9,773		885	9,773
	Dec	25662	885	10,658		885	10,658
2011	Jan	26547	885	885		885	885
	Feb	27432	885	1,770		885	1,770
	Mar	28317	885	2,655		885	2,655
	Apr	29202	885	3,540		885	3,540
	May	30087	885	4,425		885	4,425
	Jun	30972	885	5,310		885	5,310
	Jul	31857	885	6,195		885	6,195
	Aug	32742	885	7,080		885	7,080
	Sep	33627	885	7,965		885	7,965
	Oct	34512	885	8,850		885	8,850
	Nov	35397	885	9,735		885	9,735
	Dec	36282	885	10,620		885	10,620
2012	Jan	37167	885	885		885	885
	Feb	38052	885	1,770		885	1,770
	Mar	38937	885	2,655		885	2,655
	Apr	39822	885	3,540		885	3,540
	May	40707	885	4,425		885	4,425
	Jun	41592	885	5,310		885	5,310
	Jul	42477	885	6,195		885	6,195
	Aug	38345	–4,132	2,063	38345	667	6,862
	Sep	39113	768	2,831	39113	768	7,630
	Oct	39811	698	3,529	39811	698	8,328
	Nov	40515	704	4,233	40515	704	9,032
	Dec	41230	715	4,948	41230	715	9,747
2013	Jan	41951	721	721	41951	721	721

difference between the two most recent actual meter readings (September 2009 and August 2011). This one-time estimate is determined as

$$(38{,}345\ \text{ft}^3 - 23{,}007\ \text{ft}^3)/23\ \text{months} = 667\ \text{ft}^3 \tag{3-6}$$

By September 2012, when the second consecutive actual monthly meter reading was obtained, estimates are no longer utilized, and billed consumption once again matches registered consumption. The benefit to the operational integrity of data using separate billed and registered consumption fields is shown by comparing the cumulative consumption for 2012 in Column E and Column H, or 4,948 ft^3 and 9,747 ft^3, respectively (Table 3-12). If only a single field is used for consumption, the billed value of 4,948 ft^3 greatly understates the actual consumption for the year. The registered consumption value of 9,747 ft^3 is a much more representative value of the water consumed by this account during 2012.

Step 3-2A3. Policy and procedure shortcomings. Apparent losses can occur because of policies and procedures that are shortsighted or poorly designed, implemented, or managed. Such occurrences can be subtle and numerous. Chapter 5 illustrates how flowcharting the customer billing process—with a focus on impacts to customer consumption values—gives insight to the likelihood of these types of apparent losses. Some of the common occurrences to consider are

- ignoring the installation of meters in certain customer classes despite company goals to meter all customers (this is common for municipally owned buildings in water utilities run by local governments);
- provisions allowing customer accounts to enter nonbilled status, a potential loophole often exploited by fraud or poor management;
- bureaucratic regulations or inefficiencies that cause delays in permitting, metering, or billing operations; and
- poor customer account management (accounts not initiated, lost, or transferred erroneously).

The degree to which such shortcomings in billing account management exists is largely dependent on the accountability “culture” that exists in the water utility. If accountability is only casually emphasized, it is likely that numerous opportunities for missed consumption exist. If sound accountability is trumpeted by the utility’s leaders and managed at all levels of staff, then such occurrences are likely to be isolated and of minor significance. The water auditor should consider including an estimate of apparent loss that represents the collective policy and procedure shortcomings of the water utility. During the top-down audit, perhaps only a rough approximation can be ventured. During subsequent audits, bottom-up investigations can give greater insight to such problems, and corrections can be identified.

The quantity attributed to policy and procedure shortcomings for CWC is estimated to be 11.63 mil gal. This number is added to the quantity of systematic data transfer errors of 12.57 mil gal and systematic data analysis error of 8.72 mil gal to give a total Systematic Data Handling Errors quantity of 32.92 mil gal for the audit year. This quantity is entered into the Reporting Worksheet in Figure 3-5 in the row for Systematic Data Handling Errors in the cell under the “Value” heading. Alternatively, if the auditor is not able to undertake a detailed quantification of this component, then the default value may be selected. If the default option is used, then the Audit Software calculates a Systematic Data Handling Errors quantity equal to 0.25 percent of Billed Metered Consumption.

Step 3-2A4. Determine the appropriate Data Grading value for the Systematic Data Handling Errors component. To select a representative Data Grading for Systematic Data Handling Errors, the auditor has two options. If the auditor employs the use of the default value of 0.25 percent of the Billed Metered Consumption, then a Data Grading of 5 is automatically assigned by the Audit Software. However, if the auditor rigorously quantifies the subcomponents of Systematic Data Handling Errors (as done previously in Steps 3-2A1 through 3-2A3), then he or she should consider the status of utility policies and procedures, record keeping, robustness of the billing system, and data auditing practices and frequency. The criteria listed in the Grading Matrix worksheet of the Audit Software should be consulted. Since CWC conducted a rigorous evaluation of its systematic data handling errors, the default value was not employed. CWC has a reasonably strong billing policy and employs a computerized customer billing system, which provides several management reports on billing trends. However, CWC staff has not flowcharted or audited its billing process in detail and knows that its billing system does create values of negative water consumption to create credits to customers. No third-party auditors are used to verify the billing system integrity. Given these factors, the CWC auditor assigns a Data Grading of 6 based on the criteria in the Grading Matrix worksheet of the Audit Software.

Step 3-2B. Estimate Customer Metering Inaccuracies. For water utilities with unmetered customer consumption, there is no amount of apparent loss caused by customer metering inaccuracies; therefore, this component does not apply. Most drinking water utilities in North America, however, provide meters on all or most of their customer service connection piping to measure customer consumption. This is good industry practice supported by AWWA. However, meters typically are not 100 percent accurate in all situations. Meters are subject to wear and loss of accuracy with continued use. Another common source of meter inaccuracy occurs when meters are oversized or undersized for the flow profile that they encounter. Many meter types fail to accurately measure low flow rates; therefore meters frequently experiencing low flows will be less accurate than appropriately sized meters. Chapters 4 and 5 also provide guidance on meter management and the means to maintain a high degree of accuracy in the customer population.

Meter right-sizing. Historically, meter sizing calculations have been based on conservative techniques, basing the size of the meter on the peak flow it might encounter, despite the high likelihood that the peak would be experienced only on rare occasions. Meters sized in this way are usually larger than they need to be, resulting in substantial meter inaccuracy at low flows. This practice has resulted in a significant number of oversized meters in many water utilities. Changing building uses, such as a factory converted to office space, can result in an oversized meter if the original meter that passed high flows remains in place after the low-flow office setting is established. Leakage within customer premises can generate low flows that are commonly unrecorded or underrecorded, even by new meters. The degree of inaccuracy in the meter population at any point in time depends on the meter types that were specified, the amount of cumulative flow that meters have registered, whether the meters are appropriately sized and installed, the aggressiveness of the water in creating internal corrosion, and the degree of upkeep in the meter population by the water utility management. Taking these factors into account, the water auditor can determine an estimate of the composite amount of water lost to the inaccuracy of customer meters. Meter right-sizing programs can recoup much of that loss with significant gains in billed consumption. Flow recorders (data loggers), such as shown in Figure 3-12, can provide accurate flow-rate data to assist meter right-sizing decisions.

Because there are typically many hundreds or thousands of customer meters in any drinking water utility, it is not practical to inspect and test every one each year. Instead, periodic inspections and testing should be considered for all high-revenue meters, along

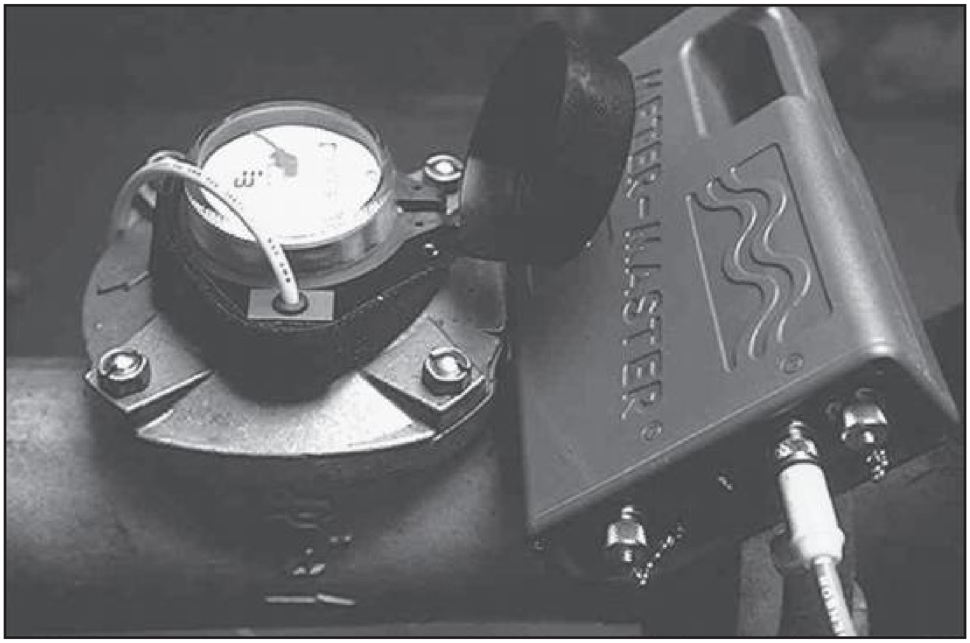


Figure 3-12 Customer meter flow recorder

Courtesy of F.S. Brainard and Co.

with a random sample of smaller meters. As a minimum, it is important to ensure that the meters serving the largest users are sized properly and tested on a regular basis.

Step 3-2B1. Check for proper meter installation. The utility's practices on meter selection, sizing, and installation should be reviewed to determine whether current practices result in a high accuracy customer meter population. If they do not, the practices should be revised as necessary so that meters will operate correctly. Refer to AWWA Manual M6, *Water Meters—Selection, Installation, Testing, and Maintenance* (2012), and AWWA Manual M22, *Sizing Water Service Lines and Meters* (2014a).

Large industrial, commercial, and agricultural meters typically produce a much larger share of revenue per account than do residential meters. These accounts should be inspected for proper selection, sizing, and installation. In addition, best practice dictates that all meters should be inspected and tested before they are used. Not all new meters are sufficiently accurate. The results of a large-scale project for testing of residential meters can be found in the research report *Accuracy of In-Service Water Meters at Low and High Flow Rates* (WRF 2011).

Step 3-2B2. Test residential meters for accuracy. A random sample of residential meters should be tested; as few as 50 to 100 may be a sufficient number, but the optimal number to be tested depends on the size of the customer meter population, the degree of confidence required in the test results, and the variance in the actual test results observed. Residential meters may be tested on a utility-owned test bench or sent to the factory or a testing service contractor for testing. (For more information, see AWWA Manual M6, *Water Meters—Selection, Installation, Testing, and Maintenance* [AWWA 2012].)

Meter testing and replacement programs. Many utilities operate meter testing and replacement programs. Particularly for small meters, it has become more cost-effective to replace meters than to repair them. Random or targeted testing to determine the accuracy of installed customer meters can be conducted to monitor the wear of meters. A representative sample of newly purchased residential meters should also be tested to confirm the acceptability of the delivered meters. This test data represents a good source of information to infer the overall degree of inaccuracy existing in the customer meter population. Large

Table 3-13 Example of weighting factors for flow rates related to volume percentages for ⅝-in. water meters in County Water Company

Flow	Range (gpm)	% Volume*
Low	<0.75	15
Medium	0.75–5.5	50
High	>5.5	35

*Percent volume refers to the proportion of water consumed at the specified flow rate, as compared to the total volume consumed at all rates. In this example, only 15 percent of the total water consumed occurs at the low-flow range of less than 0.75 gpm.

The optimal determination of % volume weighting for each flow range should come from sample flow logging of residential accounts for a given utility. See the "Customer Consumption Data Collection" sidebar on Austin Water Utility.

meter replacement programs offer an excellent opportunity to ensure that older meters are replaced with the correct type and size new meters. Flow recorders (data loggers) can assist with this selection process by recording the daily variation of flows and ensure that low-flow regimes are identified and included in the meter sizing determination. Both compound and turbine meters offer advantages for specific flow profiles. However, the potential inaccuracy of older meters and any flow data recorded from them should be considered if they have not been maintained properly. Solid-state meters, including electromagnetic and ultrasonic meters, are growing in use within the drinking water industry and offer a number of capabilities.

Conducting meter accuracy testing. A water meter testing apparatus (test bench) is precision instrumentation and must be operated and maintained properly to provide representative accuracy results for meters being tested. Proper testing procedures must also be followed and the results carefully documented. It is important that skilled, trained technicians are employed as the testing operators; this job should not be assigned to unskilled workers. The investment for a water utility to purchase a meter testing apparatus and assign trained technicians as operators is a considerable one. If the water utility cannot provide sufficient financial and human resources to conduct meter testing properly, then it is better that it contract to have customer meters reliably tested by qualified consultants or meter testing services. This is also an appropriate approach if the customer meter population is small and the number of meters to be tested each year is small. If the testing program is not well run, unrepresentative results will be obtained, wasting the value of the investment and potentially misguiding decisions on meter replacement goals.

The fundamental meter accuracy testing protocol calls for testing customer meters at three flow rates: low, medium, and high (always test the low flow first to avoid disturbing any particulate matter in the meter that will be washed away during a high flow test). Accuracy measurements can be obtained for each flow rate. It is also important to know the relative portion of the water supply to meters occurring in the low, medium, and high flow regimes. Tables 3-13 through 3-16 illustrate how this information is employed to calculate a composite customer meter accuracy value for the meter population, or subset of the population, such as residential meters.

The "Customer Consumption Data Collection" sidebar provides an account of small, residential meter accuracy testing and data-logging work conducted in Austin, Texas. The testing work allowed the Austin Water Utility to determine the composite accuracy for ⅝-in. water meters. Data-logging work allowed the utility to determine the composite amount of flow occurring at the low, medium, and high flow regimes, which were found to be 13.1 percent, 52.5 percent, and 34.4 percent, respectively. These composite flow profiles are representative of ⅝-in. meter customers in the Austin service area and cannot be

Table 3-14 Meter testing data from a random sample of 50 meters for County Water Company

Test Flow Rates (gpm)	Mean Registration (%)
Low (0.25)	88.67
Medium (2.0)	96.01
High (15.0)	95.11

Table 3-15 Sample calculation of residential water meter error

Flow Rates	Tested Accuracy (%)	% Volume	Weighted Accuracy (%)
Low	88.67	15	13.3
Medium	96.01	50	48.0
High	95.11	35	33.3
Weighted meter accuracy			94.6

Table 3-16 Calculation of residential water meter error

Percent Volume* (%V)	Total Sales Volume† (Vt) (mil gal)	Volume at Flow Rate (Vf) (%V × Vt) (mil gal)	Meter Registration (R)‡ (%)	Meter Error (ME) ME = Vf/(0.01R) – Vf (mil gal)	Meter Error (mil gal)
15	2,318.8	347.82	88.67	[(347.82/0.8867) – 347.82]	44.44
50	2,318.8	1,159.40	96.01	[(1,159.40/0.9601) – 1,159.40]	48.18
35	2,318.8	811.58	95.11	[(811.58/0.9511) – 811.58]	41.72
Composite residential meter innacuracy volume					134.34

* From Table 3-13.

† Based on residential water sales data in Table 3-8.

‡ From Table 3-14.

taken to be levels representative of other utilities. Ideally, water utilities should undertake their own assessment of these levels, as Austin Water Utility conducted. However, it is realized that not all utilities have the resources and time to conduct this work.

Step 3-2B3. Calculate the composite Customer Metering Inaccuracies. Total customer consumption meter error includes meter errors from all meter sizes, and those of all usage categories including residential, industrial, commercial, agricultural, and others. In general, meter sizes of ⅝-in. and ¾-in. can be considered small, residential use meters. All other meters, which include industrial, commercial, agricultural, and others, are typically referred to as large meters. Because the water usage patterns of small and large meter accounts are different, and the types and function of small and large meters are different, it is worthwhile to quantify inaccuracies in each of these two types of accounts and add them to obtain the composite quantity of loss due to customer metering inaccuracies.

Calculate residential (small) meter error for CWC. Water meters should be tested at low, medium, and high flows. The results, shown as a percentage of accuracy, are used to calculate the total meter error at average flow rates. Tables 3-13 through 3-15 demonstrate how to use existing meter test data to calculate composite total residential meter errors. The data in these tables are based on the audit year customer consumption for CWC shown in Table 3-8. Table 3-13 lists the percentage of typical residential flows that occur in CWC

Customer Consumption Data Collection and Meter Accuracy Testing in Austin, Texas

Knowing your meter accuracy is critical for calculating apparent losses, and it will vary for every utility. Factors such as meter age and total flows recorded, water quality, manufacturer and model of meters, and customer usage patterns are going to affect accuracy, particularly the low and high flow ranges. Consequently, utilities should provide for testing to determine the accuracy of their customer meter population.

Soon after stepping up its water loss control efforts, Austin Water Utility decided that it wanted to improve the accuracy of its apparent loss calculations. First, the utility pulled a random sample of small meters of up to size 2 in. (meters 3 in. and larger are tested regularly and brought to within AWWA standards). The meters were tested on a test bench, and each meter size's test results were averaged together, yielding accuracy rates of between 86 percent and 98 percent for low flow rates, 98 percent and 99 percent on medium flows, and 98 percent and 100 percent on high flows.

However, to combine those average accuracy rates into a single rate for each meter size, the utility had to know what percentages of customer water moved through the meters at low, medium, and high flow rates. So the utility installed data loggers on the accounts where the tested meters had been pulled, and tracked flows for a week. The data logging yielded flow percentages of 8 percent to 28 percent for low flows, 42 percent to 52 percent for medium flows, and 24 percent to 41 percent for high flows. By multiplying the accuracy rates by the flow percentages for low, medium, and high flows and summing them, Austin Water Utility determined that its customer meters were between 97.32 percent and 98.90 percent accurate, depending on the size of the meter.

Sample meter accuracy for ⅝-in. meters*

Flow Rates†	Tested Accuracy (%)	Portion of Total Flows (%)	Flow Times Accuracy (%)
Low (<0.7 gpm)	86.04	13.1	11.27
Medium (0.7–5.45 gpm)	99.47	52.5	52.22
High (>5.45 gpm)	99.43	34.4	34.20
Total accuracy:			**97.69%**

* Tested accuracy rates and portion of total flows were measured by Austin Water Utility for its own specific meter population and operating conditions.

† Flow rates are for classifying flows as data-logged through customer meters. Tested flow rates were taken from AWWA Manual M6, *Water Meters—Selection, Installation, Testing, and Maintenance* (2012). For ⅝-in. meters, the test rates used were 0.25 gpm for low flows, 2 gpm for medium flows, and 15 gpm for high flows.

at the low, medium, and high flow rates. This information was calculated by CWC after data-logging 100 residential customer accounts and performing analysis such as that conducted by Austin Water Utility in the "Customer Consumption Data Collection" sidebar. Meter accuracy testing was also conducted by CWC throughout the audit year by selecting a mix of 50 randomly selected meters and high cumulative consumption meters. The results of this testing are shown in Table 3-14.

CWC found that the low flow accuracy of the tested residential meters was 88.67 percent. It is likely that very low flows occurring in CWC properties—such as toilet leaks—are not registered at all. The accuracy at medium and high flow rates was better, at 96.01 percent and 95.11 percent, respectively. Table 3-15 shows that the composite or weighted accuracy of this test group of meters is 94.6 percent.

Table 3-17 Example volume percentages for large meters for County Water Company*

Flow Rates	% Volume Delivered
Low	10
Medium	65
High	25

*CWC conducted flow recordings for 24-hour periods in July and February for 25 large meter accounts to indicate the percentage of volume delivered by large meters at low, medium, and high flow rates.

Table 3-18 Meter test data for large meters for County Water Company

Meter ID Number	Size (in.)	Meter Type	Date of Installation	Manufacturer	Test Date	Mean Registration at Various Flow Rates (designated as percentage of registration)		
						Low	Medium	High
XYZ001	3	Turbine	June 1991	Sensus	Apr 2013	89	93.0	100
X00ZAA	3	Turbine	June 1993	Sensus	Apr 2013	70	95.2	98
NB123	4	Turbine	July 2001	Neptune	Apr 2013	95	99.0	102
NB456	6	Compound	Sept 2004	Badger	Oct 2013	98	96.5	102
AA002	6	Magnetic	May 2010	ABB	Oct 2013	98	99.0	103
Sum of mean registrations						450	482.7	505
Mean registration for five meters tested						90	96.54	101

Table 3-16 shows the calculation used to determine the volume of water occurring as an apparent loss due to residential customer metering inaccuracies. For CWC, this is 134.34 mil gal.

Calculate industrial/commercial (large) meter error. Tables 3-17 through 3-19 show how to use existing meter test data to calculate the composite meter inaccuracy for the large customer meter population. The mean registration data in Table 3-17 are used to calculate the meter inaccuracy for large meters. As noted in Table 3-17, the percentage of flow occurring in the low, medium, and high ranges was derived by conducting flow recordings (data logging) on 25 large meter accounts during the audit year. Table 3-18 shows the individual meter accuracy test results for five large meters tested by CWC during the audit year, and the mean registration for these meters. Table 3-19 shows the calculations used to quantify the composite large meter inaccuracy volume for CWC. The accuracy test data shown in Table 3-18 is used in the calculations shown in Table 3-19. As determined from Table 3-7, CWC has 706 large water meters of size 1-in. and larger in its system. With this sized population, the test sample of only five large meters may be too small to be fully representative as a means to calculate the composite inaccuracy volume of the large meter population. CWC would likely obtain more representative results by testing 15–20 large meters during the next audit year.

One of the benefits of a water audit is the potential increase in revenue resulting from testing, replacing, or right-sizing large meters. While testing can be used to better quantify composite loss volumes for the water audit and to improve data validity, the utility can also directly act on meters found to be sorely inaccurate, thereby realizing a fast recoup of missing revenue. The auditor can estimate the amount of revenue to be gained by improving the function of large meters by applying the appropriate cost factor.

Table 3-19 Calculation of large water meter error

Percent Volume* (%V)	Total Sales Volume† (Vt) (mil gal)	Volume at Flow Rate (Vf) (%V × Vt) (mil gal)	Meter Registration (R)‡ (%)	Meter Error (ME) ME = Vf/(0.01R) – Vf (mil gal)	Meter Error (mil gal)
10	939.2	93.92	90.0	[(93.92/0.90) – 93.92]	10.43
65	939.2	610.48	96.54	[(610.48/0.9654) – 610.48]	21.85
25	939.2	234.80	101.0	[(234.80/1.01) – 234.80]	–2.32
				Composite large meter inaccuracy volume for large meters	29.96

* Data from Table 3-17.

† Data from Table 3-8 sum of industrial, commercial, and agricultural metered consumption.

‡ Data from Table 3-18.

The resulting commercial/industrial meter error from Table 3-19 for CWC is 29.96 mil gal. This number is added to the residential meter error of 134.34 mil gal, and a total volume of Customer Metering Inaccuracies of 164.3 mil gal is quantified and entered into the Reporting Worksheet in Figure 3-5 under the "Value" heading. Note that the Audit Software also gives the auditor the option to enter a composite percentage of metering inaccuracies for the customer meter population. This can be done if the auditor has not been able to undertake calculations as shown in Table 3-16 and Table 3-19. In such a case, the Audit Software calculates a volume based on the percent inaccuracy selected by the auditor multiplied by the volume of Billed Metered Consumption.

Step 3-2B4. Determine the appropriate Data Grading value for the Customer Metering Inaccuracies. To select a representative Data Grading value for Customer Metering Inaccuracies, the auditor should refer to the criteria listed in the Grading Matrix worksheet of the Audit Software. Factors affecting data grading for this input include the level of meter record keeping, the type and extent of customer meter testing and replacement, and data auditing. CWC has good records of its customer meters, which are stored in the customer billing system. It tests a small but generally representative number of customer meters each year and replaces meters found to be inaccurate or having exceeded an expected life. Given these factors, the CWC auditor assigns a Data Grading of 8 based on the criteria in the Grading Matrix worksheet of the Audit Software. CWC can improve its Data Grading value by testing more meters and letting the results guide replacement schedules. It can also accelerate its research and implementation of emerging meter types, possibly with greater use of solid-state meters such as electromagnetic and ultrasonic meters.

Step 3-2C. Estimate Unauthorized Consumption. Unauthorized Consumption includes water that is taken against the policies of the water utility and can include

- illegal connections,
- open bypasses,
- buried or otherwise obscured meters,
- misuse of fire hydrants (see the "Fire Hydrant Usage Policy" sidebar earlier in this chapter and the discussion in chapter 5 on fire hydrant policy and management),
- unauthorized connections into dedicated fire-fighting systems piping (unmetered fire lines),
- vandalized or bypassed consumption meters (meter tampering),

- tampering with meter reading equipment,
- unauthorized opening of intentionally closed valves or curb stops on customer service piping that has been discontinued or shut off for nonpayment, and
- unauthorized opening of intentionally closed valves to neighboring water distribution systems designed for emergency or special use.

Water utilities sometimes allow a spacer pipe to be installed in place of a water meter in new building construction, with the intention to install a water meter at a later time in the occupancy process. Unfortunately, water utilities sometimes forget to install the meter and, although the customer may be aware that they are not being billed for water use, continue to consume water without notifying the water utility. Policies that allow water service to be established in this manner without a meter are discouraged. However, if such a policy is required, a periodic audit should be conducted to verify that each property has a meter and that occupied buildings show positive water consumption.

The potential for unauthorized consumption exists in any drinking water utility but varies from system to system. In large, urban systems, occurrences of unauthorized consumption are likely to be more numerous than that of medium or small systems in suburban or rural settings. For large and medium-sized systems, the total annual volume of water lost to unauthorized consumption is likely to be a small portion of the utility's water supply volume. For expediency during the top-down water audit, the auditor may choose to use the default value of 0.25 percent of the Water Supplied volume. This percentage has been found to be representative of this component of loss in water audits compiled worldwide. In this case, the Audit Software calculates the volume of water lost to unauthorized consumption.

For CWC, the auditor determines that there are not sufficient resources available to fully investigate the occurrence of unauthorized consumption, although it is known that a certain amount of such consumption occurs. In this case, the auditor selects the default value, which is calculated as (Water Supplied) × (.0025) = (4,402.16) × (.0025) = 11.005 mil gal. The default value is selected by clicking on the radio button to the right of the Unauthorized Consumption component. If an actual quantification of unauthorized consumption is obtained, the Value radio button should be clicked and the quantity entered under the "Value" heading.

For small systems, the occurrence of unauthorized consumption may be a larger portion of the Water Supplied volume than that of large systems. If the auditor believes that this consumption is significant and has the time and resources to investigate, he or she can conduct work to examine the occurrences of unauthorized consumption and obtain quantities for these components. This work can be tedious, however, and the auditor should use judgment to determine whether the extra effort to obtain specific estimates of unauthorized consumption is worthwhile compared to merely applying the default value.

Step 3-2C1. Determine the appropriate Data Grading value for Unauthorized Consumption. To select a representative Data Grading value for Unauthorized Consumption, the auditor has two options. If the auditor employs the use of the default value of 0.25 percent of the Water Supplied volume, then a Data Grading of 5 is automatically assigned (but not displayed) by the Audit Software. Since CWC did not conduct a rigorous evaluation of its unauthorized consumption, and instead employed the default value, a Data Grading of 5 is automatically assigned by the Audit Software. However, if the auditor rigorously quantifies various subcomponents of Unauthorized Consumption, then he or she should consider the status of utility policies clearly defining the authorized and unauthorized uses of water, means to detect unauthorized consumption when it occurs, and the ability to enforce penalties on offenders. The criteria listed in the Grading Matrix worksheet of the Audit Software should be consulted and used as a guide for the auditor to select the most representative Data Grading based on a utility's current practices in addressing unauthorized consumption.

Step 3-2D. Calculate the Apparent Losses volume. The total apparent losses are determined by adding the apparent loss components for systematic data handling errors, customer metering inaccuracies, and unauthorized consumption.

The Reporting Worksheet in Figure 3-5 calculates the apparent loss volume for the audit year. For CWC, the apparent loss is calculated to be 208.225 mil gal.

Step 3-3. Quantify the Current Annual Real Losses volume. Water losses consist of the apparent losses plus the real losses occurring in the drinking water utility operations and management. The Audit Software mathematically calculates Current Annual Real Losses (CARL) simply as total water losses (Step 3-1) minus apparent losses. The means to rigorously quantify system leakage using free software is explained in the "Leakage Component Analysis" section in chapter 7.

The Reporting Worksheet in Figure 3-5 calculates the volume of Real Losses as Real Losses = Water Losses – Apparent Losses, or (944.720 – 208.225) mil gal = 736.495 mil gal.

While the straightforward approach of the Audit Software makes the Real Losses calculation easy to determine mathematically, care should be taken in the interpretation of the volume of real losses determined in this manner. By this method of calculation, real (leakage) losses are a "catch-all" quantity, basically the amount of water left over after authorized consumption and apparent losses have been quantified. The quantification of the amount of leakage losses is therefore only approximate because

- the accumulated inaccuracies in the other components will directly affect the estimate of real losses;
- the catch-all nature of this estimate of leakage losses gives no indication of the breakdown of individual leakage components, particularly unreported leaks and background losses; and
- a water balance normally covers a completed (retrospective) 12-month period, so it has limited value as an early warning system for identifying new leaks.

For these reasons, leakage losses should also be assessed by additional bottom-up methods, namely,

- leakage component analysis of real losses, and
- quantification of leakage components via field measurements and minimum-hour flow analysis.

These methods are discussed in detail in chapters 6 and 7.

Task 4—Calculate Non-Revenue Water

Non-revenue water is the portion of the water that a utility places into the distribution system that is not billed and, therefore, recovers no revenue for the utility. NRW consists of the sum of Unbilled Metered (Step 2-3A in this chapter) and Unbilled Unmetered (Step 2-3C11) Consumption, Apparent Losses, and Real Losses. NRW can also be calculated as the Water

Supplied volume minus the sum of Billed Metered (Step 2-1C) and Billed Unmetered (Step 2-2) Consumption.

Step 4-1. Calculate non-revenue water. The Reporting Worksheet in Figure 3-5 calculates NRW as the volume of Water Supplied minus the sum of the Billed Metered Consumption and the Billed Unmetered Consumption. For CWC, this is determined as 4,402.16 – (3,258.20 + 0.0) = 1,143.96 mil gal.

Task 5—Collect Distribution System and Cost Data

This section of the Reporting Worksheet in Figure 3-5 provides for the entry of pertinent water distribution system data that are necessary to describe the utility and calculate the performance indicators. The information is provided under two headings: System Data and Cost Data. The water audit approach assumes that the utility distribution system is operated 365 days per year and is continually pressurized during these operations. This is true for North American systems; however, in many developing countries, intermittent supply systems are typical, providing pressurized water supply for only a portion of each day or only for certain days of the week.

Step 5-1. Calculate the length of mains. The length of mains is the length of all pipelines (except service connections) in the system starting from the point of system input metering (e.g., at the effluent of the water treatment plant). It is also recommended to include in this measure the total length of fire hydrant lead pipe. Hydrant lead pipe is the pipe branching from the water main to the fire hydrant. Fire hydrant leads are typically of a sufficiently large size that is more representative of a pipeline than a service connection. The average length of hydrant leads across the entire system can be assumed if not known and multiplied by the number of fire hydrants in the system, which can also be assumed if not known. This value can then be added to the total pipeline length. Total length of mains can therefore be calculated as

$$\begin{aligned}\text{length of mains (miles)} = {} & \text{(total pipeline length, miles)} \\ & + [\{\text{(average fire hydrant lead length, ft)} \\ & \times \text{(number of fire hydrants)}\} / 5{,}280 \text{ ft/mi}]\end{aligned} \quad (3\text{-}7)$$

Enter the total Length of Mains on the Reporting Worksheet in Figure 3-5. For CWC, the auditor enters the quantity of 256.3 miles of pipeline. The units for this length will be in miles unless the auditor selects metric units on the Instructions Worksheet, in which case, the length will be in kilometres.

Step 5-1A. Determine the appropriate Data Grading value for the Length of Mains parameter. The criteria listed in the Grading Matrix worksheet of the Audit Software should be consulted. Factors affecting data grading for this parameter include the sophistication of the mapping format (paper vs. electronic) employed by the water utility and policies/procedures for permitting, commissioning, and documenting new/replacement water mains. CWC has a system of paper maps of its water distribution system. While it has a strong policy for upkeep of records, the management of this function has slipped in the past five years and it is believed that the records of new piping installed in several housing developments has not yet been recorded in the mapping system. The CWC auditor assesses the Grading Matrix worksheet and assigns a Data Grading of 4 for this parameter. Ultimately, CWC could best improve the validity and data grading of this value by installing an electronic record-keeping system, most likely a GIS, and ensuring that sufficient staff resources are assigned to keep the system up to date.

Step 5-2. Calculate the Number of Active and Inactive Service Connections. This is the number of customer service connections extending from the water main to supply water to a customer. This includes the actual number of distinct piping connections, including fire connections, whether active or inactive. This may differ substantially from the number of customers (or number of accounts). Note: This number does not include the pipeline leads to fire hydrants.

Enter the Number of Active and Inactive Service Connections on the Reporting Worksheet in Figure 3-5. For CWC, the auditor enters the quantity of 12,196 active and abandoned customer service lines. After this number is entered, the Audit Software automatically calculates the Service Connection Density by dividing this number by the length of mains. For CWC, the Service Connection Density is calculated and displayed as 48 connections per mile of pipeline.

Step 5-2A. Determine the appropriate Data Grading value for the Number of Active and Inactive Service Connections. The criteria listed in the Grading Matrix worksheet of the Audit Software should be consulted. Factors affecting data grading for this input include new customer account activation policies and procedures, customer information system format (paper vs. electronic), and degree of inventory discrepancy between database and field checks. CWC has a robust electronic customer billing system that manages its customer accounts; however, it uses a system of paper maps of its water distribution system. Some of the same issues in keeping good track of the Length of Mains parameter also plague the count of customer services. Notably, it is believed that the records of new piping installed in several housing developments have not yet been recorded in the mapping system; thus the new service connections are also not recorded. The CWC auditor assesses the Grading Matrix worksheet and assigns a Data Grading of 4 for this parameter. Again, CWC can best improve the validity and data grading of this value by installing an electronic record-keeping system, most likely a GIS, and ensuring that sufficient staff resources are assigned to keep the system up to date.

Step 5-3. Calculate the Average Length of Customer Service Line. This is the average length of a service connection piping under customer responsibility. Worldwide, the majority of leaks occur on customer service piping and not on water mains and appurtenances. Many water utilities have policies that require the customer to own and maintain a portion, or all, of the customer service connection piping. When leaks on service connections are detected on the portion of the piping that falls under the responsibility of the customer, leak run times are inherently much longer than leaks on the utility-owned piping. Customers are not as versed in arranging for leak repairs as the water utility, and many customers balk at the expense of this work. The IWA/AWWA Water Audit Method reflects this difference in leakage management of customer- and utility-owned service piping, and the "Average Length of Customer Service Line" refers to the average length in the water utility for which the customer is responsible for leakage repairs.

This value is determined based on the water utility's policy for leak repair responsibility and the delineation point of this responsibility, such as the curb stop or customer water meter. Figures 3-13 through 3-15 show the definition of this value in various customer service connection piping and metering configurations. Policies that require the utility to implement repairs result in faster repair times and shorter leak run times than repairs arranged by customers using contractors or plumbers. The average length needed for this parameter can be approximated if not known. If the utility's policy and practice are to place the customer water meter at the customer curb stop or property line, this value is zero since the water utility owns the service connection piping upstream of the customer water meter, which serves as the customer end point in the water audit. For customer service connection piping configurations as shown in Figure 3-13, the average length of

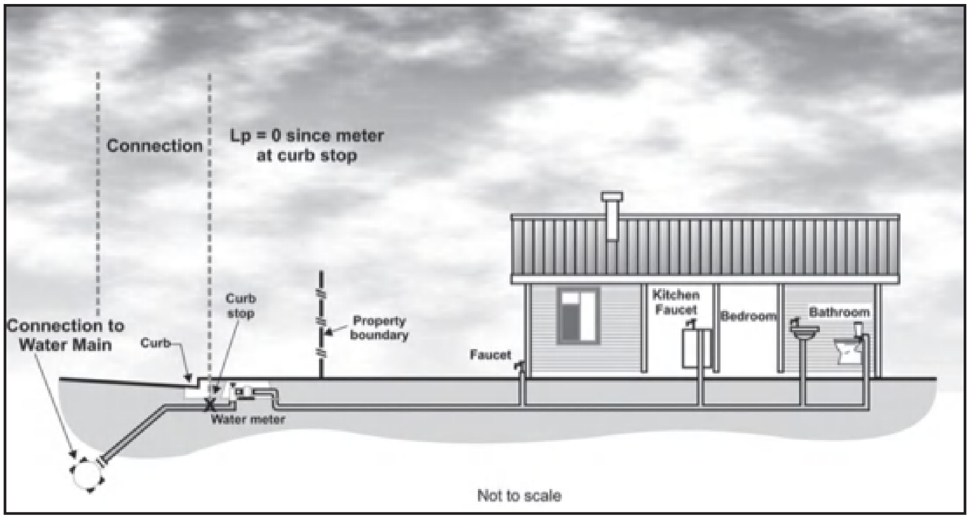


Figure 3-13 Determining the average length of customer service line, Lp, for customer meter located at the curb stop

Courtesy of Ronnie McKenzie, WRP Pty Ltd.

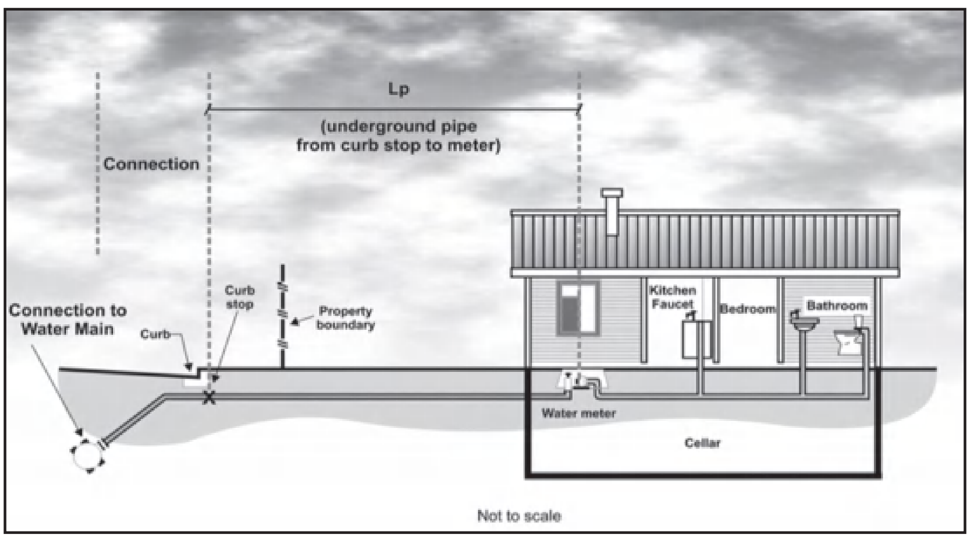


Figure 3-14 Determining the average length of customer service line, Lp, for customer meter located inside customer premise

Courtesy of Ronnie McKenzie, WRP Pty Ltd.

customer service line, Lp, is zero and the Data Grading is a 10. The Audit Software includes a question asking whether the customer water meter is located next to the curb stop or property boundary. If the auditor selects "Yes" in the dropdown box, the Audit Software automatically enters a value of zero, and a Data Grading of 10 is assigned.

Enter the Average Length of Customer Service Line on the Reporting Worksheet in Figure 3-5. In CWC, most of the customer water meters are located inside customer building premises. Based on measurements of 12–15 locations, the CWC auditor estimates that the average value for this length across the water distribution system is 18 ft.

Step 5-3A. Determine the appropriate Data Grading value for the Average Length of Customer Service Line. The criteria listed in the Grading Matrix worksheet of the Audit

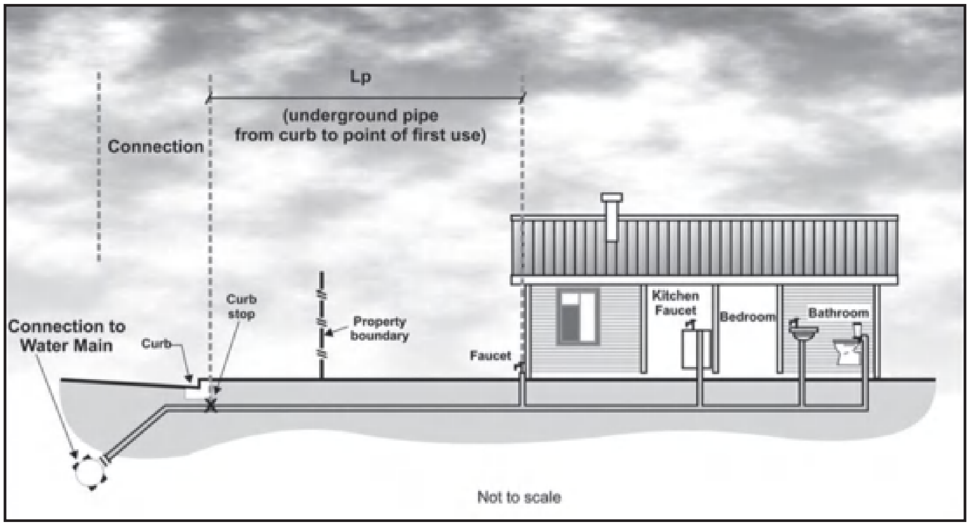


Figure 3-15 Determining the average length of customer service line, Lp, for unmetered customer properties

Courtesy of Ronnie McKenzie, WRP Pty Ltd.

Software should be consulted. Factors affecting data grading for this input include policies regarding delineation of service line ownership and responsibility between water utility and customer, customer information system format (paper vs. electronic), and degree of discrepancy between written policy and field checks. CWC has a robust electronic customer billing system that manages its customer accounts; however, it uses a system of paper maps of its water distribution system. CWC has not yet had the opportunity to do more than 12–15 field checks at varying building configurations that represent a range of service connection lengths. The CWC auditor assesses the Grading Matrix worksheet and assigns a Data Grading of 5 for this parameter. By conducting field measurements of the length of approximately 100 customer services of various configurations, CWC can significantly elevate its Data Grading for this parameter.

Step 5-4. Calculate the Average Operating Pressure. This is the average operating pressure in the distribution system that is the subject of the water audit. Many water utilities have a calibrated hydraulic model of their water distribution system that can be used to obtain a very accurate quantity of average pressure. In the absence of a hydraulic model, the average pressure may be approximated by obtaining readings of static water pressure from a representative sample of fire hydrants or other system access points evenly located across the system. A weighted average of the pressure can be assembled, but be sure to take into account the elevation of the fire hydrants, which typically exist several feet higher than the level of buried water pipelines. If the water utility is compiling the water audit for the first time, the average pressure can be approximated, but a low data grading should be assigned. In subsequent years of auditing, effort should be made to improve the accuracy of this quantity and qualify for a higher data grading. The “Determining Average Operating Pressure” sidebar, Tables 3-20 and 3-21, and Figure 3-16 give guidance on calculating the average operating pressure. Care should be taken to derive the average operating pressure value accurately, as some of the audit performance indicators are highly sensitive to any error that exists in this number.

An example calculation for determining average zone pressure in a given zone is shown in Table 3-21. The example focuses on one region of CWC’s service area: the downtown region. The water piping grid for this region is also displayed in Figure 3-16, wherein fire hydrant locations are shown as well as ground-elevation contours at 10-ft intervals.

Determining Average Operating Pressure in a Water Utility Distribution System

Water utility managers need to understand the variation of water pressure across their distribution systems to assess the potential for improved pressure management and to calculate the Unavoidable Annual Real Losses (UARL) parameter using Eq. 3-8 (later in this chapter). The UARL is typically calculated for the entire water distribution system, and the average operating pressure across the network is one of the inputs into Eq. 3-8. Although a mathematical average of the pressure throughout the water distribution system can be calculated, pressures can vary considerably from one part of the system to another, particularly if the system exists in hilly or mountainous terrain. In such cases, the utility manager should become familiar with those regions where static system pressures are notably lower or higher than the average level, and the impact of these regional pressures on leakage rates and levels of customer service. Chapters 6 and 7 discuss pressure management.

Calculating Average Pressure Across a Water Distribution System

Several means exist to determine the average system pressure with sufficient accuracy to calculate the UARL.

- A calibrated hydraulic model can be used, which can provide pressures at nodes across the water distribution system under various water demand conditions. The average pressure in each zone can be readily calculated by the data from this model, and a weighted average pressure among zones calculated for the system (see Table 3-20). In the absence of a calibrated hydraulic model, one of the following methods may be selected to approximate the average pressure.
- For water distribution systems existing across a relatively flat service area, the average pressure can be determined by gathering static pressure readings from approximately 30 fire hydrants spaced proportionally across the system. The mathematical average of these readings should be calculated. Because fire hydrants in North America are typically located aboveground, water pressure in the underground pipelines is slightly higher (1–2 psi, depending on depth) than the level measured at the fire hydrant.
- For water utilities whose distribution system extends across hilly or mountainous terrain, the distribution system should be sectioned into several distinct zones that represent different pressure regimes. In each zone, topographical data (ground-level elevations) should be gathered and a weighted average technique should be used to determine the location of the average elevation. Water pressure can be measured at the average elevation site from a fire hydrant or other system appurtenance to give a good approximation of the average pressure in the specific zone. The average pressure values from individual zones can then be used to calculate the weighted average pressure among zones for the system (see Table 3-20).

In calculating weighted average pressure among zones, the auditor should first determine miles of main and the number of connections per zone, then calculate a weighted average based on both of these parameters. The overall weighted density of connections should then be used to determine which weighting basis to use:

- If >32 connections/mile of main overall weighted density, use the number of connections as the basis for weighting.
- If ≤32 connections/mile of main overall weighted density, use miles of main as the basis for weighting.

Overall density of connections should be weighted using length of mains. Additionally, the auditor is cautioned not to use “number of billed properties” in lieu of “number of connections,” because these two values are generally not the same. An example table depicting the calculation of weighted average pressure among zones is presented in Table 3-20.

Table 3-20 Determining average operating pressure in a water utility distribution system with varying topography

Zone Reference	Length of Mains (Lm) (miles)	Number of Customer Service Connections (Ns)	Connection Density per Mile/Main	Average Zone Pressure (Pav)* (psi)	Ns × Pav	Lm × Pav
A	253.9	8,124	32.0	52.5	426,510	13,330
B	153.0	5,760	37.6	38.1	219,456	5,829
C	175.1	5,204	29.7	61.0	317,444	10,681
D	135.3	4,483	33.1	43.4	194,562	5,872
E	110.7	2,722	24.6	62.0	168,764	6,863
F	54.8	2,332	42.6	55.1	128,493	3,019
G	60.0	2,162	36.0	48.7	105,289	2,922
Column totals	943	30,787	—	Column totals =	1,560,519	
Number of zones	7	7	—	Divide by	Ns = 30,787	Lm = 943
Zone average	134.7	4,398	32.7†	System Pav estimate =	50.7	51.4
System density is >32/mile, so best estimate of system Pav =					50.7 psi	

* Average daily pressure measured at the location of the average elevation in the zone

† Weighted average, using Length of Mains as basis of weighting

The ground elevation of this region varies from 850 ft to more than 910 ft above sea level. In calculating the average operating pressure in this zone, this value can also serve as the average zone pressure if the utility is applying pressure management techniques. The example also shows the means to determine the location of the critical point and its value. See chapter 7 for the specifics of pressure management design.

Enter the Average Operating Pressure on the Reporting Worksheet in Figure 3-5. CWC is largely located in an area of relatively flat terrain, but a small portion of the system exists in an elevated area where water pressures are lower than average, and another section of the system exists in a valley where higher water pressures prevail. CWC does not have a calibrated hydraulic model of its system and relies on mapping of the system and topography along with pressure data from six locations monitored by its SCADA system to obtain a value of the average operating pressure for the entire system, which is determined to be 65 psi. The auditor for CWC enters the value of 65 psi on the Reporting Worksheet shown in Figure 3-5 for the average operating pressure.

Step 5-4A. Determine the appropriate Data Grading value for the Average Operating Pressure. The criteria listed in the Grading Matrix worksheet of the Audit Software should be consulted. Factors affecting data grading for this input include the extent of telemetry or SCADA pressure monitoring in the distribution system, the extent of pressure controls between distinct hydraulic zones, and the quality of pressure measurements data serving as the basis for the calculation of average pressure. The availability of a calibrated hydraulic model is also a strong factor. CWC operates three pressure zones, but the integrity of the valving that forms boundaries between the zones is known to be suspect; it is believed that several valves allow water to pass from one zone to another. Although CWC does have a reliable SCADA system that provides pressure at several

Table 3-21 Determining average system pressure in a section of a water utility distribution system (see Figure 3-16 for reference)

County Water Company—Downtown Region Listing of Fire Hydrants and Ground-Level Elevation

Street	Cross Street	Elevation	Street	Cross Street	Elevation
Washington	1st	850.0	Washington	W. of 3rd	865.0
1st	N. of Adams	854.0	3rd	N. of Adams	872.5
1st	N. of Jefferson	861.5	Adams	W. of 3rd	873.0
1st	N. of Madison	869.0	3rd	N. of Jefferson	879.5
Madison	1st	872.5	Jefferson	E. of 3rd	882.0
1st	N. of Monroe	877.5	Madison	W. of 3rd	885.0
Monroe	1st	879.5	Madison	E. of 3rd	888.5
1st	N. of Jackson	883.0	3rd	N. of Monroe	892.5
Jackson	1st	886.0	3rd	N. of Jackson	899.0
2nd	N. of Washington	854.5	Jackson	E. of 3rd	902.0
2nd	N. of Adams	863.0	Washington	W. of 4th	874.5
Adams	W. of 2nd	862.0	Adams	E. of 4th	883.0
2nd	N. of Jefferson	871.0	Adams	W. of 4th	882.0
Jefferson	W. of 2nd	871.0	4th	N. of Jefferson	887.0
Madison	W. of 2nd	879.0	4th	N. of Madison	893.0
2nd	N. of Monroe	885.0	Madison	E. of 4th	898.0
Monroe	W. of 2nd	884.5	4th	N. of Monroe	902.0
Jackson	W. of 2nd	890.5	4th	N. of Jackson	909.5
2nd	S. of Jackson	893.5	Jackson	W. of 4th	910.0

Weighted Average Calculations

Lower Limit	Upper Limit	Mid-point	Hydrant Count	Count Times Mid-Point	
850	860	855	3	2,565	Weighted average ground elevation = 33,480/38 = 881.0 ft
860	870	865	5	4,325	Nearest location of average zone point: 881.0 ft
870	880	875	10	8,750	Adams, W. of 4th: 882.0 ft
880	890	885	10	8,850	Measured pressure at this fire hydrant = 58 psi; for underground piping, take as 57 psi
890	900	895	6	5,370	Nearest location of zone critical point: 910.0 ft
900	910	905	4	3,620	Jackson, W. of 4th: 910.0 ft
—	—	Total	38	33,480	Measured pressure at this fire hydrant = 45 psi; for underground piping, take as 44 psi

Notes: The *average zone point (AZP)* in a zone is defined as the location of the average static water pressure. The *critical point (CP)* in a zone is defined as the location of the lowest static water pressure. The auditor is cautioned not to assume that the AZP is the average of the zone inlet and CP pressures. In this example, the AZP and CP are taken as the location of the average and highest elevations, respectively. It is recognized that the locations of the AZP and CP are influenced by both elevation and the level of head loss in the distribution system. Identifying these locations is therefore most accurate when using a hydraulic model. However, the method shown in this example gives a reliable way to identify the AZP and CP with limited data collection needs.

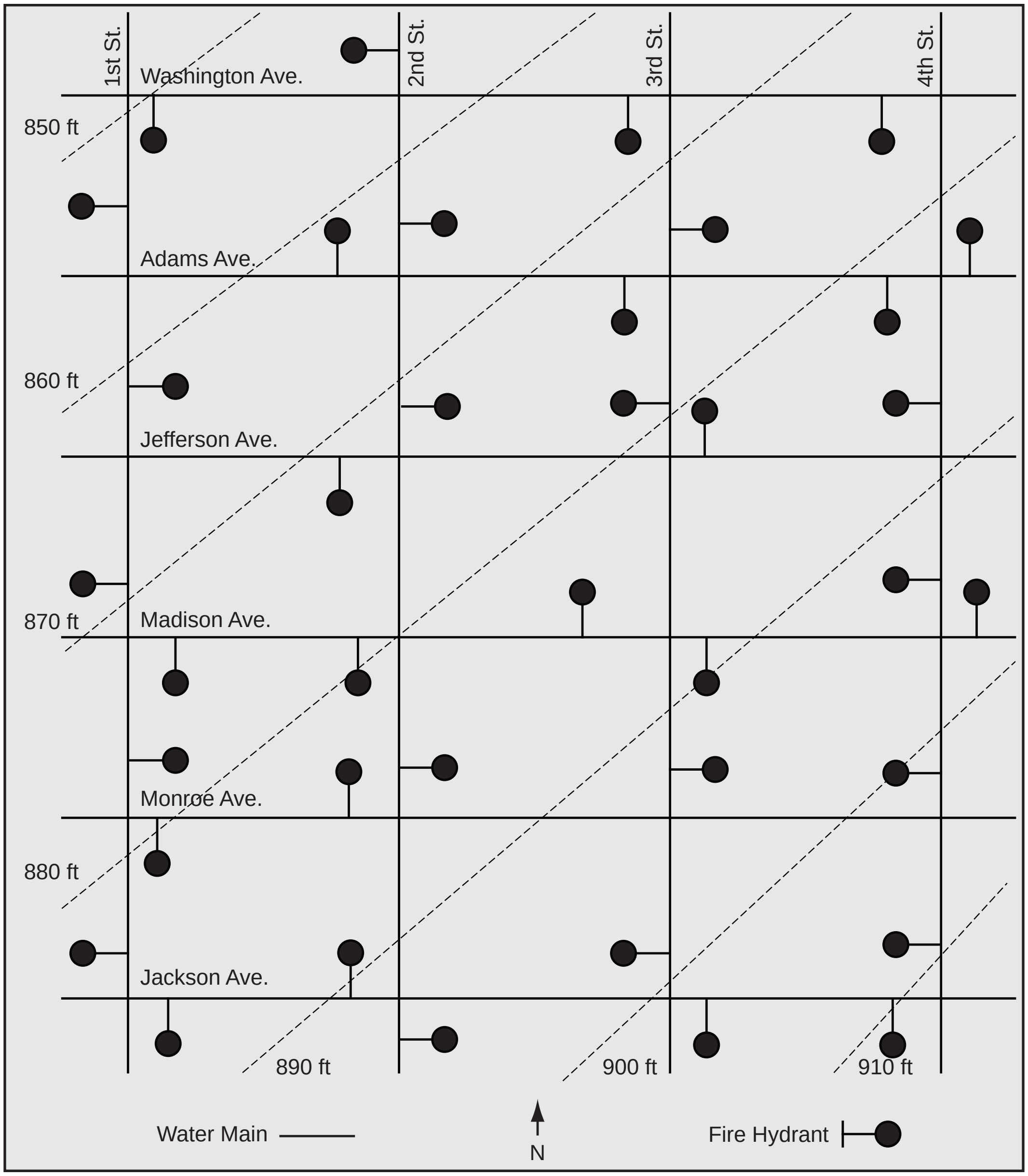


Figure 3-16 Map of fire hydrants in a section of a water utility distribution system (used to assist the calculation of average operating pressure)

locations, the auditor did not have the time or resources to gather additional pressure data from a sample of fire hydrants across the system. Since the calculation of average operating pressure is based on very limited data, the auditor assigns a Data Grading of 3 to this parameter.

Step 5-5. Calculate the Total Annual Cost of Operating Water System. These costs include those for operations, maintenance, and any annually incurred costs for long-term upkeep of the drinking water supply and distribution system. This value should include the costs of day-to-day upkeep and long-term financing such as repayment of capital bonds for infrastructure expansion or improvement. Typical costs include employee salaries and benefits, materials, equipment, insurance, fees, administrative costs, and all other costs that exist to sustain the drinking water supply. Depending on water utility accounting procedures or regulatory agency requirements, it may be appropriate to include depreciation in the total of this cost. This cost should not include any costs to operate wastewater, biosolids, or other systems outside of drinking water.

Enter the Total Annual Cost of Operating Water System on the Reporting Worksheet in Figure 3-5. The auditor for CWC requested that the accounting department of the company assemble the needed data to calculate this cost, which was determined to be $9,600,000.

Step 5-5A. Determine the appropriate Data Grading value for the Total Annual Cost of Operating Water System. The criteria listed in the Grading Matrix worksheet of the Audit Software should be consulted. Factors affecting data grading for this input include the cost accounting system format (paper vs. electronic), the extent of pertinent costs that are tracked, and the extent and frequency by which the cost information is audited. CWC maintains a highly robust financial and cost accounting computer application, which includes routine monthly and annual reporting of all data. A certified public accountant (CPA) conducts an audit of the finances every other year. CWC is managing its finances with a high degree of rigor, and the auditor assigns a Data Grading of 9 for this parameter. CWC need only increase the frequency of its CPA financial audit to yearly in order to qualify for a Data Grading of 10 for this cost component.

Step 5-6. Calculate the Customer Retail Unit Cost. The Customer Retail Unit Cost represents the charge that customers pay for water service. This unit cost is applied routinely to the components of Apparent Loss, since these losses represent water reaching customers but not (fully) paid for. Since most water utilities have a rate structure that includes a variety of costs based on class of customer, a weighted average of individual costs and number of customer accounts in each class can be calculated to determine a single composite cost that should be entered into this cell. Finally, the weighted average cost should also include additional charges for sewer, stormwater, or biosolids processing, but only if these charges are based on the volume of potable water consumed. Water utilities can avail themselves of the services of consultants who specialize in water rates and charges if they need assistance in structuring or assessing their water rate structure.

For water utilities in regions with limited water resources and a questionable ability to meet the drinking water demands in the future, the Customer Retail Unit Cost might also be applied to value the Real Losses, instead of applying the Variable Production Cost to Real (leakage) Losses. In this way, it is assumed that every unit volume of leakage reduced by leakage management activities will be sold to a customer. As noted below, the Audit Software provides the auditor a means of selecting to apply the Customer Retail Unit Cost to Real Losses.

Enter the Customer Retail Unit Cost on the Reporting Worksheet shown in Figure 3-5. Note: The Audit Software requires the user to select the appropriate units that are charged to customers (either $/1,000 gallons, $/hundred cubic feet, or $/1,000 litres) and automatically converts these units to the units that appear in the "Water Supplied" box. The monetary units are US dollars, $. When the auditor enters the cost into the Cost cell, the cell to the right of it presents a message to alert the auditor to select the appropriate units from a dropdown box that appears. The auditor for CWC obtains the data from its water rates consultant and it is $3.95/1,000 gallons.

Step 5-6A. Determine the appropriate Data Grading value for the Customer Retail Unit Cost. The criteria listed in the Grading Matrix worksheet of the Audit Software should be consulted. Factors affecting data grading for this input include the complexity of the utility's water rate structure and the nature of the averaging method (simple vs.

weighted) used among distinct customer classes. CWC has a longstanding relationship with a reputable water rates consultant who provided this cost value. The water rate structure is reviewed once every three years, and revisions to the rate structure have occurred at an average rate of once every four years over the past 20 years. CWC's water rate structure is well managed and there is a high degree of validity in this unit cost value. Thus, the auditor assigns a Data Grading of 10 for this parameter.

Step 5-7. Calculate the Variable Production Cost. Lastly, real losses should be valued at an appropriate rate. The cost rate, which depends on the local economic and water resource considerations of the utility, can vary

- from, at lowest, the short-term variable production costs or bulk supply purchase cost (or combination thereof), plus variable treatment and pumping costs;
- to, at highest, the customer retail rate, in situations where water resources are very constrained and every drop of abated leakage can be projected as water sales to a customer.

Assessing costs for real losses can be complex, but the methods included in this manual allow the auditor to keep the evaluation simple. Real losses include water that has been extracted from a water source, treated, energized, and transported a distance before being lost from the distribution system. Because these quantities of loss occur in addition to the water successfully supplied to customers, real losses effectively impose on the water utility excess extraction, treatment, and delivery charges, and/or excess imported water purchase charges. This variable, or marginal, production cost includes, but is not limited to, the basic costs to provide the next unit (e.g., million gallons) of water, which is typically the costs of treatment and power for pumping to convey the water through the distribution system. If water is purchased from another water utility, the unit purchase cost is used. Some systems may supplement internal sources with purchased imported water. Most drinking water utilities compile all of these costs, and the data are readily available.

Other long-term costs also exist for real losses. Pertinent additional costs beyond power, treatment, and imported water purchase costs (if applicable) such as liability for damages, residuals management, and depreciation from wear and tear on equipment should be considered if applicable, especially if real losses are high. A utility's capital improvement plan can be consulted to check for any impending expansion of supply or treatment capacity, which may justify a substantial "avoided cost" value to be assigned to the reduction of real losses.

Additionally, because real losses represent volumes of water taken from a source that do not generate a benefit, these losses could also be assessed costs relating to their environmental, economic, and social impacts. Reducing leakage could mean smaller withdrawals from a river, which could improve instream flows, benefiting aquatic life, recreation (boating, fishing), or economic development (waterfront amenities). Clearly, in the long term, such impacts exist. Because these impacts are difficult to quantify and are system specific, methods to derive them are not included in this manual. If any costs are missing, an estimate can be used until a separate cost assessment can be performed at a later time.

The simplest method to derive Variable Production Cost is to sum the annualized costs for all applicable items described above in dollars and divide this sum cost by the sum of Volume From Own Sources and Water Imported (defined in Task 1) in million gallons, yielding an answer in units of $/mil gal.

Another situation for consideration is that of a water utility facing extremely constrained water resources with water-use restrictions in effect. In this case, real losses might be valued at the retail rate (same as apparent losses) because the reduction of these losses could result in the sale of like volumes of water to customers, thereby allowing new development to occur without increasing water withdrawals. The Audit Software includes

Table 3-22 Component values of the UARL calculation

Infrastructure Component	Background (undetectable) Leakage	Reported Leaks and Breaks	Unreported Leaks and Breaks
Mains or pipelines	8.5 gal/mi/hr	0.20 breaks/mi/year at 50 gpm for 3 days' duration	0.01 breaks/mi/year at 25 gpm for 50 days' duration
Service connections, main to curb stop	0.33 gal/service connection/hr	2.25 leaks/1,000 service connections at 7 gpm for 8 days' duration	0.75 leaks/1,000 service connections at 7 gpm for 100 days' duration
Service connections, curb stop to meter or property line (for 50 ft average length)	0.13 gal/service connection/hr	1.5 leaks/1,000 service connections at 7 gpm for 9 days' duration	0.50 leaks/1,000 service connections at 7 gpm for 101 days' duration

Note: All flow rates are specified at a reference pressure of 70 psi.

Source: *Lambert et al. 1999*

a check box to the right of the Variable Production Cost cell, which the auditor should select if he or she desires to apply the Customer Retail Unit Cost to the valuation of Real (leakage) Losses.

Enter the Variable Production Cost on the Reporting Worksheet shown in Figure 3-5. The auditor for CWC obtains this value from the accounting unit of the company, which is $190/mil gal.

Step 5-7A. Determine the appropriate Data Grading value for the Variable Production Cost. The criteria listed in the Grading Matrix worksheet of the Audit Software should be consulted. Factors affecting data grading for this input include the cost accounting system format (paper vs. electronic), the extent of pertinent costs that are included in the calculation, and the extent and frequency by which the cost information is audited. CWC maintains a highly robust financial and cost accounting computer application, which includes routine monthly and annual reporting of all data. CWC includes pertinent indirect costs for liability, residuals management, and equipment degradation. A CPA conducts an audit of the finances every other year. CWC is managing its finances with a high degree of rigor, and the auditor assigns a Data Grading of 9 for this parameter. CWC need only increase the frequency of its CPA financial audit to yearly to qualify for a Data Grading of 10 for this cost component. Although CWC is located in a semi-arid region, it has a reliable long-term water supply from a mountain reservoir system operated by a regional water authority. Thus the auditor does not believe that the long-term water supply outlook is constrained, and the variable production cost should be applied to Real Losses rather than the Customer Unit Retail Cost.

Task 6—Determine System Attributes

Step 6-1. Calculating Unavoidable Annual Real Losses (UARL). The UARL is a reference value and does not refer to a specific type of leakage occurring in the water distribution system. The UARL represents the minimum level of leakage that is calculated in a system-specific manner for a water utility. It represents the theoretical low limit of leakage that could be achieved in a system that is well managed and in good condition, at a given average pressure level.

The derivation of the UARL calculation is given in Tables 3-22 and 3-23. Equation 3-8 represents the calculation for the UARL for an individual water distribution system. The data needed to calculate the UARL are typically available to water utility staff and include the

Table 3-23 Standard unit values used for the UARL calculation

Infrastructure Component	Background Leakage	Reported Leaks and Breaks	Unreported Leaks and Breaks	UARL Total*	Units
Mains, gal/mi of main/d/psi	2.87	1.75	0.77	5.4	Gal/mi of main/d/psi
Service connections, main to curb stop, gal/service connection/d/psi	0.112	0.007	0.030	0.15	Gal/service connection/d/psi
Service connections, curb stop to meter, gal/mi of service connection/d/psi	4.78	0.57	2.12	7.5	Gal/mi of service connection/d/psi

* The UARL is calculated via Eq. 3-8.

Source: *Lambert et al. 1999*

- total length of water main piping in the distribution system;
- average operating pressure across the distribution system;
- number of active and inactive customer service connections; and
- miles of service connection piping maintained by the water customer, taken as the average length of customer service line, Lp (see Step 5-3), multiplied by the number of customer service connections (see Step 5-2).

The UARL calculation was devised by the IWA Water Loss Specialist Group (formerly the Water Loss Task Force) during its development of the water audit method. In conducting work to develop a reliable benchmarking performance indicator (the Infrastructure Leakage Index, or ILI), the Water Loss Specialist Group determined to devise a means to evaluate the technical low limit of leakage that could be expected to be achieved in a given water distribution system. It is recognized that leakage in any water distribution system can never be totally eliminated, and there is no reasonable expectation that such is possible. However, several water utilities have been successful in driving leakage down to extremely low levels and maintaining very low-loss operations.

The Water Loss Specialist Group obtained data from dozens of water utilities with strong leakage control practices and observed the rate at which new leaks arise despite having comprehensive leakage controls in place. From this information, data allowances were created for various leak types according to response times typical of strong leakage management operations. The allowances were developed for the three leak types: background leakage, reported leakage, and unreported leakage. These types are defined and discussed in chapters 6 and 7. An allowance for each leakage type was assigned for key infrastructure components, such as water mains, customer service connection piping maintained by the water utility, and customer service piping typically maintained by the customer.

Leakage events serving as the basis for these allowances are shown in Table 3-22. The equivalent leakage rates that occur under the conditions in Table 3-22 are shown in Table 3-23. The Audit Software Reporting Worksheet shown in Figure 3-5 shows data for CWC (miles of water main, average pressure, average length of customer service line, and number of customer active and inactive service connections) that is used to calculate the UARL value.

$$\text{UARL (gal)} = (5.4L_m + 0.15Nc + 7.5Lc) \times P \times 365 \text{ d/year} \tag{3-8}$$

Where:

L_m = length of water mains (miles; including hydrant lead length)

Nc = number of customer service connections

Lc = total length of customer service connection line (miles)
(Nc × Lp)/5,280 ft/mi, where Lp = average length of customer service line (ft, see Figures 3-13 through 3-15)

P = average operating pressure in the system (psi)
In Eq. 3-8, 365 d/year is included given that water distribution systems in developed countries operate with continuous service for all 365 days in the audit year. For systems that operate with intermittent service, the number of days that the system was operated should be used instead of 365 days.

Note: The UARL calculation is not valid for small systems that meet the following condition:

- in gallons per day: (L_m × 32) + Nc < 3,000 or P < 35 psi
- in litres per day: (L_m × 20) + Nc < 3,000 or P < 25 m

Systems at or below these levels can rely on the Real Losses performance indicator, in gallons per mile of main per day, as a measure of their real loss standing.

For CWC, the UARL is calculated by the Audit Software to be 83.69 mil gal for the audit year. This is shown in the System Attributes and Performance Indicators worksheet shown in Figure 3-6.

Step 6-2. Calculating the Cost Impact of Apparent and Real Losses. The process of compiling a water audit is effective in tracing the water supplied by a drinking water utility to its various destinations; primarily customers but also including losses. Of equal importance, however, the method detailed in this publication also assesses the cost impact of all water audit components. Water utilities, like any business entity, cannot operate efficiently without knowing their costs and impacts on budgeting, operations, revenue collection, capital financing, and all other financial aspects of utility management. The Audit Software provides a means to calculate costs for each of the pertinent components in the water audit calculated on the System Attributes and Performance Indicators worksheet (Figure 3-6).

The nature of the valuation process of the water audit is compelling in the stark difference between apparent and real losses. Because apparent losses are quantified by the amount of water improperly recorded at the customer's delivery point, this water is valued at the retail cost that is charged to the customer. Apparent losses cost water utilities a portion of their revenue. Often, the cost impact of apparent losses is higher than that of real losses, which are typically valued at the variable production costs to treat and deliver the water (however, if water resources are constrained, the utility might also be justified in valuing real losses at the customer retail rate). For most water suppliers, the retail rate charged to customers is notably higher than the variable production costs to provide the water. Therefore, apparent losses can have a dramatic financial impact to the water utility's revenue stream.

Step 6-2A. Cost impact of Apparent Loss components. To determine the total cost impact of apparent losses, the Audit Software multiplies the Apparent Losses volume by the Customer Retail Unit Cost (which is converted to $/mil gal by the Audit Software if gallons units are selected on the Reporting Worksheet by the auditor.)

The System Attributes and Performance Indicators worksheet shown in Figure 3-6 displays the calculated Annual Cost of Apparent Losses, which for CWC is $821,449 for the audit year.

Step 6-2B. Cost impact of Real Loss components. To determine the total cost of real losses, the Audit Software multiplies the Real Losses volume by the Variable Production Cost. If the auditor deemed it justified to assess the cost of real losses at the Customer Retail Unit Rate, the total cost of real losses would be determined by multiplying the Real Losses volume by the Customer Retail Unit Cost in $/mil gal.

The System Attributes and Performance Indicators worksheet shown in Figure 3-6 displays the calculated Annual Cost of Real Losses, which for CWC is $139,934 for the audit year.

Task 7—Performance Indicators

The IWA/AWWA Water Audit Method published in *Performance Indicators for Water Supply Services* (Alegre et al. 2000) includes a highly useful array of performance indicators, which represent one of the greatest strengths of the method. With this methodology, multiple indicators of varying detail became available to water utilities, allowing a realistic assessment of water loss standing. The performance indicators published in 2000 are defined in Table 3-24 and are endorsed by the AWWA Water Loss Control Committee. These performance indicators appear throughout this manual and within the AWWA Free Water Audit Software.

Prior to 2000, the sole performance indicator used in many parts of the world had been the imprecise "unaccounted-for" water percentage, which usually took some form of the amount of water losses over system input volume. Several flaws existed in this approach, including the following:

- Practices to define the volume of unaccounted-for water varied widely; therefore, the calculation of this percentage has been widely inconsistent, eliminating any meaning for reliable performance comparisons.
- This indicator is highly sensitive to the level of customer consumption in the water utility. If consumption increases or decreases noticeably, the percentage can change, despite that no change in loss levels may have occurred.
- This indicator does not segregate apparent and real losses. Also, it includes no information on water volumes and costs, the two most important parameters in assessing water loss.

Some have used the inverse of the unaccounted-for water percentage or the *metered water ratio* as the amount of billed water over the system input volume. Even the name of this *indicator* is misleading, as some drinking water utilities do not meter their customers. The concept behind both of these expressions was reviewed in the development of the method detailed in this manual, and led to the creation of a specifically defined performance indicator of NRW by volume. This new indicator has some value but only as a high-level financial indicator, and it is not sufficiently detailed to be useful as an operational indicator. NRW is the sum of Unbilled Metered Consumption, Unbilled Unmetered Consumption, Apparent Losses, and Real Losses. This indicator is calculated by the Audit Software as the NRW volume divided by the Water Supplied volume.

The method includes performance indicators in financial and operational areas of water supply functions. The performance indicators were also established in three levels of detail—labeled 1, 2, and 3—representing high level, broad indicators (1) down to very

Table 3-24 IWA/AWWA Water Audit Method—Performance indicators

Function	Level*	Code*	Performance Indicator	Comments
Financial: Non-revenue water (NRW) by volume	1 Basic	Fi36	Volume of NRW as a percentage of system input volume	Easily calculated from water audit data; has limited value in high-level financial terms only; it is misleading to use this as a measure of operational efficiency. This indicator should not be used for year-to-year tracking or for benchmarking with other water utilities.
Financial: NRW by cost	3 Detailed	Fi37	Value of NRW as a percentage of the annual cost of running the system	Incorporates different unit costs for non-revenue components; good financial indicator; should not be used for long-term performance tracking by the water utility or for benchmarking with other utilities.
Operational: Apparent Losses	1 Basic	Op23	[gal/service connection/d]	Basic but meaningful performance indicator for apparent losses. Easy to calculate once apparent losses are quantified.
Operational: Real Losses	1 Basic	Op24	[gal/service connection/d] or [gal/mi of mains/d] (only if service connection density is less than 32/mi)	Best of the simple "traditional" performance indicators; useful for target-setting; limited use for comparisons between systems.
Operational: Real Losses	2 Intermediate	—	[gal/service connection/d/psi] or [gal/mi of mains/d/psi] (only if service connection density is less than 32/mi)	Divides the Op24 performance indicator by the average system pressure. Easy to calculate this indicator if the Infrastructure Leakage Index (ILI) is not yet known; useful for comparisons between systems.
Operational: Unavoidable Annual Real Losses (UARL)	3 Detailed	UARL	UARL (gal) = (5.41Lm + 0.15Nc + 7.5Lc) × P × 365 d/year (Eq. 3-8) Where: Lm = length of water mains, miles Nc = number of service connections Lc = total length of private service connection pipe, miles where Lc = Nc × average distance from curb stop to customer meter, Lp (see Figures 3-13 through 3-15) to determine Lp P = average pressure in the system, psi	A theoretical reference value representing the technical low limit of leakage that could be achieved if all of today's best technology could be successfully applied. A key variable in the calculation of the ILI. The UARL calculation has not yet been proven fully valid for very small or low-pressure water systems. In Eq. 3-8, 365 d/year is included given that water distribution systems in developed countries operate with continuous service for all 365 days in the audit year. For systems that operate with intermittent service, the number of days that the system was operated should be used instead of 365 days.
Operational: Real Losses	3 Detailed	Op25	ILI (dimensionless) = CARL/UARL	Ratio of Current Annual Real Losses (CARL) to UARL; best indicator for comparisons among systems. This indicator is best applied only after sufficient water audit data validity is achieved and all justifiable pressure management is complete.

* Descriptors assigned to the performance indicators in the IWA publication *Performance Indicators for Water Supply Services* (Alegre et al. 2000).

detailed indicators (3). The method includes performance indicators at each of these levels as shown in Table 3-24.

The full array of performance indicators is automatically calculated by the Audit Software after entering all the input data. Individually, these performance indicators give good insight to the loss standing in particular functional areas. Collectively, they give a very realistic, objective assessment of overall loss standing in the water utility and are viewed as the current best practice means to assess water loss standing in water utilities.

Step 7-1. Financial performance indicators. The water audit method includes two financial performance indicators that are useful in assessing a water utility's fiscal standing regarding water losses.

Step 7-1A. Non-Revenue Water by Volume. The first indicator is expressed as a percentage of the volume of NRW over the Water Supplied volume and labeled as Fi36 on Table 3-24. This performance indicator is closest in its definition to the conceptual unaccounted-for water percentage used inconsistently in the past. However, by employing the specifically defined NRW in the numerator, this performance indicator avoids the inconsistencies that have crippled the interpretation of unaccounted-for-water percentages. This indicator has some usefulness but only on a high-level financial basis to assess overall water supply management. Because it does not provide specific insight to the level of apparent loss or real loss management and is skewed by varying levels of customer consumption, it is not useful as an operational performance indicator. **Thus, the performance indicator Non-Revenue Water by Volume should <u>not</u> be used for year-to-year operational performance tracking by water utilities nor by water utilities to compare or benchmark their operational performance with other water utilities. This performance indicator should <u>not</u> be used in any type of regulatory rulemaking.**

As shown in the System Attributes and Performance Indicators worksheet in Figure 3-6, the financial performance indicator for CWC known as Non-Revenue Water as Percent by Volume of Water Supplied, is calculated to be 26.0 percent.

Step 7-1B. Non-Revenue Water by Cost. The second financial performance indicator is very revealing by quantifying the financial impact to the water utility from losses. This indicator is expressed as the cost of non-revenue water over the total annual cost of running the water supply system, or non-revenue water by cost. These latter costs include those for operations, maintenance, and any annually incurred costs for long-term upkeep of the system, such as repayment of capital bonds for infrastructure expansion or improvement. Typical costs include employee salaries and benefits, materials, equipment, insurance, fees, administrative costs, and all other costs that exist to sustain the drinking water supply. Depending on water utility accounting procedures or regulatory agency requirements, it may be appropriate to include depreciation in the total of this cost. The annual costs of operating the water supply system should not include any costs to operate wastewater, biosolids, or other systems outside of drinking water.

This performance indicator gives important insight to water utility managers, the financial community, regulators, customers, and advocacy groups about the overall financial impact of losses on the water utility. It is an important indicator that could be referenced when issuing bonds, setting water rates, communicating to customers, or employing other financial or public relations functions typically undertaken by water utilities. A water utility can use this indicator to assess their ongoing financial performance, but for only a short-term horizon unless the time value of money is factored into the costs assembled during the water audit. **The performance indicator Non-Revenue Water by Cost should <u>not</u> be used for long-term operational performance tracking by water utilities nor by water utilities to compare or benchmark their operational performance with other water utilities.**

As shown in the System Attributes and Performance Indicators worksheet in Figure 3-6, the financial performance indicator for CWC known as Non-Revenue Water as Percent by Cost is calculated to be 10.4 percent. Because this is a more detailed indicator than Non-Revenue Water as Percent by Volume of Water Supplied, its value of 10.4 percent is a better reflection of the financial impact of losses occurring in CWC. On its own, Non-Revenue Water as Percent by Volume of Water Supplied appears to overstate the impact of losses on CWC.

Step 7-2. Operational performance indicators. The method also includes five operational performance indicators. These indicators include basic (1), intermediate (2), and detailed (3) levels of representation. As shown in Table 3-24, one performance indicator exists for Apparent Losses and four indicators exist for Real Losses.

Step 7-2A. Apparent Losses normalized (Op23 basic indicator). This performance indicator, measured in gallons of apparent losses per service connection per day, is effective in assessing apparent loss standing and is useful to track year-by-year improvements as apparent loss controls are implemented. It is important to recognize that the cost impact of apparent losses is also an important parameter to track, particularly because the valuation of apparent losses at the retail customer rate is typically substantial. Apparent loss costs represent revenue that can be potentially recovered, a portion of which can often occur with very modest recovery effort. Also, it is highly important to note that whenever the water utility enacts a water rate increase, the cost impact of apparent losses increases at a commensurate level.

As shown in the System Attributes and Performance Indicators worksheet in Figure 3-6, Apparent Losses per Service Connection per Day for CWC is calculated to be 46.78 gallons per service connection per day. The cost impact of apparent losses is $821,449 for the audit year.

Step 7-2B. Real Losses normalized. Two normalized performance indicators exist for real losses: a basic indicator and an intermediate indicator.

Step 7-2B1. Real Losses normalized (Op24 basic indicator). The basic indicator has two versions. For most North American water utilities, it is measured in units of gallons of real losses per service connection per day. However, for water utilities with a low density of service connections (such as rural systems), this indicator is measured in gallons per mile of main per day. Those systems that have a systemwide average density of less than 32 service connections per mile of main should apply the latter indicator.

As shown in the System Attributes and Performance Indicators worksheet in Figure 3-6, Real Losses per Service Connection per Day for CWC is calculated to be 165.45 gallons per service connection per day. The cost impact of real losses is $139,934 for the audit year.

In the Audit Software, the appropriate version of the Real Losses indicator is automatically calculated based on system attributes.

The basic performance indicator is effective for trending the status of real losses in a water utility and for basic target-setting. As leakage management controls are successfully implemented, the downward trend in this measure should be observed.

Step 7-2B2. Real Losses normalized (Op24 intermediate indicator). The intermediate indicator is the same form as the basic indicator, but it is divided by the average operating pressure in the system. It also has two versions: gallons of real losses per service connection per day per psi except for water utilities with a low density of service connections (such as rural systems) wherein this indicator is measured in gallons per mile of main per day per psi. Those systems that have a systemwide average density of less than 32 service connections per mile of main should apply the latter indicator. Note: the Audit Software does not calculate the low-density-system version of this performance indicator.

As shown in the System Attributes and Performance Indicators worksheet in Figure 3-6, Real Losses per Service Connection per Day per psi for CWC is calculated to be 2.55 gallons per service connection per day per psi of pressure.

Step 7-2B3. Unavoidable Annual Real Losses (UARL). This is a reference value used to calculate the ILI. The derivation and calculation of the UARL are described in Step 6-1. The use of the UARL to calculate the ILI is described in Step 7-2B4.

Step 7-2B4. Infrastructure Leakage Index (ILI). The ILI is a performance indicator designed for benchmarking of leakage standing among water utilities over a certain size (see Step 6-1 for UARL limitations). For water utilities that are just starting to audit their supply, the ILI can also be used as a preliminary target-setting mechanism (see chapter 7). Setting targets via the ILI carries a caveat, however: Because average pressure is included in the UARL and ILI calculations, changes in pressure (as might be performed in pressure management strategies) will alter the UARL and ILI. It is possible that leakage reductions might be achieved via improved pressure management, yet the ILI may remain unchanged, or even rise. Once a water utility has moved past its initial water auditing and loss control efforts, with the DVS falling at least in the Level III criteria, the ILI should serve only as a benchmarking indicator. Real losses reduction can then be tracked via the Op24 basic performance indicator.

The ILI is calculated as the ratio of the level of CARL (Step 3-3) to the UARL (Step 6-1).

For CWC, the CARL is 736.49 mil gal and the UARL is calculated to be 83.69 mil gal for the year. The ILI is calculated as the ratio of CARL over UARL and is determined to be 8.8, or a current level of real losses 8.8 times greater than the technical low level that could be achieved, in theory, if all possible leakage interventions were successfully applied.

Water audit data and performance indicators are reported for several water utilities and included in appendix E.

Task 8—Compile the Water Balance

After all data is entered into the Audit Software, quantities from the key consumption and loss components can be shown on the water balance. The completed water balance for CWC is shown in Figure 3-2 and is automatically populated in the Audit Software. It can be seen that the summation of the component volumes in each column moving left to right is 4,402.16 mil gal; hence all flows "balance." The water balance reflects that all water managed by the drinking water utility is accounted for in the various categories of consumption and loss. Hence, no water is "unaccounted for," and no such term exists in the recommended water audit method.

It is recognized that by quantifying the amount of real losses as the residual volume that is left after subtracting authorized consumption and apparent losses from water supplied, the data is forced to balance. The discussion under Step 3-3 notes that this does not necessarily represent a wholly accurate quantification of the real losses because inaccuracies in the quantities reported for water supplied, authorized consumption, or apparent losses could induce a degree of error in the real loss value. The reader is referred to the "Leakage Component Analysis" section in chapter 7 to learn of the methods and tools to rigorously quantify and assess leakage volumes in a systematic way that guides strategic leakage management planning.

Task 9—Assess the Data Validity Score

After all data is entered into the Audit Software and performance indicators are reviewed, the auditor should review the DVS calculated for the water audit and reference the Water Loss Control Planning Guide worksheet to determine in which of the five levels the water utility resides. This worksheet gives general guidance to the auditor on their loss control efforts.

For CWC, the DVS is 66, which places them in Level III of the Water Loss Control Planning Guide shown in Figure 3-8.

With a DVS placing them in Level III of the Water Loss Control Planning Guide, CWC exists in the intermediate level of data validity. Thus it can place sufficient trust in its data that it can begin to strategize and launch loss control interventions in specific areas, such as customer meter testing, increased leak detection, and better assessments of unauthorized consumption. At Level III it can also begin to reliably use the performance indicators to track its ongoing loss control performance from year to year and may begin to compare its data with other water utilities, preferably utilities that have similar characteristics to CWC. CWC should refer again to the Grading Matrix worksheet for each of the individual components that stand with a low value of data grading. Guidance is provided in this worksheet on steps that the utility can take to improve its data validity/data grading and make improvements in its operations.

At this stage, CWC has completed its water audit for the audit year. The manager for CWC can now proceed to implement needed loss control interventions, as described in chapters 4 through 7 of this manual.

SUMMARY

Water utility managers can assemble the top-down water audit by gathering records, data, and procedures from various operations routinely occurring in their provision of drinking water. The top-down water audit is largely a desktop exercise, with minimal field testing or investigations required. The advantage is that the top-down audit can be assembled relatively quickly and give a reasonable sense of the utility's accountability status and the nature and extent of its losses. It is extremely important that the water utility verify the accuracy of its source meters and correct any gross malfunctions of these devices as part of the top-down process. To refine the top-down water audit and formulate strategies to cut losses, work should then shift to the bottom-up approach. Over time, bottom-up activities should be pursued to better audit and control apparent losses (described in chapters 4 and 5) and real losses (described in chapters 6 and 7).

REFERENCES

Alegre, H., W. Hirner, J. Baptista, and R. Parena. 2000. *Performance Indicators for Water Supply Services*. Manual of Best Practice series. London: IWA Publishing.

AWWA (American Water Works Association). 2006. Manual M33. *Flowmeters in Water Supply*. Denver, Colo.: AWWA.

AWWA (American Water Works Association). 2012. Manual M6. *Water Meters—Selection, Installation, Testing, and Maintenance*. Denver, Colo.: AWWA.

AWWA (American Water Works Association). 2014a. Manual M22. *Sizing Water Service Lines and Meters*. Denver, Colo.: AWWA.

AWWA (American Water Works Association). 2014b. Water Loss Control Resource Community, www.awwa.org/resources-tools/water-knowledge/water-loss-control .aspx. Accessed Nov. 11, 2014.

Kunkel, G., et al. 2003. Water Loss Control Committee report: Applying worldwide BMPs in water loss control. *Journal AWWA*, 95(8):65–79.

Lambert, A., T.G. Brown, M. Takizawa, and D. Weimer. 1999. A review of performance indicators for real losses from water supply systems. *Aqua*, 48(6):227.

WRF (Water Research Foundation). 2011. *Accuracy of In-Service Meters at Low and High Flow Rates*. Denver, Colo.: WRF.

This page intentionally blank.

Chapter 4

The Occurrence and Impacts of Apparent Losses

Water losses include the water volumes that do not achieve beneficial use or that cost utilities a portion of the revenue to which they could otherwise recover. Water losses in drinking water utilities occur as two distinct types. *Real losses* are the physical losses from distribution systems, and include leakage and overflows of treated drinking water from storage reservoirs/tanks. *Apparent losses* are the nonphysical losses that occur when water is successfully delivered to a water user but, for various reasons, is not measured or recorded accurately, thereby inducing a degree of error in the amount of actual customer consumption. When apparent losses occur systematically in an appreciable volume, the aggregate measure of water consumption can be greatly distorted and cause significant revenue loss.

Apparent losses are considered nonphysical losses in that no water is physically lost from the water distribution system due to pipeline, equipment, or operator failure, which are the causes of real, or physical, losses. However, the metering, accounting, and data handling inefficiencies that constitute apparent losses of the water utility can have a significant impact. They are caused by faulty, improperly sized, or badly read water meters; corruption of water consumption data in billing systems; and water that is taken from the distribution system by users without proper authorization. Apparent losses consist of three primary components:

1. Systematic data handling errors in tracking customer consumption, particularly in customer billing systems;*

* This component was established by the AWWA Water Loss Control Committee and does not explicitly exist in the definition of apparent losses established by the International Water Association (IWA) Water Loss Task Force in the IWA publication Manual of Best Practice: *Performance Indicators for Water Supply Services* (Alegre et al. 2000).

2. Customer metering inaccuracies; and
3. Unauthorized consumption.

The causes of certain apparent losses are readily identified, but a number of components of apparent loss are subtle and assumptions must be made to quantify these occurrences. These assumptions can be verified as bottom-up investigations are conducted and the water loss control strategy develops. This chapter explains the causes of apparent losses and describes the significant impacts that these losses exert on consumption data integrity and revenue recovery in systems with metered customers. Insight into quantifying apparent losses is given in chapter 3, while strategies and programs to economically control apparent losses are detailed in chapter 5.

HOW APPARENT LOSSES OCCUR

Apparent losses occur as a result of inefficiencies in the measurement, recording, archiving, and accounting operations used to track water volumes in a water utility. These inefficiencies can be caused by inaccurate or improperly sized customer meters, poor meter reading, and lapses in the billing and accounting practices of the customer billing system. Apparent losses also occur from unauthorized consumption, which is caused by individual customers or others tampering with meters or meter reading devices, illegally drawing water from fire hydrants, and other causes. In some water utilities unauthorized consumption may be negligible, but in other systems it could be a significant volume of loss. For any type of apparent loss, it is incumbent on utility mangers and operators to realistically assess metering and billing inconsistencies, and then develop internal policies and establish programs to economically minimize these inefficiencies. It is also important to clearly communicate with customers, governing bodies of the utility and municipalities, financing agencies, and the media about the problems of apparent losses and the need to control them.

The specific ways in which apparent losses occur vary greatly and, particularly with unauthorized consumption, are always changing. Individuals who purposely choose not to pay for water do so for many reasons. Some believe water should be free. Some do not believe that they have the financial resources to pay for the service, while others are always thinking of new ways to “beat the system.”

The water utility must, therefore, be vigilant in its effort to manage its product (water) via effective meter management and rational billing, collection, and enforcement policies to realize projected levels of revenue from consumption of water and to maintain accurate measures of the water that it supplies.

A note regarding collections: Not all customers pay their water bill as required nor pay their bill in a timely fashion. The *collection rate* is a financial performance indicator that reflects the rate at which customers pay their water bills. The collected payments are measured as a percentage of the money billed each month for the utility’s services. Collection rates at the 30-, 60-, and 90-day milestones are typically tracked to provide a representative picture of the customer population’s payment record. While the collection rate is a highly important measure that represents the pace at which revenue is gained by the water utility, collections are not included in the water audit methodology detailed in this manual. The collection rate measures payments based on billed consumption, whether or not all water has passed through customer meters or has been accurately measured. The water audit methodology has as its terminal boundary the customer meter, which generates the consumption data that is the basis for the customer billing. This manual provides utilities guidance in maximizing the efficiency of their water billing process, while collections focus on payment efficiency, which is beyond the scope of this manual. Water utilities are urged to track their collection rate and institute policies that maximize collections.

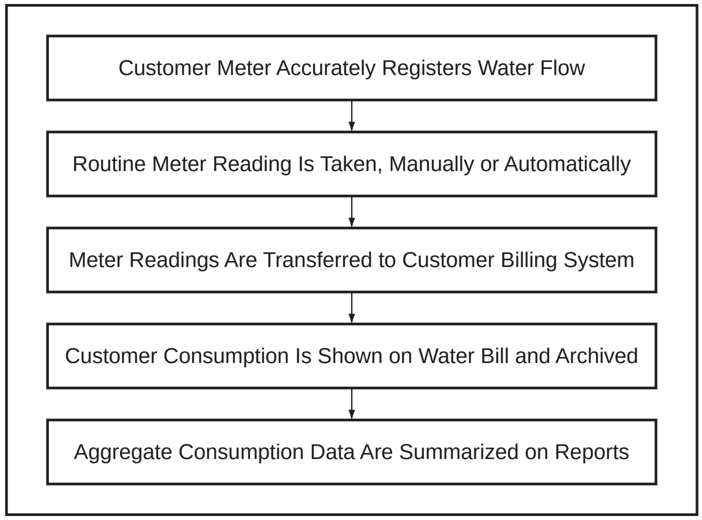


Figure 4-1 Metered consumption data archival path

Systematic Data Handling Errors

Not all water utilities meter the consumption of their customers; however, in North America the use of water meters is standard practice for many water utilities. Meters are relied on to provide a measure of the water passing through the meter and customer service line. While the meter must provide an accurate measure of the water flow, the subsequent processes—including those to obtain and transfer meter readings (manually or automatically) to billing systems, data processing and manipulation by billing systems, and archival and reporting operations—must also be handled accurately, otherwise the actual customer consumption will be distorted or lost entirely for certain accounts. In many water utilities, it is not uncommon to find accurate meter data transposed erroneously, adjusted improperly, or incorrectly archived or reported. If any part of the data path lacks integrity, it is easy to misinterpret apparent losses solely as meter inaccuracy, with potentially costly consequences if loss control decisions (such as replacing large numbers of accurate meters) are based on this faulty assumption.

Since water utilities input metered consumption volumes into their customer billing system, the data and reports available from the billing system provide utility managers the information needed to assess the consumption patterns of the customer population. Thus the customer billing system is the recommended starting point for systems to assess their overall water accountability.

The reading generated by a customer water meter is the first step in a sometimes complicated trail that ultimately generates a large amount of customer consumption data. Because most water utilities manage data for many thousands of customers, systematic data inaccuracies can easily be masked by the sheer volume of the bulk data. Figure 4-1 gives an overview of the typical steps existing in the data trail from meter to historical archive. Errors in the data collection (transfer), billing, or archival and reporting processes can result in distortions in the summary data that is ultimately documented as customer consumption.

Obtaining water meter readings. Although the customer meter may record customer consumption accurately, the manner in which the meter displays the reading, how the reading is obtained by the water utility, and how the reading is transferred into a customer billing system are processes that have the potential of incurring systematic data handling errors. Many water utilities have a variety of meter types in their system, with many made by different manufacturers. The same type and model of meter from a single manufacturer may have undergone design changes over several years; thus, even water utilities with a relatively homogeneous meter population may find important differences between individual meters. Meters used in most North American water utilities typically measure the volume of consumption in volume units of gallons or cubic feet, while metric units (litres) are common in Canada and other parts of the world. In many instances, the unit of measure of the meter is not the same as the unit employed in the customer billing system. For example, a meter may measure the flow of water in gallons, totalize the flow in hundreds of gallons, with billing to the customer shown in hundreds of cubic feet. The granularity of the consumption data refers to the unit of measure employed by the meter. A smaller unit of measure is considered more "granular"; hence, using the unit of gallons is more granular than using cubic feet because one gallon of water is a smaller volume than one cubic foot of water (1 gal = 0.134 ft^3). The smaller, or more granular, volume unit is considered to be more accurate for water loss control purposes than a larger, or coarser, volume unit of measure.

The volume displayed or recorded by the meter may not be the volume transferred to the customer billing system by an automatic meter reading (AMR) or advanced metering infrastructure (AMI) system. Older technology displacement meter heads use a system of gears to rotate the dials on the meter register. Many of the original AMR systems were not equipped to capture the data from every digit on the display totalizer on the meter register. Typical meter registers contain six digit totalizers, but older reading technology may record only four of the six digits. The precise totalizer digits of a given meter being read can vary considerably, depending on meter reading technology and meter manufacturer.

Water utilities use a variety of methods to read meters. These can include manual (visual) reading, reading by touchpad or handheld recording device, mobile (drive-by) radio reading, and a variety of AMR and AMI technologies, with fixed (communication) network features of AMI technology being the most comprehensive data collection method to date. Many water utilities have in place a mix of the above methods, as they either transition from one technology to another or target specific regions such as pilot areas or by covering high-density and accessible areas by manually reading meters but using AMR or AMI technology in low-density and/or hard-to-access areas.

Historically, water utilities conducted manual meter reading with readings visually gathered and then written on paper cards or forms. Since the 1990s, AMR technology has become available and the use of handwritten records has decreased. However, for those utilities that still employ paper meter-reading forms, opportunity exists for transposition errors to occur. Utilities using AMR/AMI technology typically have software gathering the data from the meters, with a programmed interface connecting to the customer billing system. Errors can also occur in AMR/AMI systems if programming errors exist in the data transfer interface. One possibility is meter readings assigned to the wrong customer premises. Also, AMR/AMI equipment can fail and the temporary lack of data can create the possibility of error occurring. Weak procedures for data continuity during meter replacement can also create errors. A multitude of possibilities exist that can induce error into the data path. Additional information on the features and considerations in using AMR/AMI systems is given in chapter 5.

Data transfer errors occurring in the meter reading process. The process that obtains meter readings from meters and transfers them into the customer billing system can be rife with potential for apparent losses if strong procedures and oversight do not exist. Some of the ways in which the integrity of customer consumption data may be compromised from poor data transfer practices include the following:

Figure 4-2 Accumulation of moisture inside a water meter register obscures the dial and prevents visual meter readings

- *Manual meter reading misread.* This can occur due to poor lighting, water in outdoor meter vaults or pits, or dirt/debris interfering with the visual observation of the meter reader. Utilities that have a wide variety of meters (and registers) from different manufacturers may cause confusion for meter readers, even when the meter register is clearly visible. When a manual reading is taken to check the validity of data in the billing system, field personnel may perpetuate past incorrect assumptions of the units or totalizer dials to read based on a printed history of incorrect readings from the billing system. Manual meter reading errors can also occur when all dials on a meter totalizer are not read, particularly when the dials being read vary among meters in the same system. Figure 4-2 shows a water meter register that cannot be read manually because of moisture that has accumulated inside the meter register. Finally, it is not uncommon for meter readers to enter an approximate meter reading rather than gather an actual reading. This might occur when the meter reader is avoiding entry to a hard-to-access meter location or is reluctant to deal with harsh weather, excessive traffic, or other challenges of the manual meter reading process.
- *Manual meter reading data entry and transposition errors.* An accurate reading can be transposed incorrectly, particularly if readings are handwritten on paper cards or forms. Error can also occur when the correct numbers are entered in the wrong columns. This often happens in systems that do not read every dial on meter totalizers. Readings may also be entered incorrectly into handheld devices, although handheld devices that read directly from the meter/AMR equipment avoid this problem. Sometimes a correct meter reading is entered, but an incorrect code is entered for the account (such as mistakenly entering a "property vacant" code).
- *Manual meter reading masquerading as an automatic meter reading.* Utilities employing plug-in type automated meter reading technology or drive-by radio read technology can experience this type of error. The technology used may require or allow field employees to read the data on a display and later enter the displayed data into a field data logger or directly into the customer billing system. Meter readers may keep a handwritten list of displayed reads and enter these at the end of their shift, incorrectly believing that this practice increases efficiency. Aside from the possibility of errors in entering the numbers, this is also a possibility of entering a valid reading into the wrong customer account. Office staff may or may not be aware of this practice, and the coding in the customer billing system will indicate

that the reading was obtained automatically, making these types of errors particularly difficult to detect.

- *Automatic meter reading error or equipment failure.* Most AMR equipment is durable but none is infallible. Meter reading devices connected to customer meters periodically fail. Water utility managers and AMR equipment providers should ensure that these systems have alerts that immediately inform personnel when equipment failure has occurred. Similarly, procedures should exist to ensure a timely repair or replacement of defective AMR equipment.
- *Improper meter register units or truncation factors erroneously programmed into meter reading equipment.* Utility managers should be very careful to ensure that the proper units and factors are entered into meter reading equipment. This is particularly important if many different meter types and brands exist in the meter population.
- *Errors due to mixed meter reading type, frequency, and granularity.* Many water utilities, particularly those piloting AMR/AMI technology, have a mix of manual and automatic meter reading processes in place. In such cases, procedures should exist to ensure that meter readings are entered into the customer billing system accurately and according to the appropriate billing cycle. If a portion of accounts are read and billed on different cycles (some monthly, some quarterly), the potential exists for data transfer errors to occur. The granularity of meter reading volumes can also create the potential for data distortion. Meters reading in gallons but billed in units of cubic feet risk the potential for data disruption if sufficient controls are not in place to ensure that the correct unit conversion programming is in place. The greater the variety in meter reading and billing mechanisms, the greater the need for careful management of metering and billing data.
- *Procedural/data entry errors during meter replacements.* When a meter is replaced, the reading on the new meter's register should be used to initiate a new billing sequence. If the final read from the former meter and the reading from the new meter are not properly reconciled at this point, then a distorted consumption value may result.

Data analysis errors in the archived data or in management reports. Once valid data on customer consumption is reliably transferred into the customer billing system, the potential remains for additional systematic data handling errors to be inducted into the data path. Some of the ways in which the integrity of customer consumption data may be compromised from data analysis errors include the following:

- *Use of poorly estimated volumes in lieu of meter readings.* When a meter reading cannot be obtained or the gathered reading is in obvious error, it is common practice to enter a reading value that provides a representative estimate of the customer's consumption. The procedure for estimating meter readings is typically based on either an average of historic consumption or a similar period from the historic database. When estimates occur on multiple billing periods for the same billing account, the likelihood of error in billed consumption compared to registered consumption can grow.
- *Customer billing adjustments granted by manipulating actual metered consumption data.* Customer billing systems are typically designed with a focus on the financial aspects of the customer relationship—issuing bills and maintaining cash flow to the utility. The dual role of the consumption volume as an operational or engineering parameter may or may not have been considered in the billing system design. As part of standard financial transactions, water utilities need the ability

to periodically issue a monetary credit to a customer, just as they have the ability to issue a charge. A credit is typically issued when a valid, actual meter reading is obtained after several periods of billed consumption based on poorly estimated volumes. Some billing systems implement credits by adjusting meter readings or consumption volumes to create a negative charge. A large one-time adjustment to a customer account, however, can cause a distortion of the actual consumption. This is particularly disruptive if the adjustment accounts for a long period that spans reporting years. See Step 3-2A2 in chapter 3 for a detailed example of this issue.

- *Poor customer account management.* Procedures for closing accounts and for transferring ownership of meters and premises can lead to accounts not being properly activated and meters not being read.
- *Aggregate data error in the archival and/or reporting processes.* The annual water audit relies on metered consumption reported from the customer billing system for aggregated groups of customers in the audited system. For most water utilities (perhaps other than those employing fixed-network AMI technology), meter readings are collected on different days throughout each meter reading cycle. A reporting procedure is typically used to collect and manipulate the actual meter reading data from different days to aggregate it across the billing period. The data are further aggregated into quarterly and annualized data in the archives and shown on various management reports. The frequency of meter readings can affect the accuracy of annualized data, as the monthly data will need less manipulation than quarterly data. The granularity of the meter readings can also affect the accuracy of annualized data, as readings taken in the smaller measure of gallons are more accurate than volume based on billings in the larger measure of cubic feet.

Policy and procedure shortcomings. Poorly conceived or implemented policies can allow apparent losses to occur, often without the impact being realized. Longstanding practices ("that's the way we've always done it!") are often prevalent instead of structured procedures that include accountability and transparency. Examples of such shortcomings include

- despite policies for universal customer metering, certain customers are intentionally left unmeasured or unread—common for municipally owned buildings in water utilities run by local governments;
- provisions allowing certain customer accounts to enter "nonbilled" status, which often becomes a loophole that is exploited by customer fraud, or is a source of unintended loss if the water utility is not rigorous in its oversight of these accounts;
- billing adjustment policies that do not take into account preservation of actual customer consumption;
- bureaucratic regulations or performance lapses that cause delays in permitting of new accounts, installation of water meters, or timely activation of billing functions; and
- organizational divisions ("silos") or tensions within groups of the utility; that is, individual groups fail to coordinate with peer groups since they do not recognize the big-picture importance of water loss control within the water utility.

The above list provides but a few of the major data handling problems that might be encountered in a drinking water utility. It is not exhaustive, however, and any utility might identify an apparent loss situation that is unique to its organization. Any action that unduly reduces the actual volume of customer consumption can be considered as contributing to apparent loss.

Customer billing system. The customer billing system is a standard feature of drinking water utilities. The implications of the use of customer meter reading and billing data on the financial and engineering functions of the water utility are detailed in the "Using the Customer Billing System to Extract Customer Water Consumption" sidebar in chapter 3 and the reader is urged to carefully review this discussion.

The customer consumption data gathering process, from meter installation and meter reading through billing, can be flowcharted (see chapter 5) and confirmed by the utility to determine the potential for apparent losses from systematic data handling errors. This type of error can be subtle and require appreciable investigative time to detect. However, corrections can often be implemented quickly and inexpensively, sometimes requiring only minor procedural or programming changes in the billing system software. In pursuing these types of apparent loss recoveries, a fast and cost-effective payback can often be attained from the resulting additional revenue recovery. Addressing systematic data handling errors early in the water loss control program also creates a foundation of data integrity that is essential as the loss control program matures.

Customer Meter Inaccuracy

Customer meters that inaccurately measure the volumes passing through them can be a major source of apparent loss in drinking water systems. Although most North American drinking water utilities meter their customer consumption, a notable number do not. When auditing unmetered systems, meter accuracy cannot be evaluated as an apparent loss, and these utilities must employ other methods to quantify the annual volume of customer consumption and separate this volume from components of authorized consumption and water losses.

AWWA maintains a policy statement on metering and accountability that supports metering of all water production flows and all customer consumption, and this manual supports this policy. Therefore, this discussion exists in the context of water utilities having fully metered customer populations. Systems that do not meter their customers can obtain an approximation of customer consumption by metering and data-logging representative samples of customer accounts and statistically evaluating the results to infer general customer consumption trends.

Metering customers provides valuable information on consumption trends for long-term planning and data needed to evaluate loss control and conservation programs. It also elevates the value of water in the mind of the consumer by linking a price with a volume. With highly capable water meters, and AMR/AMI systems now widely available, the accuracy and richness of customer consumption information has grown considerably. This is assisting improved management of water utility operations and the water resources of individual watersheds or regions.

A thorough discussion of customer meters is beyond the scope of this manual. AWWA provides excellent guidance in several publications that cover all aspects of sound meter management. AWWA Manual M6, *Water Meters—Selection, Installation, Testing, and Maintenance*, provides comprehensive information on the basics of customer meter management (AWWA 2012). AWWA Manual M22, *Sizing Water Service Lines and Meters*, provides outstanding guidance on customer demand profiling and sizing criteria that are critical for meter accuracy (AWWA 2014). The Water Research Foundation publication titled *Advanced Metering Infrastructure: Best Practices for Water Utilities* provides excellent guidance on planning, installing, and leveraging a water utility AMR or AMI system (Schlenger et al. 2011).

In general, meter accuracy is influenced in four principal manners: the physical accuracy of the meter as a flow-measuring device, the appropriate sizing of the meter to fit the customer's consumption profile, the appropriate type of meter to best record the variations in flow, and proper installation of the meter.

Physical accuracy. To assess whether meters are functioning properly, it is recommended that the water utility own, install, and test customer water meters as part of an ongoing program. As volumes of water pass through the meter, it will eventually wear and lose accuracy, some more quickly than others. Therefore, meters must be tested, repaired, or replaced with new or refurbished meters. Water utilities provide service to a wide variety of customers, from residential service (⅝-in. meters typically) to large industrial complexes (up to 12-in. meters). Some water utilities require meters on fire connections and others do not. All meters—even meters newly received from the manufacturer—can be expected to register flow with varying degrees of accuracy. The suggested best practice per AWWA Manual M6 is to test new meters as complete assemblies before installation in a customer service line (AWWA 2012).

Appropriate meter sizing. Approaches to meter functionality and management have advanced in ways that promote greater accuracy of customer consumption measurements. In the past, it was common to size customer service connections and meters based on the peak flow rates that the meter was expected to encounter. Because peak flows occur only rarely, most of the time meters registered flows at the low end of their design range. Many meter types are less accurate at the low end of their flow range with very low flows not captured at all. Current wisdom focuses on the flow range most usually encountered, not seldom-occurring peak flows. Many water utilities have recovered considerable water and revenue from right-sizing oversized customer meters. Between 1990 and 1992, for example, the Boston Water and Sewer Commission's meter downsizing program recovered more than 100,000 ft^3 of additional water per day in apparent water loss, which translated into millions of dollars in subsequent additional revenue (Sullivan and Speranza 1991).

Conversely, meters that are undersized for the flow profile that they serve will pass much higher flows of water than they are designed to accommodate, and the result is often a rapid degradation of accuracy. Utility managers should monitor their billing data to flag billing accounts with unusually high consumption for the existing sized meter, and test these meters with additional frequency. Meters that are confirmed to be undersized should be replaced with a larger meter.

Appropriate type of meter. Many meter types exist to measure flows in a wide variety of settings. Displacement meters historically have been most common for smaller residential service. Compound, turbine, single-jet, and propeller meters are examples of the types of meters employed to serve large commercial or industrial connections of greater than 1 in. The use of ultrasonic and electromagnetic flowmeters is increasing in customer applications. Fire service meters have unique features for this type of service. Metering technology is constantly advancing, with new types of meters and metering capabilities being developed.

Utility managers should carefully evaluate the performance specifications of water meters that are being considered for particular applications and select those with a range of accuracy that meets the flow profile of the proposed use. For instance, an irrigation-only account that serves a large area could use a meter with a low-flow threshold that is relatively high and still provide accurate registration. This would be the case since this type of account typically consumes water at a relatively high rate of flow for nearly 100 percent of the time that water is used. Conversely, a large residential property that has high periodic irrigation demands for its landscaping needs might also encounter numerous times when only relatively low domestic flows are encountered. This type of account requires a type of meter that is highly accurate over a wide range of flows, from low flow to high flow.

Figure 4-3 A water meter installed upside down is an example of a poorly installed meter; water meters should be installed upright and in the horizontal position

Figure 4-4 A bank of water meters showing numerous meters improperly installed at an angle instead of being properly installed upright and horizontal

The cost of the meter tends to rise as the range of accuracy expands, but the long-term recovery of apparent loss costs generally justifies the additional expense.

Correct installation. Fully functional water meters may incur inaccuracy if they are not installed properly. All meter manufacturers provide specifications and guidance for the proper installation of their water meters, and water utilities should follow this guidance. Generally, water meters must be installed in the horizontal position, with adequate spacing and appurtenances (strainers) as required. A water meter should be installed in a space free from the extremes of weather and other stresses. Figures 4-3 and 4-4 show water meters that have not been properly installed and therefore may suffer compromised accuracy and performance. Meters should be inspected upon receipt of delivery to ensure that any damage in transit is identified and these meters are not installed in a customer site.

Monitoring Meter Performance

Although most brands of water meters commercially available are highly accurate and reliable, it is incumbent on the water utility to regularly monitor customer consumption data to flag potential problems from meter malfunction or outright failure. Meter performance may be compromised in a number of manners, including the following:

- *Frozen* or *Stuck* meters fail to advance; hence, zero consumption is recorded for the meter reading period. This condition usually reflects a complete failure of the meter (unless tampering of the meter is confirmed as the cause).

- *Intermittent performance* of some meters results in under-registration from the meter running "slow" or in interrupted fashion. This can happen due to cold temperatures, sediment in the water, or other malfunction of the meter apparatus. Meter readings from intermittently performing meters typically show a pattern of low consumption rather than zero consumption. The reading history in the billing system may show a remarkably consistent low consumption level from period to period, and poorly designed meter consumption "flags" or alerts in the customer billing system may not identify these under-registering meters.

The use of water meters to measure customer consumption is a cost-effective way for water utilities to track the end use of the water supply and properly bill customers based on the volume consumed. However, water utility managers should be proactive in ensuring that meters are properly specified, sized, installed, and monitored to provide this service to the water utility. Lapses in this process result in apparent losses due to customer metering inaccuracies for the water utility.

Unauthorized Consumption

Unauthorized consumption occurs to some extent in virtually every drinking water utility. It often occurs through the deliberate actions of customers or other persons who take water from the system without appropriately metering the use and paying for the water. The nature and extent of unauthorized consumption in a system will depend on the combination of

- the economic health of the community;
- the value the community accords to water as a resource, often as a function of the relative abundance or scarcity of water in the region;
- the retail cost charged to customers for water service;
- the strength and consistency of the enforcement policies and practices existing in the water utility; and
- the political will of water utility management and public officials to enact and enforce effective policies to thwart unauthorized consumption.

The value that the community and water utility place on water supply and the management effectiveness of the water utility are often reflected by the amount of unauthorized consumption occurring in a locale. Establishing features of a good accountability and loss control program—water auditing being foremost—will inevitably uncover situations where unauthorized consumption is occurring. Unauthorized consumption can occur in many ways, including

- illegal connections;
- open bypasses around large customer meters;
- buried or otherwise obscured meters;
- misuse of fire hydrants and fire-fighting systems (tapping connections to unmetered fire lines);
- vandalizing consumption meters (meter tampering);
- tampering with meter reading equipment;
- illegally opening intentionally closed valves or curb stops on customer service piping that has been discontinued or shut off for nonpayment;

- illegally opening intentionally closed valves to neighboring water distribution systems designed for emergency or special use;
- failing to notify the water utility to activate a billing account after water use has been initiated; and
- fabricated meter reading data from a meter reader acting in bad faith to generate an illicit discount for a customer, perhaps in return for an illegal payment or "kickback."

The water audit should quantify the component of unauthorized consumption occurring in the utility. The water utility auditor has the opportunity to quantify a volume of unauthorized consumption directly or to apply the default value of 0.25 percent of water supplied in the AWWA Free Water Audit Software. For water utilities with well-established water audits or those believing that unauthorized consumption is excessive, the extent and nature of unauthorized consumption should be investigated through inspection of suspect customer accounts. Policies and practices that may unwittingly create opportunities to manipulate metering equipment to reduce or avoid payment should also be researched. As an example, the utility manager could institute a routine auditing function to investigate a sample of customer accounts that register zero consumption for consecutive billing cycles. Accounts with meters being tampered might be identified during these inspections. As another example, the utility manager might periodically inspect fire connections in large commercial/industrial buildings within the service area. These inspections could detect the presence of illegal piping tapped into an unmetered fire line. The opportunities for water to be stolen from the water utility are functions of individual customers who either cannot or will not pay for the rendered services. All utility systems are susceptible to the occurrence of unauthorized consumption, and this occurrence is substantial for some. Further ways to detect and control unauthorized consumption are discussed in chapter 5.

Recognizing that a portion of customers in any region live with real economic hardship, the water utility may choose to operate programs offering appropriate discounts, grants, or similar services to qualified customers to keep essential water service affordable. Having such a program working in tandem with persistent unauthorized consumption enforcement is the best policy. It is appropriate that water utilities recognize the limitations of certain customers in verifiable need and offer them an avenue to legitimately purchase water service at affordable rates. Some utilities have established a separate tier of "life-line" water rates to apply to this subpopulation of customers.

PROBLEMS CREATED BY APPARENT LOSSES

Because apparent losses under-record the volume of customer consumption, they generate two major impacts on water resources management:

1. Apparent losses induce a degree of error into the quantification of customer water demand, thereby impacting the decision-making processes used to determine needed source water withdrawals, calculate the appropriate capacities of water supply infrastructure, and evaluate conservation practices.
2. Apparent losses cause water utilities to underbill a portion of the customer population and suffer a loss of revenue potential.

Both of these impacts can be significant. If a high level of apparent loss exists in a water utility, its recorded volume of customer consumption could be subject to a significant degree of error. Consider a water utility that documents customer consumption of 3.65 billion gallons of water in a year (10 million gallons per day, or mgd). If routine water auditing found apparent losses equal to 1 mgd (10 percent of consumption), actual customer consumption during the year being audited was 4.015 billion gallons, an increase of 365 mil gal. Such a loss creates a distortion of the true customer consumption volume, in this case understating it by 365 mil gal. Activities that rely on accurate customer data are compromised by this degree of error. These can include efforts to evaluate the success of water conservation programs, using consumption data to assign demands in hydraulic models, and evaluating community drinking water requirements needed for regional water resource plans. Apparent losses, therefore, represent a degree of error that is interjected into a wide range of analytical and decision-making processes regarding water resources management. Given that the water industry in the United States is highly fragmented, with many different sized water utilities existing in any given region, the degree of error from apparent losses can be compounded by the varying errors existing in many disparate water utilities. Gauging true customer needs on a regional basis can be difficult without a reasonable assessment of the apparent losses existing in the region's water utilities.

From a financial perspective, apparent losses can exert a tremendous impact on the water utility's bottom line. The annual water audit for the Philadelphia Water Department for the fiscal year ending June 30, 2013, quantified apparent losses at 7,495 mil gal, representing uncaptured revenue valued at more than $43 million (City of Philadelphia 2014). With increasing pressures from a variety of forces and limited funding, most water utilities stand to make great gains from the revenue recovery potential of apparent loss control. Because apparent losses are quantified by the amount of water improperly recorded at the customer's delivery point, this water is valued at the retail cost that is charged to the customer. Water rates frequently include a wastewater charge that is also based on the volume of consumption. The cost impact of apparent losses is frequently higher than the impact of real losses, which are usually valued at the variable production costs to treat and deliver the water (however, when water resources are greatly limited, real losses can also be valued at the retail rate based on the premise that any water saved by real loss reduction can be sold to customers). For most water suppliers, the retail rate charged to customers is higher than the variable production costs. Therefore, apparent losses can have a dramatic financial impact on the water utility's revenue stream and overall financial condition.

The revenue impact from apparent losses also creates a problem of equity for the community. Apparent losses occur when the actual amount of water delivered is greater than what is metered and billed to customers. Hence, a portion of the customer population obtains discounted or free water service. This means that the paying customer population effectively subsidizes those customers who are underpaying or not paying. This situation is particularly troubling as water utilities encounter pressure to raise water rates, with the paying customers shouldering an even greater financial burden for the entire water-using community.

Reducing apparent losses and recovering missed revenue can reduce the frequency of, or defer the need for, water rate increases by identifying underpaying and nonpaying customers and adding them to the active billing rolls.

The recovery of apparent losses can create a direct financial improvement to the water utility, and many apparent losses can be recovered with relatively little effort and expense. This is important in terms of seeking early success and payback to the water loss control program. Funds recovered early in the program in this manner can serve to seed further activities in the long-term water loss control effort.

SUMMARY

An assessment of the overall level of apparent losses gives a more realistic picture of the actual customer demand of the community and a preliminary measure of the distribution system efficiency. The reliability of the estimate of apparent losses has bearing on all quantitative aspects of accountability and the loss control program. Additionally, apparent losses exert a strong financial impact to the water utility, typically by inhibiting revenue capture for a portion of the customer population. Addressing apparent losses, particularly early in the water loss control program, therefore gives the potential for strong payback and a springboard of success in expanding the water loss control program to address real losses through improved leakage management. Chapter 5 discusses the specific means to economically control apparent losses.

REFERENCES

Alegre, H., W. Hirner, J. Baptista, and R. Parena. 2000. *Performance Indicators for Water Supply Services*. Manual of Best Practice series. London: IWA Publishing.

AWWA (American Water Works Association). 2012. Manual M6. *Water Meters—Selection, Installation, Testing, and Maintenance*. Denver, Colo.: AWWA.

AWWA (American Water Works Association). 2014. Manual M22. *Sizing Water Service Lines and Meters*. Denver, Colo.: AWWA.

City of Philadelphia, Philadelphia Water Department and Water Revenue Bureau. 2014. *Annual Water Audit Report for the City of Philadelphia for Fiscal Year 2013—July 1 2012–June 30, 2013*.

Schlenger, D.L., D.M. Hughes, and A. Green. 2011. *Advanced Metering Infrastructure: Best Practices for Water Utilities*. Denver, Colo.: Water Research Foundation.

Sullivan, J.P., and E.M. Speranza. 1991. Proper meter sizing for increased accountability and revenues. In *Proceedings, AWWA Annual Conference and Exposition*. Denver, Colo.: American Water Works Association.

Chapter 5

Controlling Apparent Losses: Optimized Revenue Capture and Customer Data Integrity

Apparent losses occur when water is delivered to a water user but, for various reasons, is not measured or recorded accurately, thereby inducing a degree of error in the amount of actual customer consumption. When apparent losses occur systematically in an appreciable volume, the aggregate measure of water consumption can be significantly understated and cause a resulting revenue loss. Apparent losses consist of three primary components:

1. Systematic data handling errors in tracking customer consumption, particularly in customer billing systems;
2. Customer metering inaccuracies; and
3. Unauthorized consumption.

The nature and causes of apparent losses are explained in detail in chapter 4. Chapter 5 takes the utility manager to the next level by defining the cost-effective means to address apparent losses and control them to economic levels.

There is a tendency for many in the drinking water industry to assume that their system's apparent losses are solely caused by customer metering inaccuracies and that the identification and replacement of large numbers of supposedly faulty meters is the appropriate remedy. Before reaching this conclusion, the water utility should first consider the water auditing process detailed in chapter 3 that clearly describes the three manners in which apparent losses occur. It is important that the auditor first assemble the water audit and identify the nature, quantity, and cost impact of the three apparent loss components, and only then develop a rational loss control strategy. Flowcharting the process of the customer billing system is a recommended first step. It is a very expensive and inefficient proposition to implement comprehensive customer meter replacement if the bulk of the apparent losses are actually caused by billing system data errors or unauthorized consumption. Yet, many water utilities have done just this (extensive meter replacement) and are perplexed when, after spending up to millions of dollars on new meters, their apparent loss standing remains unchanged. Conversely, data handling errors in the customer billing system may be addressed by relatively inexpensive computer programming or procedural improvements. In this way, a quick payback can be earned by additional revenue recovery. Planning the apparent loss control strategy based on the results of the water audit is the best way to proceed. And many unauthorized uses can be investigated by checking fire services and bypass lines that may be found open. If significant meter inaccuracies are still suspected, random meter testing may provide necessary insight to that potential cause.

QUANTIFYING APPARENT LOSSES IN THE WATER AUDIT

Chapter 3 details the process used to assemble the best practice water audit. Once the water audit is assembled, the utility manager has a good initial sense of the quantities of apparent loss components. The approximate total volume of apparent losses and their effects on revenue shortcomings can be used as the basis to begin to develop an apparent loss control strategy. To refine the apparent loss strategy, however, the auditor should begin to perform more detailed investigations of the source data and metering/billing activities to validate the preliminary data and obtain a more accurate picture of the apparent losses. These “bottom-up” auditing practices involve launching more detailed investigative auditing work, similar to detailed financial audits that accountants perform. The distinctions between “top-down” and “bottom-up” auditing approaches are explained in the “Water Auditing: Top-Down vs. Bottom-Up Approach” sidebar in chapter 3.

This chapter focuses on the bottom-up water auditing and targeted loss control functions that utilities should employ to address apparent losses. The water utility manager should consider the following as the primary activities to launch such work:

- Step 1. Analyze the workings of the customer billing system to identify deficiencies in the water consumption data handling process resulting in apparent losses. Flowcharting the data handling pathways is a good way to perform this analysis.
- Step 2. Compile listings of basic customer account demographics, including number of meters by meter size, customer type, and consumption ranges. Look for anomalies such as groups of small meters registering large cumulative flows or large meter accounts registering unusually small cumulative flows. Verify that each compound and fire service meter without a totalizing register has two accounts in the billing system (one for the primary meter and one for the bypass meter). Confirm that the correct meter multipliers are being used for large water meters, and check that the absolute encoder register digits are being read correctly through any automated reading equipment used by the utility.
- Step 3. Perform meter accuracy testing for a variety of sample meter installations to establish an understanding of the functional status of the meter population.
- Step 4. Assess a sample of customer accounts or locations for unauthorized consumption potential. Make certain that all valves for bypass lines on large customer meter installations are both closed and secured.

Additional activities can be conducted in each of the above steps and these are described in this chapter. It is recommended that the billing system analysis always be performed as the initial step, because gaps in this process could affect the data that are evaluated in the other steps.

CUSTOMER BILLING SYSTEM

Most North American water utilities meter their customers and store customer meter readings in a computerized billing system that calculates water consumption, determines the charges, and bills the customer. For these utilities, the customer billing system serves as the source of all customer attribute data, in addition to the water consumption history. Revenue is generated via billings to customers for water consumption, traditionally on either a monthly, bimonthly, or quarterly basis. It is important to realize that most customer billing systems historically have been designed with a primarily *financial* purpose—to generate bills that result in revenue collection. However, water utilities have also come to rely on customer billing data for a variety of *engineering* purposes, including tracking water conservation trends, water loss studies, and assigning water demands in distribution system hydraulic models.

It is important that water utility managers understand the workings of the customer billing system with regard to consumption data integrity. Many billing systems—while configured with sound billing intentions—may unknowingly corrupt the engineering integrity of water consumption data. Frequent billing adjustments may change the customer consumption generated by meter readings. The implications of the use of customer meter reading and billing data on the financial and engineering functions of the water utility are detailed in the "Using the Customer Billing System to Extract Customer Water Consumption" sidebar in chapter 3, and the reader is urged to carefully review this discussion.

For the above reason, the utility should undertake a flowcharting exercise of the billing process to identify any impacts to customer consumption integrity, as well as to identify any apparent loss components from the data handling process. If consumption data are found to be modified by billing operations, the utility manager should consider reprogramming the billing system to record both the *registered*, or actual, consumption as the engineering value and the *billed* consumption as the financial value in separate fields in the computer record. This will help ensure that the accuracy of billing functions and customer consumption data are preserved. Until this is implemented, an estimate of the impact of such adjustment activity should be included as a component of the apparent losses.

AUTOMATIC METER READING AND ADVANCED METERING INFRASTRUCTURE SYSTEMS

Automatic meter reading (AMR) and advanced metering infrastructure (AMI) systems are innovative technologies that can provide numerous benefits to water utilities in controlling apparent losses, as well as improving operational efficiency, financial standing, and customer relations. AMR systems gather customer meter readings typically every 30–60 days via a one-way communication device (handheld by meter readers or by mobile patrols in vehicles). AMI uses a fixed communication network (electronic communication equipment such collectors/repeaters or cellular technology) to provide two-way communication to obtain meter readings as often as every 15 minutes while allowing the utility to send commands to the customer end point to activate remote shutoff valves or perform other functions. The primary capabilities and distinctions of AMR and AMI systems are listed in Table 5-1.

AMR/AMI technology is rapidly improving and expanding in both its use and functionality in water utilities, and it is worthwhile for virtually any water utility to consider

Table 5-1 Comparison of automatic meter reading systems to advanced metering infrastructure systems

Features and Capabilities	Automatic Meter Reading System	Advanced Metering Infrastructure System
Data collection methods	Handheld device, mobile (drive-by)	Fixed communication network
Data collection type	One-way communication	Two-way communication
Typical meter reading interval	Monthly	As frequent as every 15 minutes
Reading protocol	Pulses from meter counted by meter interface unit	Absolute or encoded electronic register on meter
Communication reliability	No redundancy	Multi-route communications provide backup communication redundancy
Alarming capability	Alarm flags are evident when the meter is read	Alarm flags can be transmitted as they occur
Meter interface unit	Simple interface	Multiple, more complex interfaces
Typical customer end-point capabilities	Meter reading, tamper alerts	Meter reading, tamper alerts, leak noise or high-flow indicators, remote shutoff valves, reverse flow detection, and other capabilities
Additional capabilities		Real time "final" reads for properties Pinpoint sudden changes in flow (high peaks or drop to zero flow) Customer consumption profiles exist and can better assist customer service personnel and inform customers Assist leakage management activities for the utility and customer (reduce high-bill complaints by fast detection of plumbing leaks)

this technology to improve their operations. A complete review of this technology, however, is beyond the scope of this manual. The reader is instead referred to the Water Research Foundation report titled *Advanced Metering Infrastructure: Best Practices for Water Utilities* (Schlenger et al. 2011), which is an excellent guidance manual for utility personnel to investigate, procure, install, and operate an AMR or AMI system to full advantage.

Because the use of customer water meters is common in the North American drinking water industry, management of customer meter data is a significant part of utility operations, as well as the utility revenue stream. In the past it was typical for water utilities to read water meters manually and bill customers every 90 days (quarterly billing) or 180 days (twice yearly billing). More recently, many water utilities have moved to monthly meter reading and billing since customer payments are more timely and reliable at the 30-day interval compared to longer periods. Monthly data also allows customers to better manage their water consumption, an important consideration in water-scarce regions where water conservation programs are employed or the cost of water is high. In moving to monthly meter reading/billing, however, the number of meter reading visits increases, as does the number of consumption values produced by the meter readings. Moving away from manual meter reading reduces the potential for reading errors that hamper the efficiency of the data collection process. Meter reading and billing activities occur at a cost to the water utility, and manual meter reading is no longer cost-efficient for many (but not all) water utilities. AMR and AMI system technologies can address the many challenges in the meter reading and billing processes, as well as offer other efficiency enhancements.

In North America, the electric power utility sector spurred the widespread use of AMR technology several decades ago. Eventually, certain AMR benefits gained in the electric power sector were also realized as possible for water utilities, and many water utilities began to install AMR systems starting in the late 1990s. By the early 2000s, water utilities began to install AMI systems to achieve even greater efficiencies in operations and to transform the customer experience with access to daily consumption data. By 2011, it was estimated that "almost half of all North American water meters were equipped with AMR or AMI devices, or under contract for conversion, with many large and small projects underway" (Schlenger et al. 2011).

A range of meter reading options is available in AMR systems, and many water utilities have realized positive financial benefits by installing AMR. Many utilities with AMR systems typically provide meter readings every 30 days to allow for monthly billing, although there is virtually no limit to the frequency that water meters can be read via an AMI system. Moreover, usage of an AMR system allows manual meter reading staff to be reassigned to other duties such as distribution system maintenance, while providing reliable, accurate water meter reads.

AMI technology goes beyond AMR by providing a fixed communication link between the customer end point and the central computer or hosting facility that stores the meter reading and related customer data. Many AMI systems for water utilities feature two-way communication from the customer end point to the central computer or hosting facility, with meter reading and various alerts communicated to the utility host site and signals for certain capabilities—such as remote shutoff valves—sent from the utility to the customer end point. AMI allows water meter readings to be gathered at very short intervals (hourly readings are the most common format for the water industry) with the capability to obtain on-demand readings as desired. This results in highly granular customer consumption data that can reveal individual customer consumption profiles and flag anomalies quickly. These capabilities can provide substantial economies in reducing human resources previously needed for meter reading, customer service complaint investigations, account shutoffs and activations, "move-out, move-in" readings, and a host of other activities.

An AMI system offers other benefits in addition to those of an AMR system. In a fixed-base AMI system, the water utility is linked daily with its customers, and dispatching of individual trucks is not needed to address various customer issues that might have required a site visit to resolve. This may offer a reduction in staffing, equipment, and vehicle costs, and may reduce the carbon footprint of the water utility. More importantly, the detailed water consumption data create the opportunity for an enhanced knowledge of customer water usage for individual customers, portions of the distribution system, or the entire service area. This presents a transformative condition for both the customer and the water utility. Examples of the enhanced customer service features of AMI include the following:

- Proactive detection of high water consumption due to emerging plumbing or toilet leaks can alert the customer before a "high bill" is issued. This can dramatically reduce the number of high-bill complaints. Many utilities have a policy of issuing refunds that, in effect, shifts billed water to non-revenue water, and these incidents can be lessened by having this capability.
- High-bill complaints that do arise can be investigated and often resolved by customer service representatives in the office by referring to hourly data that can often pinpoint the day (and time) that high water usage commenced. Customers are often reassured once this detailed explanation is provided to them. The utility benefits since the dispatch of crews and trucks is reduced.

- Estimated bills that result from difficult meter access or inclement weather hindering manual meter reading can be reduced.
- Instant final meter readings for "move-out/move-in" activities at buildings greatly please customers during a busy period in their lives.
- Granular data can be provided (daily, as often as every 15 minutes) to customers to keep them informed, which reduces the number of telephone calls to the utility's call center.
- Greater trust and faith in the water utility is established as more accurate consumption data and error-free bills promote better customer confidence.
- Effective communications with customers is created by providing them their water consumption histories via the utility Web portal, supported by email and/or text messaging alerts.

Examples of the enhanced capabilities for the utility include

- detailed flow analysis for better meter selection and management;
- monitoring for water consumption at inactive accounts;
- the ability to quantify customer consumption in zones or district metered areas (DMAs) during minimum hours, a component that assists leakage management and allows a water balance to be assembled on a zonal basis;
- the ability to collect readings of all customer meters on the same day (e.g., December 31) to better match water consumption data with water production data, and better assist for water auditing purposes;
- usage of leak noise loggers to provide alerts through the AMI fixed network. The acoustic monitoring systems continue to improve and can assist notable reduction of real (leakage) losses; and
- shutoff valves and other customer end-point devices

AMI systems are truly the new generation of technology and a dramatic leap forward for both water utility operations and the customer experience. While there are considerable advantages of AMI systems, the costs and requirements of this technology can also be considerable; therefore, careful planning is necessary to develop a reliable business case for the procurement of this technology.

It is important to assess the benefit–cost of an AMR or AMI system over the life of the system (which may reach 20 years) rather than focusing solely on the upfront installation costs. AMI system installation costs typically exceed those of AMR systems. While the costs to install equipment at the customer end point are similar for both systems, the installation cost of the fixed, two-way communications network (i.e., collectors and possibly repeaters, or a cellular system) for AMI will have a higher initial cost. There is also both an initial and an annual fee for the analytics software that enables the utility to take full advantage of the hourly usage data, and most AMI system end-point devices have batteries that require periodic replacement. The annual maintenance fees for an AMI system are also significantly more than for an AMR system. Over the course of the long life of an AMI system, however, these costs may still be less than the ongoing meter reading costs of a mobile-read or handheld-read AMR system. The ultimate costs will be determined when the system requirements are established and the benefits are quantified. Water utilities serving large, high-density populations in a relatively flat topography will have notably different system needs than utilities serving small, low-density populations that are scattered across a wide geographical area of undulating terrain. Water utilities should assemble a rational business case for the pursuit of a new or replacement AMR or AMI system, and a rational economic assessment of the costs and benefits should be detailed in the business case.

Both AMR and AMI systems can provide enhanced capabilities, cost savings, and efficiencies to water utilities. Depending on the conditions of the water utility prior to implementing such a system, a number of utility staffing changes should be considered when implementing an AMR or AMI system. If manual meter reading is replaced by an AMR system, the meter reading staff can be reduced or reassigned as the meter reading function becomes automated. Other staffing optimizations are also likely in moving to AMR. The move to AMI technology can bring about other shifts in staffing. The utility might need to hire additional skilled staff in the functions listed below. These staffing needs stem from the large volume of data that is generated in the AMI environment.

- **Meter data management.** By gathering highly granular customer consumption data and other end-point alert and status data, AMI systems generate massive amounts of information. A large water utility might generate more than a billion data points per year. Managing such a large volume of data is a significant undertaking. Most AMI system providers offer meter data management systems as data hosting services for water utilities. This service can free the water utility from the considerable data storage and management requirements of the AMI system. Water utilities that choose to host AMI data via their own information technology staff should carefully consider the potential to hire additional information technology staff and other resources that will be required to fully serve this function.

  In addition to the data storage requirements, one or more staff members will need to be tasked with monitoring the ongoing system health and performance of the AMI system. The status of the fixed network must be monitored because equipment such as collectors and repeaters can fail or be disrupted by storms, vandalism, or other factors. Likewise, AMR and AMI system end-point units periodically fail or are vandalized and staff must be in the ready to detect and respond to these problems to keep the system performance at a high level.
- **Data analytics.** With the large amount of data generated in the AMI environment, utilities have a great opportunity to leverage considerable efficiencies—but only if they have the staffing to respond to the data as it reaches the utility. The use of data analytics can provide the utility with the tools to quickly analyze large volumes of data to detect trends and anomalies. Many AMR systems now feature a data-logging capability that allows the utility to interrogate individual customer end-point devices and download a month or more of hourly data.

  While data analytics applications from AMI can provide great insight to the customer population, the utility must have the staffing in place to provide tracking of metering and billing trends, alarms and alerts, complaints and anomalies in the data. This need is greatly aided by sophisticated meter data management (MDM) systems available through both the AMI provider and other MDM companies. AMI MDM analytics can reveal a host of trends and alerts to the water utility. With sufficient personnel and a quality system, the water utility can realize a full return on its investment and will increase customer satisfaction. AMI systems provide highly sophisticated information on the water supply system and customer population, but the true value of the system is only realized if the information that it produces is translated into meaningful action and improved outcomes.

AMR and AMI systems can provide many benefits to the water loss control program, both for apparent loss and real loss reduction. AMR/AMI systems improve overall water accountability by ensuring a high degree of success and accuracy in obtaining

Using Automatic Meter Reading and Advanced Metering Infrastructure Technologies for Change Management in Water Utilities

Available since the 1990s, automatic meter reading (AMR) has brought about a host of capabilities for improved accountability in water utilities. More recently, advanced metering infrastructure (AMI) systems give water utilities and their customers a wide range of capabilities. With fixed network communications—many of which are two-way between the end point and the controlling computer—the customer end point has become much more than a single meter reading gathered periodically. Water utilities can use AMI to provide customers with their water consumption profile and can better assist them with questions regarding high or low water consumption complaints. Many utilities with AMI have reported that the system has transformed their business model, to the benefit of their customers and utility operations. These systems need to be established with a sound business case and should dedicate adequate staffing to manage the large volume of data that is collected, respond to the alerts generated by the system, and leverage the knowledge provided by the data. The Water Research Foundation report titled *Advanced Metering Infrastructure: Best Practices for Water Utilities* is an excellent guidance manual that utilities can employ to assist them in developing the business case for the best automated technology to transform their operations (Schlenger et al. 2011).

actual customer meter readings. The number of estimated bills is greatly reduced, water usage at inactive accounts is quickly revealed, suspicious consumption patterns are made known, accounts with poor metering are more easily identified, and many other benefits might be realized to better control apparent losses. Real losses can also be better managed by employing AMR, and particularly AMI, technology. By providing accurate assessments of customer consumption, leakage losses can be more reliably quantified in pressure zones or DMAs. Leak noise loggers installed as part of an AMR or AMI system can readily detect potential leak noises as new leaks emerge, providing the water utility with the opportunity to provide a quick response and keep leakage losses to a minimum. AMR and AMI systems give water utilities strong tools to improve both their overall accountability and their efficiency in controlling losses to realize minimum levels.

Automated MDM and billing systems via AMR/AMI represent one of the most progressive developments in the drinking water industry in the past 20 years. As this technology continues to advance and is employed in a greater number of water utilities, new norms for accountability, enhanced customer service, and operational efficiency are being created. This type of technology can benefit virtually any water utility. These systems require a notable funding commitment to procure, install, and operate, but can usually deliver a positive benefit to the water utility over the life of the system. It is important for the water utility to develop a sound business case for the system to ensure that the enhanced capabilities targeted for the system are delivered at a reasonable cost.

SYSTEMATIC DATA HANDLING ERRORS

The water utility operator should develop a detailed understanding of the ways in which consumption data is managed in the utility's customer billing system. Constructing a series of flowcharts that outline the various information handling processes is a systematic approach that can reveal gaps in policy, procedures, or programming that may allow apparent losses to occur. Any such deficiencies that allow customers to exist without billing accounts, without accurate metering and meter reading, or allow metered consumption data to be unduly modified for engineering purposes can create apparent losses.

Figures 5-1 to 5-4 represent several customer billing system flowcharts for a typical water utility. Figure 5-1 is a flowchart that represents an overview of the entire billing process. Although it displays the major billing functions at a glance, it lacks sufficient detail

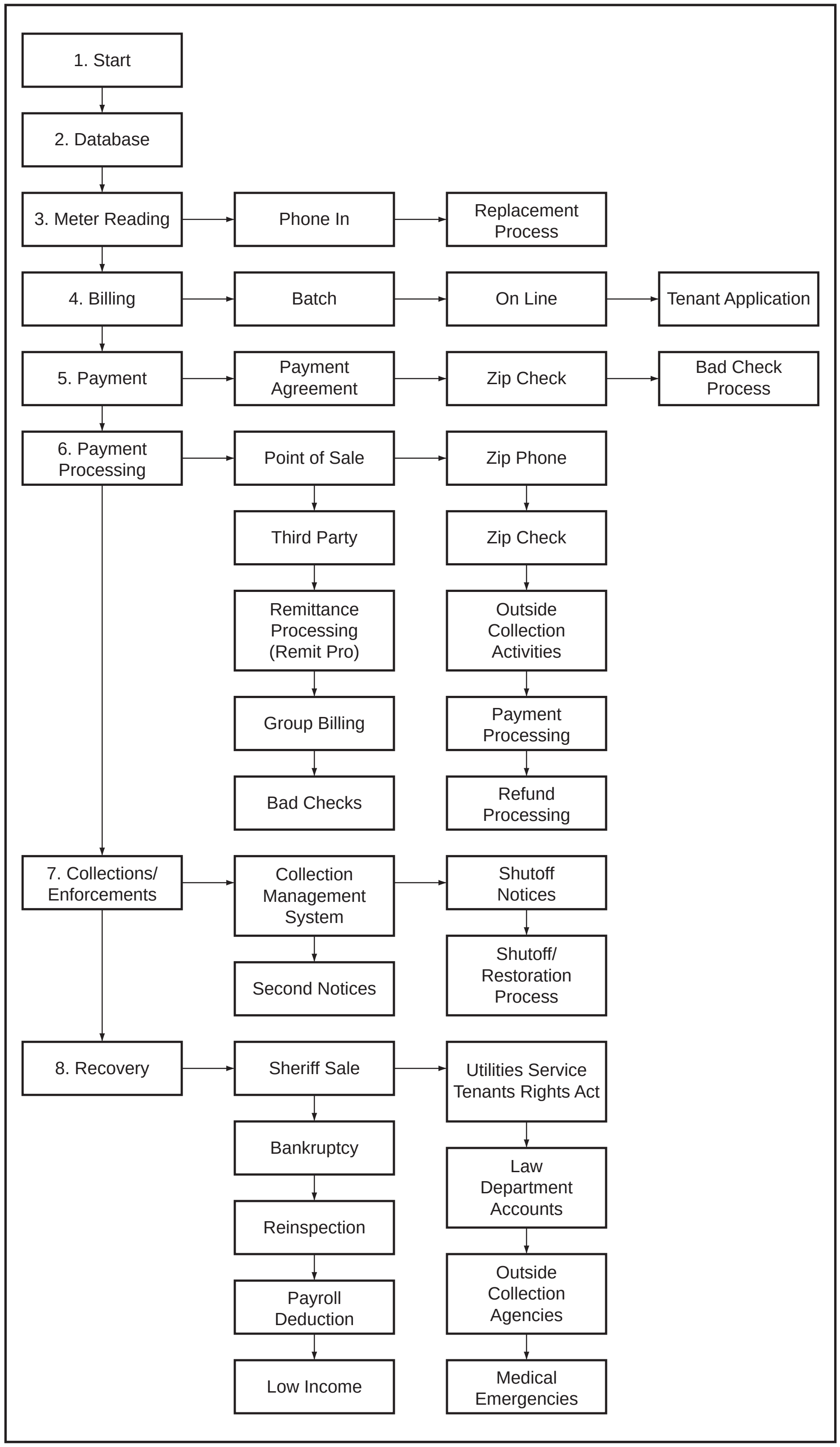


Figure 5-1 Example of a system overview flowchart of a typical customer billing system in a water utility

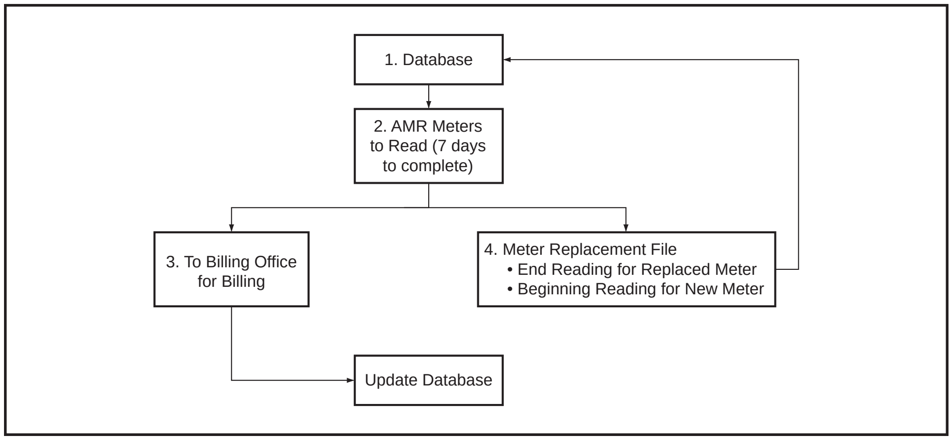


Figure 5-2 Flowchart of an automatic meter reading process in a water utility

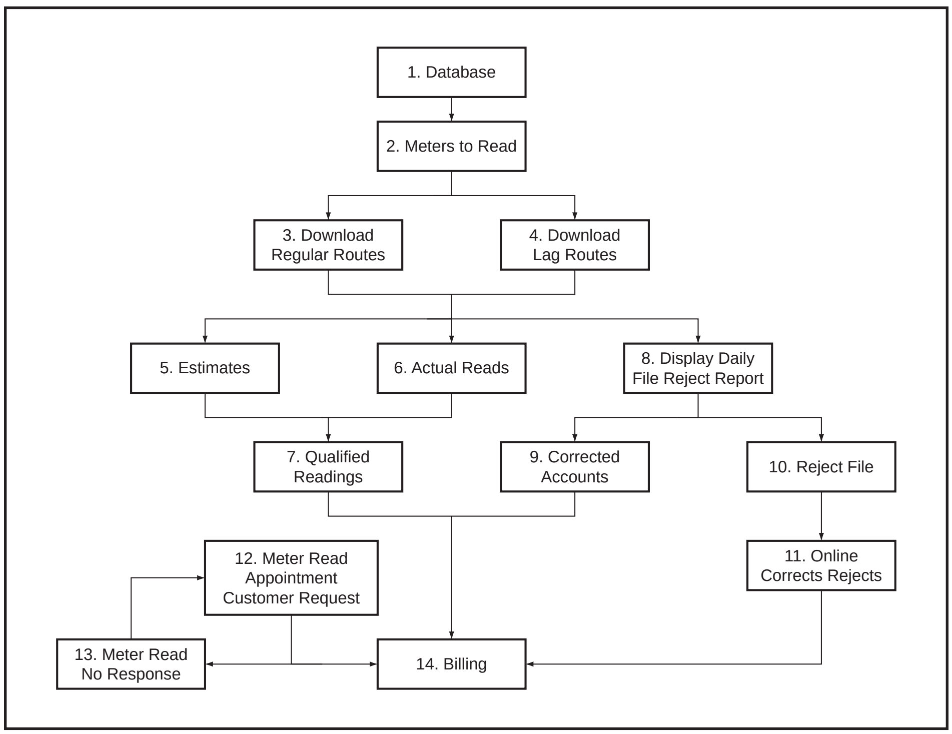


Figure 5-3 Flowchart of a manual meter reading process in a water utility

to identify likely occurrences of apparent loss. Additional flowcharts that display individual subprocesses of the customer billing system are given in Figures 5-2 through 5-4. In this example, meter reading sequences for both automatic and manually read customer meters are shown in Figures 5-2 and 5-3, respectively. It is not unusual for water utilities to employ AMR in a portion of their service area while manually reading meters in the remaining areas. The meter replacement process is shown in Figure 5-4.

Using flowcharts to assess various subprocesses of billing operations allows the auditor to confirm the billing functions that are working properly and identify gaps that cause customer consumption to be understated and the utility to underbill their customers. The billing system flowcharts shown in Figures 5-1 to 5-4 are given for illustrative purposes only and do not apply for all utilities. Each water utility has a customer billing

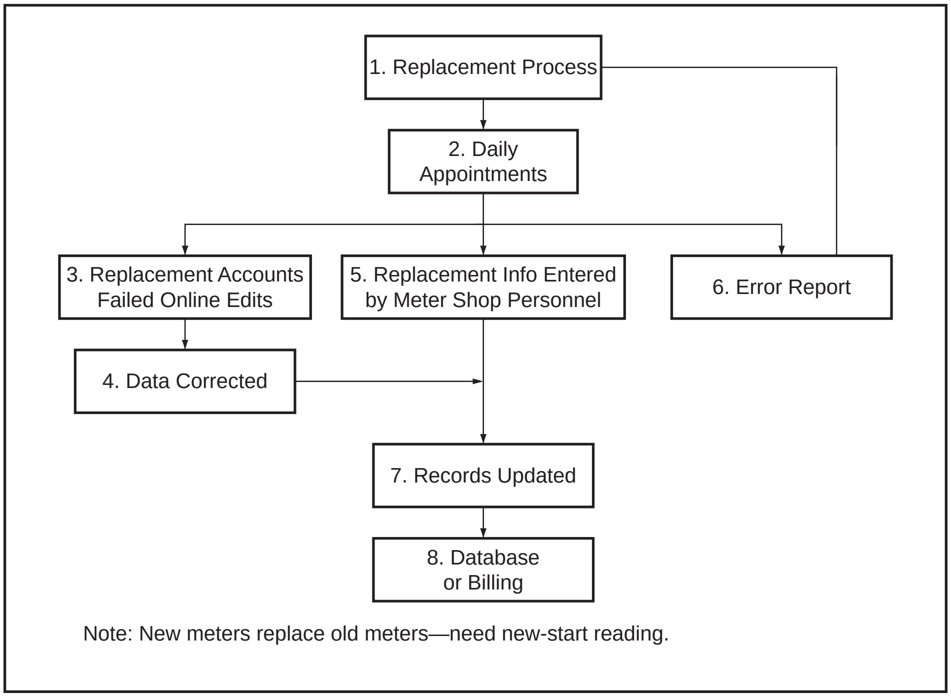


Figure 5-4 Flowchart of a typical customer meter replacement process in a water utility

process with features that are unique to their organization; therefore, each utility should generate flowcharts that reflect their individual processes.

By outlining the billing data flow paths and documenting information handling policies, procedures, and practices, the auditor can usually establish a highly detailed picture of the billing process and sources of apparent losses caused by data handling errors. A small sample of several dozen to several hundred customer accounts in various categories should be analyzed to determine if any loss impacts exist. The auditor should analyze samples of accounts in any special billing categories (municipal properties, nonbilled accounts) as well as a sample of the largest water consumers to reveal likely occurrences of apparent losses.

In analyzing customer billing system operations and billing data, the auditor should consider the following:

- Policy—Are policies regarding customer metering, billing, water rates, customer service connection piping responsibilities, and so forth, rational, consistent, codified, and well communicated?
- Procedures—Do written procedures exist? Are procedures used to ensure that consistent metering, meter reading, and billing functions are employed for all customers? Are checks and balances built into the system to flag breakdowns or gaps in the process?
- Practices—Do the actual practices reflect the mandates of the procedures? Are meter readers, billing clerks, or similar employees properly monitored and supervised to detect and minimize human error or malfeasance in transferring water consumption data and to ensure that policies and procedures are being followed?

Additionally, the following questions should be answered:

- Are certain classes of customers, such as municipal properties, exempt from metering and billing? If so, how is their water consumption accounted for by the water utility?
- Are there potential instances of customer classification miscoding, which may be resulting in misapplied billing rates to certain customer accounts? Is each customer being billed at the correct rate? For example, is a customer who lives outside the city limits being billed at the inside city limits rate? Is a customer who is connected to the sanitary sewer system not being billed for sewage fees?
- Are there potential instances of meter multiplier miscoding, which may be resulting in miscalculated water consumption values on the bill? (See the "Error in Capturing Proper Meter Readings" sidebar as an example.)
- Can customers be placed in a nonbilled status for conditions such as property vacancy, delinquent, or shutoff accounts, and so on? If so, are these accounts routinely monitored? Flowcharting can help to distinguish the actual (vs. perceived) management practices for unbilled accounts, which may reveal unintentionally unbilled volumes of water. Automated reading tends to make the inspection of such properties more of a challenge and even a new separate task to be performed.
- Are estimates of customer consumption employed if meter readings are not available? If so, how accurately does the estimate reflect actual consumption? Do checks exist to validate or periodically update the estimates?
- Does a policy exist for enforcement to deter unauthorized consumption? Can customers have service terminated for nonpayment? If so, are significant numbers of customers illegally reactivating their service? Is there a mechanism to detect and thwart this activity?
- Do programming algorithms incorporate billing adjustments that create a variance between "volume registered" and "volume billed," such as shown in Tables 3-11 and 3-12? This may reflect unintentional modification of legitimate consumption volumes in the billing adjustment algorithms.
- Are metering, meter reading, and billing functions actively tracked and monitored by the issuance of routine management reports that are structured to summarize performance, identify trends, and flag anomalies?
- Do reliable procedures exist to ensure that accurate consumption volumes are measured during the meter replacement process? Proper closing readings must be gathered from the outgoing meter and a new initial reading input from the incoming meter. Do billing system operations maintain the integrity of the actual customer consumption during this transition?
- How many meters of size 1-in. and larger are a misapplied size or type of meter, which may produce billing patterns indicative of consumption under-registration and underbilling? (This topic is discussed further in the next section.)
- Are customer consumption and billing trends evaluated on a regular basis to discern specific and overall trends in consumption and loss patterns in response to water conservation efforts, loss control programs, or demographic trends such as growth in the industrial sector?

These are just some of the questions that might be posed during bottom-up auditing of the data handling process. For every water utility, certain unique processes can exist and should be scrutinized by the auditor. The exercise of flowcharting the customer billing system can be revealing, and process flaws or misunderstandings between different groups in the water utility are often discovered. For some of the system shortcomings,

Error in Capturing Proper Meter Readings Into the Customer Billing System Results in Underbilling Customers by a Factor of 10

A particular water utility located in a hot, humid coastal area of the United States has large underground meter vaults that are prone to being flooded throughout the year. In order to read the large water meters, the utility installed a touch-read automatic meter reading system. Based on the results of its own AWWA water audit, the utility suspected that it was incurring substantially high levels of apparent water loss and billing much lower water and sewer charges than expected, possibly due to errors in the utility billing system. The utility attempted to find sources of the apparent loss, and eventually—with the assistance of a consulting firm—was able to identify a mysterious source of apparent loss.

It was discovered that the purchasing department had ordered many large water meters that featured only the first five digits of the six-digit encoder register as readable digits. However, this information had not been communicated to the meter readers. When reading the large water meters, the meter readers' touch-read probe registered the truncated five-digit reading instead of the complete and accurate six-digit reading. Figure 5-A shows both a meter register of one of the meters and the resulting display of the touch-read system. Consequently, the utility was consistently underbilling those customers by a factor of 10 since the touch-read probe could not read the sixth digit of the water meter register. Utilities should audit their large meter accounts and ensure that their meter reading activities accurately read water meters to the proper degree of flow registration.

Figure 5-A Meter register showing active six digits on the meter, along with erroneous AMR touch-probe meter reading of only five digits

corrections can be implemented by relatively inexpensive computer programming changes or improved coordination between metering, meter reading, and billing groups in the utility. These corrections are usually implemented by a change in procedure, additional auditing, modification of meter reading cycles, billing processes, or revisions in computer output reports. These are all operational functions that can be executed in the office. They do not necessarily require new equipment or significant staffing changes. In some cases, the findings of the flowcharting analysis may point auditors to a questionable process that needs to be further investigated to confirm whether water volumes are being lost.

Once the customer billing process has been mapped via flowcharts, the auditor can determine whether to undertake a more detailed investigation of billing operations and the customer consumption database. If the database is extracted in digital format, the analysis can be performed in a semi-automatic manner, leveraging the functionality of database software tools such as Microsoft Excel and Access. This typically requires extraction of the database from the customer billing system, and is sometimes referred to as a *data mining* analysis. This is a more involved—but very worthwhile—undertaking. Although there is not a standard approach to this type of analysis, a utility may consider developing a process in-house or using an outside consultant to perform the task. From a data mining analysis, anomalies of all types can be flagged for further investigation, including the extent of accounts registering zero consumption for consecutive billing cycles, accounts registering negative consumption (possibly due to errant billing adjustment algorithms), accounts registering unusually high or low consumption volumes, accounts registering repeated consumption volumes, and many other possible trends of unusual activity.

At the completion of its fiscal year (FY) 2006 (July 1, 2005, to June 30, 2006), the Philadelphia Water Department (PWD) undertook a data mining analysis of its water billing data (WSO 2006). PWD employs a mobile read AMR system that reads and bills virtually all customer meters on a monthly basis. With nearly one-half million customer accounts in a large urban center, PWD generates a very large amount of billing data, and the data mining approach offered significant advantages in sleuthing unusual consumption trends. Some of the important findings of this comprehensive analysis are shown in Figures 5-5 through 5-9. Figures 5-5 and 5-6 show the billing disposition of ⅝-in. meter accounts for PWD for FY2006. These represent typical residential billing accounts. For FY2006, 465,074 residential accounts existed out of a total of 478,211 accounts, or 97.2 percent of the total number of billing accounts. Figure 5-5 lists the number of ⅝-in. accounts that fall into various annual consumption ranges. In 2006 PWD's residential accounts typically consumed an average of 7–8 ccf (hundred cubic feet) per month, equivalent to 5,236–5,984 gal. Thus, typical residential accounts generally billed between 84–96 ccf (62,836–71,813 gal) on an annual basis.

Figure 5-5 shows that 316,444 accounts of the 465,074 residential accounts (68 percent) were billed annual consumption volumes in this typical range of less than 100 ccf/year (74,805 gal/year). Another 108,394 accounts (23.3 percent) were billed at an annual consumption range of 100–200 ccf (74,805–149,610 gal), a range reflecting somewhat higher, but not inordinately high, consumption. This analysis shows that approximately 91.3 percent of all residential accounts are billed within a typical range of consumption. However, Figure 5-5 also reveals that the remaining 40,236 accounts (8.7 percent) are billed much higher consumption volumes than would be expected for residential accounts, with 1,747 accounts (0.37 percent) billed annual consumption volumes at least eight times the typical consumption rate. These high billings may reflect an error in meter reading or may identify inordinately high water usage due to internal plumbing leaks or possibly illegal water service connections clandestinely plumbed into internal piping from an adjacent building. Although such high billed consumption volumes will generate high billings, they should be investigated to attempt to halt excessive water waste or unauthorized consumption that may be the cause of the unusually high water consumption. PWD has found both such

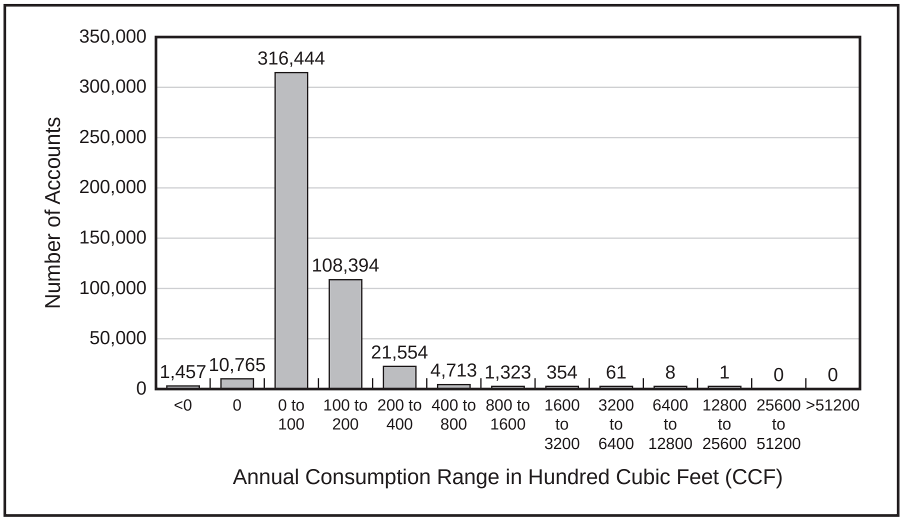


Figure 5-5 Data mining analysis chart for the Philadelphia Water Department showing the number of ⅝-in. meter customer accounts in various annual water consumption billing ranges

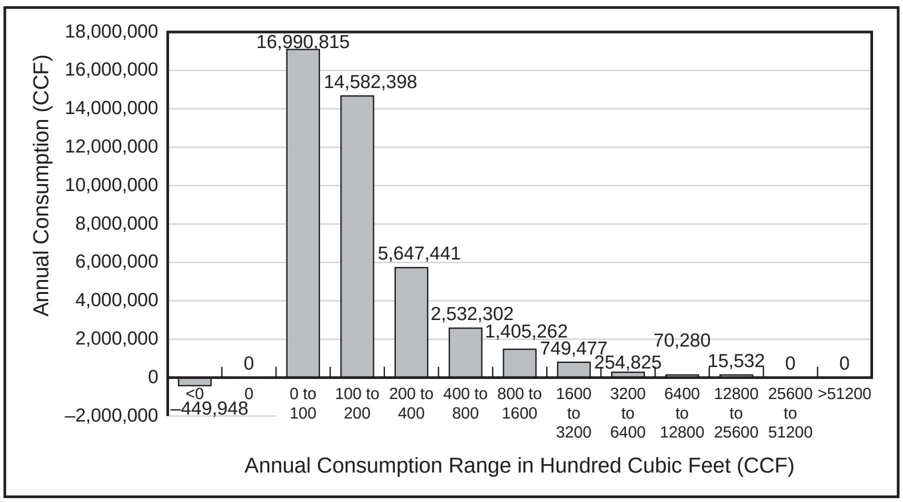


Figure 5-6 Data mining analysis chart for the Philadelphia Water Department showing annual billed water consumption for ⅝-in. meter customer accounts in various annual water consumption billing ranges

occurrences in a number of residential accounts that register very high water consumption. Additionally, Figure 5-5 shows that 10,765 accounts registered zero consumption during FY2006. Many of these billing accounts are vacant buildings that did not consume any water during FY2006; however, a portion of this total registered zero consumption due to meter and/or meter reading equipment failure, or as unauthorized consumption due to tampering of meters and/or meter reading equipment. Finally, Figure 5-5 shows that 1,457 accounts (0.31 percent) registered negative consumption for the entire FY2006. This data creates a billing anomaly for PWD that must be included in the annual water audit as systematic data handling errors.

Figure 5-6 also provides data for the residential ⅝-in. meter population, but displays the annual billed consumption volumes in various ranges of consumption. While residential accounts represent 97.2 percent of all accounts by number, they account for roughly 54.8 percent of the total billed consumption for FY2006, with accounts with larger meters tallying the remaining 45.2 percent of billed consumption. The annual billed volumes for each of the consumption ranges are given on this chart. Notable is that the annual negative volume of 449,948 ccf represents a quantity that was subtracted from the annual billed consumption volume from PWD's standard output reports in FY2006. PWD's annual water audit accounted for negative consumption quantities as components of systematic data handling errors. Since 2006, PWD has implemented a new customer billing system that features improved controls for billing adjustments that minimize the production of negative consumption values. Water utilities should take particular note of the potential for negative consumption values and consider modifications to billing algorithms to prevent negative values from corrupting the tally of customer water consumption. Again, readers can review the discussion around Tables 3-11 and 3-12 to determine how to maintain the integrity of customer consumption values for both billing and water accounting activities.

Figures 5-7 and 5-8 parallel Figures 5-5 and 5-6 but show similar data for 10-in. metered customer accounts, a class of accounts that exists for the largest of water users, typically industrial buildings. Hence, it would be expected to find the majority of accounts residing in the higher consumption ranges. However, as shown on Figure 5-7, 98 of the total 129 10-in. accounts (76 percent) registered zero consumption for the entire year. Investigation found that a number of these accounts are inactive or registered zero consumption because they serve as an emergency supply to a building or facility with more than one service connection. However, in some cases, it was determined that the 10-in. meters were vastly oversized and the relatively small water consumption was not being registered by these (typically turbine) meters. In addition to the 98 zero consumption accounts, another 10 accounts registering less than 12,800 ccf (0.958 mil gal) for the year likely represent oversized water meters. Thus only 21 of the 129 10-in. accounts registered consumption in the typical higher ranges expected for such large water users. The consumption volume profile for 10-in. accounts is shown in Figure 5-8 and reflects the large consumption volumes registered by the 21 accounts that are likely functioning adequately.

One last example of PWD's data mining activities is given in Figure 5-9, which displays additional insight into the occurrence of negative consumption data. This chart displays monthly negative consumption totals for a portion of PWD's customer population, namely, ⅝-in., 3-in., and 10-in. metered account classifications. Water consumption profile charts such as Figures 5-5 through 5-9 are very useful in visually assessing billed water consumption trends and detecting anomalies as discussed in the case of PWD for ⅝-in. and 10-in. water meters.

By flowcharting the customer meter reading and billing process, and conducting data mining analysis, the water utility will very likely be able to identify several classes of accounts with suspicious billing trends, as well as numerous individual accounts. Armed with this knowledge, the utility can then begin to conduct physical inspections of customer premises and metering installations to identify the cause of unusual consumption patterns. These inspections represent the detailed "bottom-up" auditing that is most valuable to the water utility. Such inspections do require staff time to conduct, but these visits can lead to direct revenue recovery in many instances and can reveal additional information to the water utility. In large water systems like PWD's, many suspicious accounts usually exist and inspections need to be carried out continuously for a representative number of such accounts. The scheduling of inspections can be directed by assigning priorities to those accounts that initially offer the greatest revenue payback potential or are needed to explain unusual metering or billing occurrences. For example, the Boston Water & Sewer Commission examined hotels in their systems and evaluated the ratio of gallons used per room. A high ratio for a given hotel revealed internal leaks, and low ratios revealed open bypass lines and meter issues. As the water utility matures in making refinements

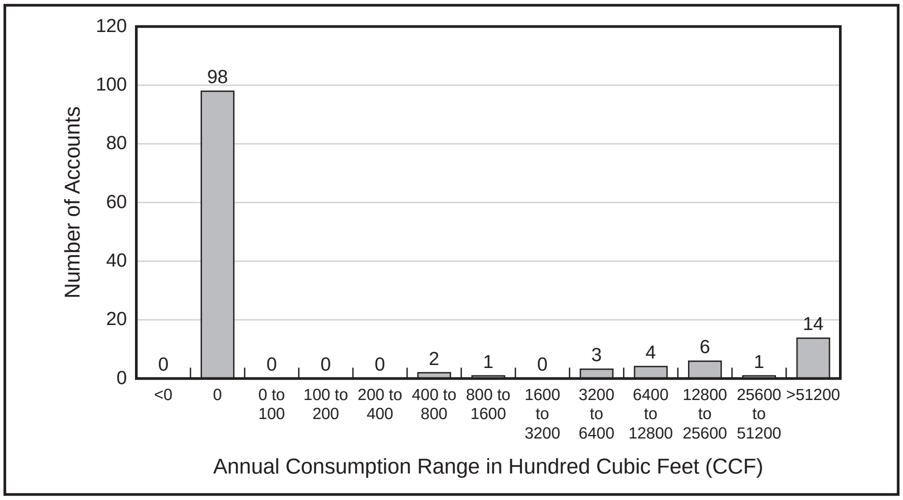


Figure 5-7 Data mining analysis chart for the Philadelphia Water Department showing the number of 10-in. meter customer accounts in various annual water consumption billing ranges

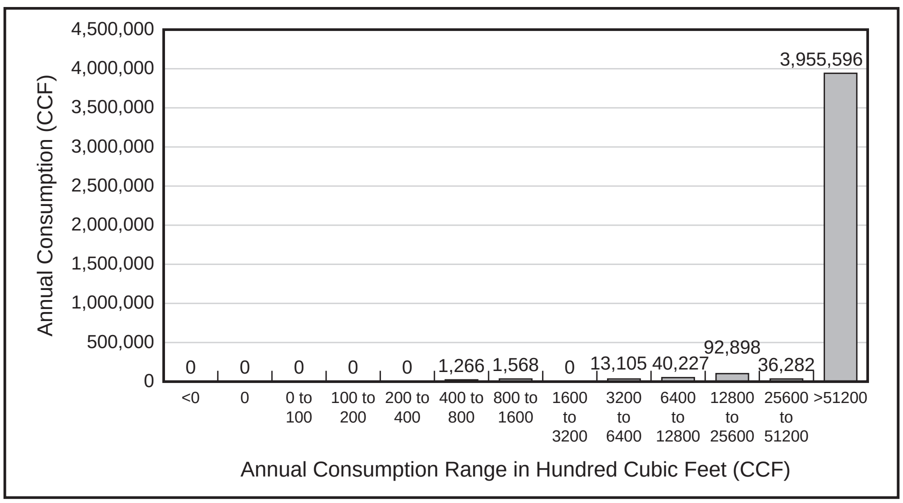


Figure 5-8 Data mining analysis chart for the Philadelphia Water Department showing annual billed water consumption for 10-in. meter customer accounts in various annual water consumption billing ranges

to its metering and billing operations, standard procedures to flag anomalies and initiate inspections can be developed to keep the water utility at a high level of billing efficiency and maximize the opportunity for revenue recovery.

Bottom-up auditing activities of suspect accounts should be carefully documented so that volumes of water and revenue recoveries can be reliably tracked. Recovered water volumes should be tallied each year in subcategories of systematic data handling errors and included in the annual water audit. Recaptured revenue should also be tallied each year to use in a benefit–cost analysis of the bottom-up auditing and loss control activities. From FY2000 through FY2013, PWD's Revenue Protection Program registered billing recoveries of more than $36 million of revenue (not adjusted for inflation). An economic analysis of activities through FY2010 found that PWD's net benefits of its Revenue Protection Program averaged approximately $1.4 million annually.

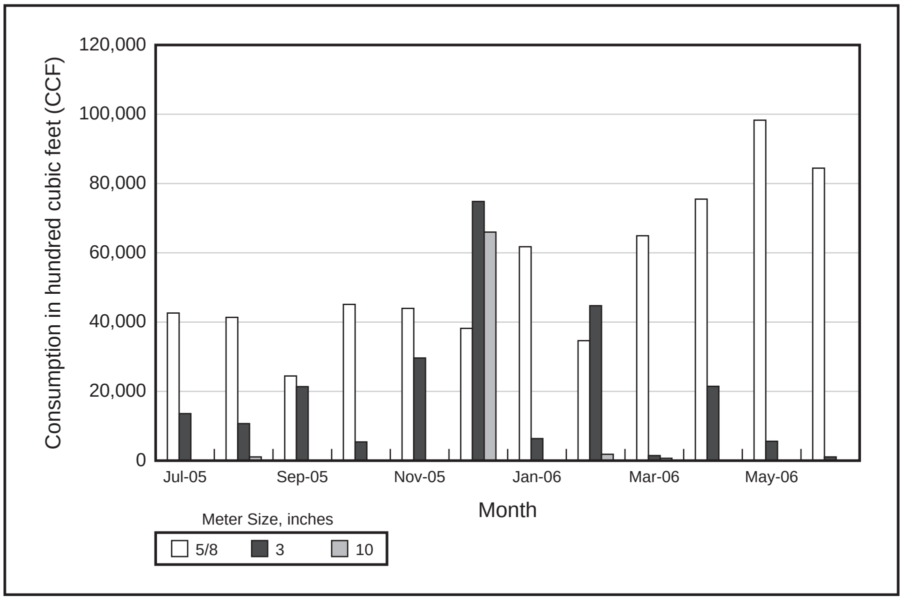


Figure 5-9 Data mining analysis chart for the Philadelphia Water Department showing annual negative billed water consumption due to billing adjustments for ⅝-in., 3-in., and 10-in. meter customer accounts by month

By investigating systematic data handling errors first, water utility managers can accelerate revenue recoveries and ensure that customer consumption data are accurately recorded. This activity is both critical to the success of the water loss control program and a significant opportunity for water utilities to infuse new revenues into their operations.

CUSTOMER METER INACCURACY

It is common in many—but not all—water utilities to use water meters to measure the amount of water passing through water service piping into customer premises. When properly installed, sized, and typed for the specific application, metering technology is accurate in recording flow across a range of flow rates, and water utilities have the potential to reliably record the collective water consumption for their customer population by installing water meters and regularly reading or collecting data from them. However, utility managers are challenged to select meters of the proper size and type for the wide variety of customer usage habits and to keep the meter population up to date. Additionally, many meters lose low-flow accuracy that is needed to capture flow from toilet leaks and other small flow-rate leaks in customer premises. With many water utilities managing thousands of water meters, the sheer scope of keeping high meter accuracy is a great challenge. Thus, virtually all water utilities that employ water meters have meter accuracy issues with some portion of their customer population.

AWWA provides detailed guidance on all aspects of customer meter management in its Manual M6 publication titled *Water Meters—Selection, Installation, Testing and Maintenance* (AWWA 2012). Utility managers responsible for meter management can familiarize themselves with best practices as presented in this publication to approach meter management in a proactive manner.

The water auditor should quantify the volume of apparent losses attributed to the collective customer metering inaccuracies in the water system. See chapter 3, Task 3, Step 3-2B for information on estimating apparent losses caused by customer metering inaccuracies.

For those water utilities that meter their customers, the consumption data trail begins at the customer meter with the flow measured by this device. Meter accuracy has several components. First, the water meter must be able to physically perform to reliably register a volume of water passed in a given period of time. Second, the meter must be appropriately sized to accurately register customer water consumption. Third, the proper type of meter must be used in a given application. Finally, proper installation of meters must be ensured to maintain meter accuracy. Customer meters must both work properly and be appropriately sized and typed for the customer demand pattern if they are to avoid under-registering flows, which cause underbillings and loss of revenue potential. Water utilities that employ best management practices for meter management likely have a thorough understanding of their customer meter demographics and the accuracy of the different meters in their system. Many water utilities, however, do not have current information about the status of their meter population or current information about the accuracy of specific types and makes of meters. It is not uncommon for an incoming water utility manager to inherit a meter population that was installed 15, 20, or 25 years ago but has not experienced ongoing meter testing, replacement, right-sizing, or right-typing. In such cases, the size, type, make, and performance of the meter population is usually poorly documented and understood. It is important to conduct bottom-up data gathering and investigations to establish the basic demographics and accuracy levels of the meter population.

Meter Demographics

If the meter population characteristics are not known, the auditor can conduct research using purchase and installation records, billing records, customer complaint histories, and meter accuracy test results to compile information on the sizes, types, manufacturers, ages, and cumulative consumption levels of customer meters. Many manufacturers can provide an approximate date that the meter was manufactured based on the serial number. Physical inspection of various customer premises (possibly an interview with larger customers) will also be necessary for some properties to verify the size, type, and make of the existing water meter. Table 5-2 is an expanded version of Table 3-7 for the fictitious County Water Company (CWC), which serves as the illustrative example throughout this manual. This table lists the summary demographics of the CWC customer meter population at the close of its calendar water audit year.

It is recommended that customer meter demographic information be integrated into the customer account and consumption data system to allow for frequent systematic analysis of meter performance and the overall accuracy of the customer meter population.

Because meter technology is always improving, new types and models of meters are frequently introduced to the water market. Many water utilities purchase meters in lots during a competitive bidding process and, over long periods of time, gradually install a variety of makes and models in their system, particularly in the large customer meter classes. It is important that the auditor have a reasonable sense of the meter population demographics to establish a sound meter testing, right-sizing, right-typing, and replacement strategy.

In the past, it was common for water utilities to periodically retrieve meters from customer locations, repair and test them, and place them back into service, typically in a different customer account. This “rotation” process has given way in more recent years to a meter “replacement,” or change-out process, with an older meter retrieved and scrapped, and a new replacement meter installed. The economics of repair and reinstallation are no longer justified for most water utilities, and replacement—particularly for small, residential meters—is now the common approach. The exception may be for large customer meters. Because of the greater purchase expense of these meters, many water utilities still repair and reinstall larger commercial and industrial account meters in their systems.

Table 5-2 Customer meter population demographics and metered consumption for County Water Company as of Dec. 31, 2013

Meter Size (in.)	Number of Meters	Percent of Total Meters	Type (No.)	Manufacturer (No.)	Average Age (years)	Percent of Metered Consumption
⅝	11,480	94.1	PD* (11,480)	Badger (6,123) Neptune (4,682) Sensus (675)	13	71.2
¾	10	0.08	PD (10)	Neptune (10)	26	0.1
1	338	2.8	PD (338)	Badger (250) Neptune (88)	18 11	2.8
1½	124	1.0	PD (124)	Badger (18) Neptune (106)	18 9	2.8
2	216	1.8	PD (216)	Sensus (54) Badger (146) Neptune (16)	12 22 20	11.7
3	15	0.12	Turbine (15)	Sensus (15)	15	6.6
4	7	0.05	PD (2) Turbine (5)	Sensus (2) Neptune (5)	15 26	2.2
6	6	0.05	Turbine (2) Combine (2) Magnetic (2)	Badger (2) Neptune (2) Elster (2)	15 9 4	2.6
Total	12,196	100.00				100.0

*PD = Positive displacement

Customer Meter Testing

To determine the physical accuracy of the meter population, many water utilities conduct regular meter accuracy testing to identify meters with declining performance, particularly on large meters. By obtaining meter accuracy test results of groups of water meters, the water utility benefits by

- calculating a quantity of the collective water consumption that is under-registered in the customer meter population throughout the audit year, thereby improving the validity of the water audit; and
- identifying individual water meters with poor accuracy that can be replaced or repaired (large meters). This serves as an intervention to reduce apparent loss from customer metering inaccuracies.

AWWA's guidance manuals on meters give excellent instruction on meter accuracy testing. AWWA Manual M6 includes an entire chapter on testing titled "Testing of Meters—Test Procedures and Equipment" (AWWA 2012). Readers are referred to this publication/chapter to obtain detailed instruction on the methods and structure of the meter testing program. In addition, the Water Research Foundation has sponsored a project that has tested a significant number of meters, and the results can be instructive about how various types of meters perform over the long run. The project, *Accuracy of In-Service Water Meters at Low and High Flow Rates* (WRF 2011), included testing of hundreds of small water meters from a wide variety of manufacturers and offers great insight to the meter accuracy testing process and accuracy findings for a large number of meters.

Generally, accuracy tests should be conducted at low, medium, and high flow rates. Meters should always be tested at low flows first since this is the most sensitive test. If meters are tested at high flows first, the strong flow of water will likely remove any scale or other deposits in the meter that may have impaired low-flow accuracy while the meter was installed in the customer premises. Conducting a low-flow test after the high-flow test may give an accuracy value that is higher than the actual low-flow accuracy for the meter when installed at the customer premises. This will not be a representative test result.

Many water utilities operate a customer meter accuracy testing program and have their own test facility and equipment to perform ongoing accuracy testing of meters. Water utilities that do not have their own meter testing facilities can outsource their testing to specialty companies. For water utilities that operate their own test equipment, it is very important for water utility managers to review the procedures and testing practices that are employed by the water utility personnel. The meter test apparatus is a precision instrument and should be operated by skilled, trained personnel who follow a standard procedure for testing and documentation of the test results. Different sizes of test "benches" exist for testing the smallest meters of size ⅝-in. through 1-in. Larger sized test benches can handle meters of size 2-in. up to 12-in. While the full spectrum of customer meters sizes can be tested on test benches, many water utility managers prefer to test large water meters (3-in. and larger) in situ at their site of installation. For this purpose, portable test equipment is available to test these large meters. This allows testing of the meter as it is performing at its commissioned site and avoids the need to remove and transport very large and heavy water meters to the meter shop for testing. An example of a successful large meter test program in the Louisville Water Company is given in the "Large Customer Meter Accuracy Testing Program" sidebar.

For small residential meters, several regimens of testing should be established; see AWWA Manual M6 for guidance (AWWA 2012). Newly received water meters should be tested to confirm that manufacturers are meeting performance specifications. Other sample groups of meters can be tested, including those with high bill complaints, low or zero consumption, or for random sampling purposes. A separate test regimen of meters with high cumulative consumption should also be tested since these meters might be starting to show wear and have the potential for reduced accuracy. Results of such longevity testing of high cumulative consumption meters can help to develop a long-term meter replacement strategy based on the identified level of cumulative consumption when accuracy begins to decline. Select large meters should also be identified for testing and/or replacement, including 1-in. through 4-in. meters, a mid-range that is sometimes overlooked by utilities. Large meters typically register high volumes of flow and contribute large proportions of revenue. Large meter testing will confirm the ability of the meters to capture optimum revenue. Utilities with test equipment should annually test between several hundred to

Large Customer Meter Accuracy Testing Program in the Louisville Water Company

The Louisville Water Company (LWC) is a proactive water utility that conducts customer meter accuracy testing of small and large meters supplying customers in Louisville, Ky., and the surrounding communities that it serves. LWC owns and operates a meter testing apparatus at its facilities, which is used mostly for testing small water meters. LWC also owns meter test equipment for testing large customer meters in situ at their sites of installation. A truck is outfitted with equipment to allow testing of these large meters, which typically exist in a meter pit adjacent to the building that is supplied water. Figures 5-10 through Figure 5-13 illustrate this equipment in use. LWC operates with a policy to test the water meters of the top 100 water-using customers on an annual basis and to test the water meters of the top 50 users on a semi-annual basis. In this way, LWC keeps a strong level of surveillance of the metering of the largest customers and revenue producers, and can act quickly to address those meters that begin to display declining meter accuracy.

Figure 5-10 Truck equipped with large meter testing apparatus for in-situ meter testing at Louisville Water Company

Courtesy of Louisville Water Company

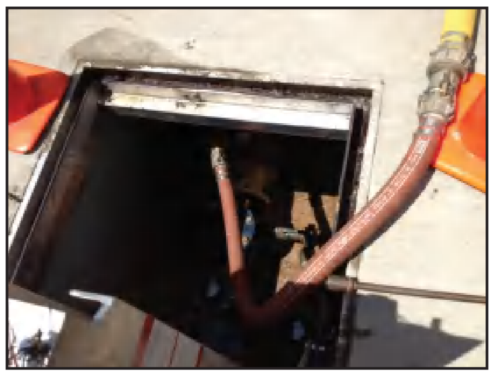


Figure 5-11 Hose connected to large meter test port in underground meter pit and ready for testing

Courtesy of Louisville Water Company

several thousand meters (depending on the size of the customer meter population) to gain a true sense of the collective accuracy of the customer meter population.

Table 5-3 gives example large meter test results for CWC as described in chapter 3. Illustrated in this table is the method of analysis to calculate a composite meter accuracy value of the five meter accuracy test results shown. The composite accuracy value can be calculated for a group of meters as shown in Table 5-3 or for specific sizes of meters. If a composite accuracy value is available for each meter size, then the degree of inaccuracy for the meter population can be determined as shown in Tables 3-17 and 3-18.

Many highly accurate meters are available to the drinking water industry. Installation and upkeep of meters should be included as part of the ongoing functions of the water utility; therefore, funds should be budgeted to accommodate regular testing and replacement of customer meters. Implementing a program that routinely tests groups of customer meters can be an efficient and economical way to provide guidance to keep a meter population current, and the program can provide essential data to develop a rational long-term meter replacement plan for the customer meter population.

Customer Meter Selection

To help determine whether meters are properly sized for existing customers, a representative sample of large meter accounts can be identified for data logging to confirm the

Figure 5-12 Interior of large meter test truck showing calibrated test meter

Courtesy of Louisville Water Company

Figure 5-13 Water being discharged to waste during large meter testing operation. Utilities should be certain to follow applicable state and local requirements for the safe discharge of drinking water to surfaces.

Courtesy of Louisville Water Company

Table 5-3 Meter test data for large meters for County Water Company

Meter ID Number	Size (in.)	Meter Type	Date of Installation	Manufacturer	Test Date	Mean Registration at Various Flow Rates (designated as percentage of registration)		
						Low	Medium	High
XYZ001	3	Turbine	June 1991	Sensus	Apr 2013	89	93.0	100
X00ZAA	3	Turbine	June 1993	Sensus	Apr 2013	70	95.2	98
NB123	4	Turbine	July 2001	Neptune	Apr 2013	95	99.0	102
NB456	6	Compound	Sept 2004	Badger	Oct 2013	98	96.5	102
AA002	6	Magnetic	May 2010	ABB	Oct 2013	98	99.0	103
				Sum of mean registrations		450	482.7	505
				Mean registration for five meters tested		90	96.54	101

customer water consumption profile. Data logging entails attaching a logging device to the meter and (depending on the meter type) recording the pulse or signal registered by the meter. These pulses can be converted to flow values and a detailed flow profile developed for the customer consumption for the period of the logging. The high, low, and average consumption values can be evaluated to determine whether a water meter is sized appropriately for the actual water usage pattern. If flow through a customer meter is mostly occurring at the low or high end of the specified range of the meter, then the meter is likely improperly sized for the application.

If large meters have been in service for many years, current customer flows may not match the water demands that existed at the time the meter was installed. Many customers have become more water efficient and/or building use may have changed from a highly water-intensive use (factory) to a low water use application (warehouse). Low flows may not be registered by some large, old meters, and data-logging data can help prove the need to downsize the existing meter to an appropriate size or select a meter type that is more accurate across a wider range of flows. Particularly for large meters, certain meter types are designed for specific flow patterns. Turbine meters are designed to capture continuous moderate and high flows, but if the user has periodic or frequent low flows, a considerable portion of the regular water usage may not be registered by the meter. Variations in flow from low to high can be measured by compound, electromagnetic ("mag"), single-jet, and ultrasonic meters and floating ball technology. Water utilities can use customer profiles to determine the consumption variation and select the appropriate type of meter. Manufacturers publish the low-flow accuracy limits of the meters that they produce, so utility managers should make certain that meters they are considering will accurately register the expected low flows at a given customer site. Compound meters by design capture high flow (usually with a built-in turbine meter) as well as low flow (usually with a built-in positive displacement meter).

In selecting meters for single-family residential service, utility managers should recognize that customer-side leakage is commonplace, and that leakage flows often occur below the "low flow" test level in the meter manufacturers' literature (¼ gpm for meters smaller than ¾ in.). As previously noted, the cost of delivering water that is unrecorded or under-recorded by the customer meter is ultimately recovered from all customers, and individual customers with hidden leaks may be unaware of this unintended consumption if it is not reflected in their water bill. Utility managers may consider investigating the use of higher performance water meters that can provide for strong accuracy at flow rates as low as ⅛ gpm, a flow rate that is typical of household leakage, particularly toilet leaks.

Another area of concern is with compound meters to measure varying flow rates, specifically the crossover flow registration. This refers to the mid-range flow rates at which the registered flow moves from the low-flow meter to the high-flow meter within the compound meter. If the customer consumption profile includes flow rates that frequently transition between high and low rates of flow, some of the flow—occurring at the transition flow rate—may not be accurately registered by the meter installation. American Water has found that a sensitive turbine meter can register more water consumption than a compound meter that may be allowing unregistered flow due to crossover issues. Knowing the crossover range for a given compound meter and the customer water consumption profile are necessary to reliably specify the appropriate size of compound meter for a large water consuming customer.

Data-logging technology provides the means to obtain detailed customer consumption profiles in a range of time increments: from hourly logging to establish a basic consumption profile, to fractions of a second using high-resolution data loggers in order to capture transient peak flow rates. AMI systems can collect data continuously at intervals of every 15–60 minutes. By obtaining and analyzing detailed logged data, the most appropriate size and type of meter can be specified for a given application. Applying this

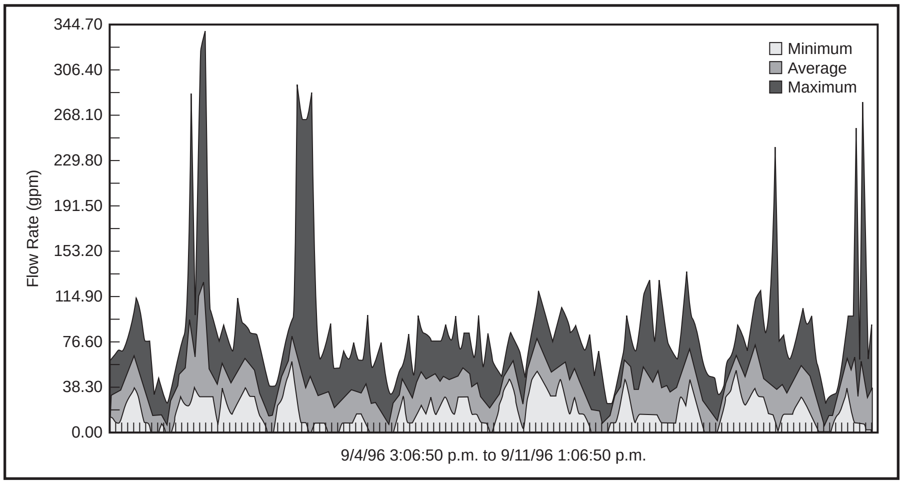


Figure 5-14 Graph produced from customer consumption meter data logging showing minimum/average/maximum flow rates

Courtesy of F.S. Brainard and Co.

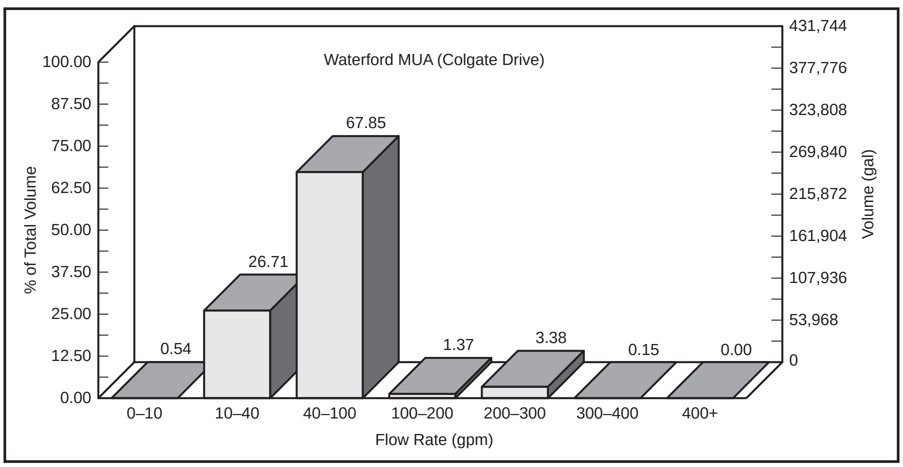


Figure 5-15 Graph produced from customer consumption meter data logging showing percentage of time in given flow ranges

Courtesy of F.S. Brainard and Co.

user-specific approach can promote superior meter accuracy, particularly in large water utilities with widely varying user classes. AWWA Manual M22, *Sizing Water Service Lines and Meters*, provides good guidance for the use of logged data to specify meters (AWWA 2014). Reliable data logging for meter sizing is dependent on the resolution of the data. When using high-resolution data logging to capture peak flow rates, the time interval should be as short as possible (e.g., 10-second intervals) while still registering appreciable nonzero flow data so that actual flow rates are recorded, as opposed to just a collection of average flow rates that may not accurately reflect the flow rate. Examples of customer consumption profile graphs derived from data logging are given in Figures 5-14 and 5-15.

Austin Water in the City of Austin, Texas, has conducted extensive data logging of many of its small customer meters up through size 2 in. For a description of this work, see the "Customer Consumption Data Collection and Meter Accuracy Testing in Austin, Texas" sidebar discussion in chapter 3.

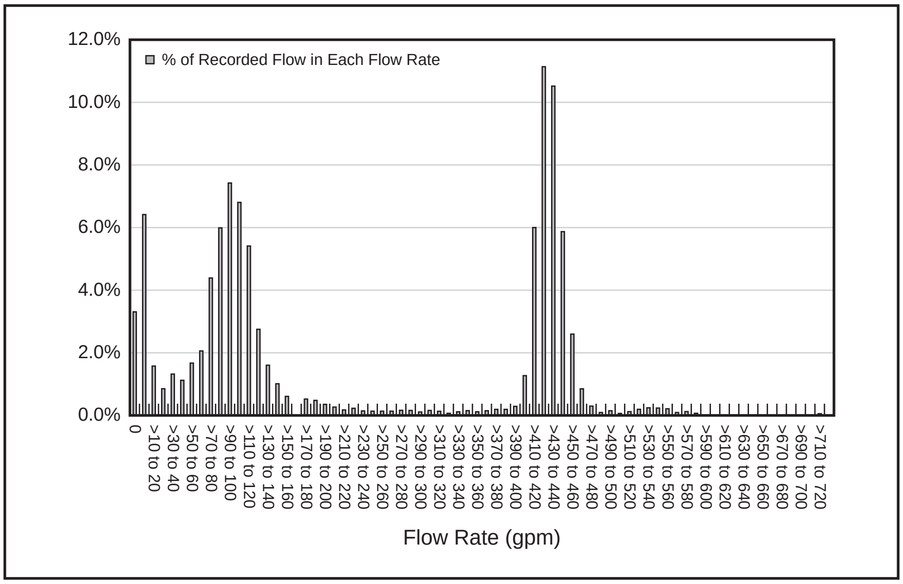


Figure 5-16 Graph produced from customer consumption meter data logging at a bottling plant in Philadelphia

Courtesy of the Philadelphia Water Department

From 2008 to 2013, the Philadelphia Water Department (PWD) conducted data-logging of several hundred large meter accounts ranging in size from 3 in. to 10 in. A wide variety of building types were logged, including school and university buildings, factories/processing plants, hospitals, hotels, and apartment buildings. While many of the profiles generated from this activity confirmed that the appropriate water meter was in use, the work identified a trend of certain metering applications that result in significant under-registration of low flows.

Figures 5-16 and 5-17 show two contrasting examples of customer profiles obtained from PWD's data-logging activities. Figure 5-16 shows data gathered from the 6-in. compound meter supplying Philadelphia's Coca Cola bottling plant, a large water-using facility. As shown in the profile—which is presented as a frequency distribution of flow ranges—two distinct peaks occur: one peak occurring in the 70–120 gpm range and a second peak from roughly 410–470 gpm. With both high and low peaks, as well as measureable water consumption across the full range between these values, the use of a compound meter is supported since this type of meter provides high accuracy for both high and low flows. A very small percentage of "zero" flows are recorded; thus the vast majority of flows are captured by the meter, indicating that the meter is not oversized for the application.

Conversely, Figure 5-17 shows a data-logging profile created from a 3-in. turbine meter on the supply to a library building at a university, a low-water-using facility. It is essential to state that data loggings for this facility found that 97 percent of the readings were recorded as zero. This is because this meter is both dramatically oversized and the wrong type of meter for this application. Thus, the data plotted in Figure 5-17 represents only the 3 percent of the recordings that actually registered any flow. For the 3-in. turbine meter that is employed at this location, the manufacturer's quoted low-flow accuracy of 98.5 percent to 101.5 percent falls within the range of 5–750 gpm. Even with the limited number of recordings shown on Figure 5-17, it is evident that flows registering higher than 5 gpm occur only about 2.5 percent of the time. For the vast majority of the time, the 3-in. turbine meter fails to register any flow and can only be expected to accurately record flow for 2.5 percent of the time. Appropriate remedies for this installation are to either downsize the meter notably (likely a 1-in. positive displacement meter will work well) or

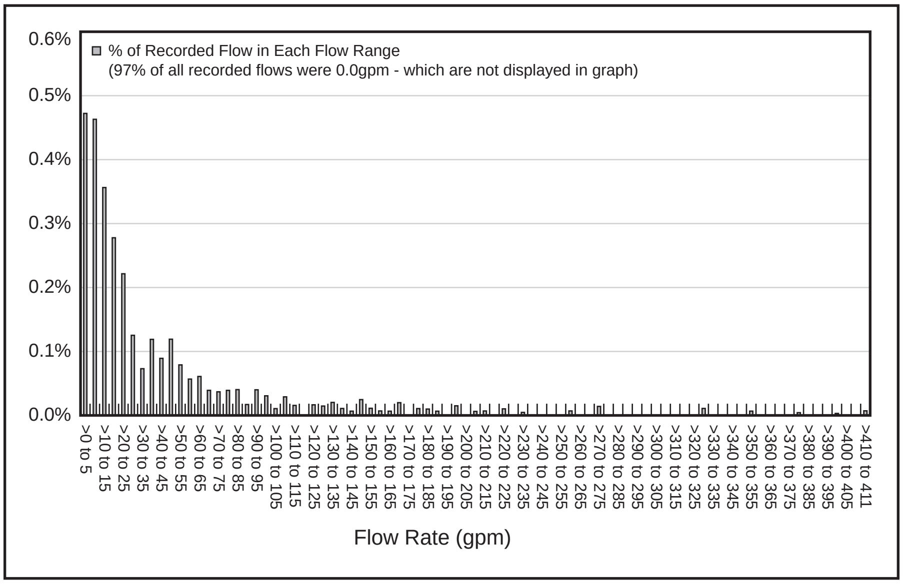


Figure 5-17 Graph produced from customer consumption meter data logging at a university library building in Philadelphia

Courtesy of the Philadelphia Water Department

replace the 3-in. turbine meter with a different type of 3-in. meter, one that is much more accurate in the low-flow range than a turbine meter. In this case, the downsizing was the more appropriate action.

The extensive data-logging work in Philadelphia found that a wide variety of relatively low-water-using buildings have been outfitted with either a 3-in. or 4-in. turbine meter. These types of meters are designed for accurate metering of moderate to high flows consistently over 5 gpm. This finding has launched an effort to further evaluate these locations for meter size or type changes, but also to review the guidance or requirements stated in the design and permitting phases of new buildings in Philadelphia that are allowing—or requiring—buildings to install inappropriate meters. It is advisable for all water utilities to review billing records and initiate data loggings or other investigative actions for customer accounts with 3-in., 4-in., or 6-in. turbine meters. It stands that many such metering installations have been misapplied and may be failing to register a large portion of the customer consumption at such accounts. This may be causing considerable apparent losses and reduced revenue potential at these sites. Replacing these meters with an appropriate smaller meter or different type of meter can likely improve accountability and revenue capture at many of these sites.

For many water utilities, more than 50 percent of revenue is received from fewer than 20 percent of customer accounts classified as commercial, multi-family, or industrial that use meters of size 1 in. and larger. It is, therefore, critical that these accounts are systematically reviewed to ensure that they are metered and billed correctly.

Traditionally, water utilities set meter replacement schedules based on years of service and meter size, with the largest of meters changed out as often as every two years and smaller residential meters extended to every 20 years. Alternatively, for small residential water meters, utility managers might consider meter testing and replacement criteria based on the cumulative flows passing through the meter rather than a fixed time interval. Targeting replacements based on cumulative measured volume is similar to automobile maintenance, where the 3,000-mile oil and filter change occurs not at any set time but only when the next 3,000-mile increment is reached on the vehicle odometer. By analyzing metered consumption data and conducting meter accuracy testing at

Using Midsize Turbine Meters for Low-Water-Consuming Buildings

It is advisable for all water utilities to review billing records and initiate data loggings or other investigative actions for customer accounts in the mid-range sizes of 3 in., 4 in., or 6 in. that employ a standard turbine meter. Particularly for low-water-using occupancies, there is a good likelihood that in many such metering installations the turbine meter is failing to register a considerable portion of the flow, which is often below the meter's low flow accuracy threshold. This may be causing considerable apparent losses and reduced revenue at these sites. Replacing these meters with an appropriate smaller meter or different type of meter can likely improve accountability and revenue capture at many of these sites.

certain levels of consumption, it may be possible to define—for a given meter size and type—the high cumulative consumption value of the meter, beyond which meter accuracy begins to decline notably. The methodology for this calculation for a small system in Arizona has been documented in a technical paper (Davis 2005). This approach can be more efficient than a time-based cycle because heavily used meters will be replaced on a timely basis that will ensure accuracy is maintained, while lightly used meters will not waste resources by replacing meters too soon while they still maintain high accuracy. The ultimate meter replacement schedule, however, can be based around the cumulative consumption target in conjunction with crew deployment and scheduling realities. It may be logistically advantageous to have crews replace multiple meters in a given area at the same time, even if some of the meters have not yet reached their cumulative target. Additional discussion on meter replacement life and economics is found in the Water Research Foundation report titled *Advanced Metering Infrastructure: Best Practices for Water Utilities* (Schlenger et al. 2011).

There are many aspects of customer meter management that water utility managers must address. By conducting meter accuracy testing, and data logging as needed, the manager can obtain data to quantify the collective accuracy of the customer meter population. If these activities are undertaken, a high grading of the customer metering inaccuracies component in the AWWA Free Water Audit Software (Audit Software) is justified. If the utility does not conduct regular meter accuracy testing or data logging, or regular meter replacement, the quantity of meter inaccuracy entered into the water audit will be a subjective estimate and should be graded at a lower level. (See chapter 3 for specific guidance on data grading in the Audit Software.) By having a high validity grading of customer metering inaccuracies, the manager can take steps to improve the accuracy of the customer population and will be able to monitor this improvement objectively. Good composite accuracy of the customer meter population can be maintained by

- replacing meters according to a rational schedule based on cumulative flow registration, age of meter, or both;
- having a means to closely monitor customer consumption trends and use meter accuracy test results to flag meters for replacement shortly before or after they begin to appreciably lose accuracy from wear;
- identifying oversized meters and replacing them with a similar meter of the appropriate smaller size;
- identifying meters of the wrong type for the application and replacing them with a more appropriate type of meter; and
- staying abreast of innovative metering technology and applying it to the benefit of the overall meter population and revenue capture.

Managing a large population of customer meters requires knowledge of meters and meter reading equipment as well as billing policies and customer relations. Policy and procedures regarding the sizing and installation of customer meters also play a role in water supply efficiency, and these should be reviewed to ensure that inappropriate meters are not installed inadvertently as a result of policy shortcomings. The benefits of accurate customer metering, however, continue to evolve as consumption data is recognized as critical to evaluate revenue protection programs, water loss control, and water conservation programs.

Metering Fire Services

It is not uncommon for customers to have fire service lines to feed internal fire sprinkler systems and, in some cases, fire hydrants and fire protection networks with pumps and tanks. These systems can either be integrated into the domestic water supply piping to the customer or installed as separate connections. The issues around unauthorized consumption occurring in fire connections are discussed in the following section. In recent years, utility managers have been installing meters on combined fire and domestic services with greater frequency to detect water consumption that may be occurring on these lines. Fire services have specific requirements, and utilities generally adhere to employing meters expressly made for use in fire lines. Water meters with significant friction losses at high flow or moving parts that may be prone to clogging can inhibit fire protection, and these concerns are guarded against in fire-specific meter designs that focus on unobstructed flow of water at high flow rates. An additional consideration is that water in a dedicated sprinkler line is stationary for long periods of time and its quality is generally not good. The typical fire/domestic meter can either be a large turbine or, more commonly, a device similar to a compound meter with high and low flow-metering capabilities.

Regarding downsizing of large commercial/industrial customer meters, additional scrutiny is needed before taking action if fire service is involved. If a meter provides both potable water and fire service to a facility, the service should not be downsized regardless of the results from the customer demand profile, and the meter should meet the AWWA C703-15 *Standard for Cold-Water Meters—Fire-Service Type*. If considerable domestic flow is being under-registered in such an installation, the water utility might investigate various brands of meters that meet the C703-15 standard but possibly provide a wider range of accurate flow registration than the existing meter.

The use of fire sprinkler systems in purely residential dwellings has been increasing in the United States. The reader is referred to AWWA C714-13 *Standard for Cold-Water Meters for Residential Fire Sprinklers in One- and Two-Family Dwellings and Manufactured Homes* for guidance on water meters for use in these applications.

UNAUTHORIZED CONSUMPTION

No water utility is immune to the occurrence of unauthorized consumption. Unauthorized consumption occurs in all water utilities; only the extent of the occurrence varies (Thornton 2002). Unauthorized consumption can occur as a result of weak policies, practices, and oversight by the water utility, coupled with deliberate actions by a segment of the customer population set on avoiding paying for water service. Unauthorized consumption can be significant for some water utilities while negligible in others; thus, utility managers should conduct investigations to estimate the general likelihood of the occurrence of unauthorized consumption and project the amount of attention that the issue requires in their operations.

Water utilities can exert control over the occurrence of unauthorized consumption by focusing on the following:

- Policy—having coherent, workable policies that clearly identify what uses of water are authorized vs. those that are not authorized. Policies should exist to cover the wide spectrum of activities that occur in providing water service.
- Detection—having good capabilities to become aware of the various unauthorized consumption events that can occur in the utility, close to the time in which the use begins.
- Enforcement—having the means to halt such consumption and invoke appropriate penalties.

Having mechanisms in place to detect trends of unauthorized consumption is most important. Flowcharting the processes of the customer billing system as illustrated in Figures 5-1 through 5-4 gives the auditor insight into loopholes that allow unauthorized consumption to occur and go unnoticed by the water utility. Once identified, loopholes can often be expeditiously closed by procedural, programming, or permitting corrections, perhaps resulting in a return of additional revenue. Water utilities should also create routine output reports that present data from the customer billing system in a way that reveals unusual consumption trends and flags data anomalies that suggest suspicious activities. Such reports should be run and carefully reviewed at the same frequency as the billing cycle. The water utility should assign appropriate staff time to this function.

An example of such a tracking report is a zero consumption report that lists accounts with unchanged meter reading (hence, zero consumption recorded) for two or more consecutive billing cycles. Customer accounts in active billing status that register unchanged meter readings for ongoing billing cycles might be indicative of vacant properties with no ongoing water consumption. This would not represent unauthorized consumption. Zero consumption can also occur because of meter failure (stopped meter) or AMR/AMI device failure. This is also not unauthorized consumption, but it is an apparent loss due to a customer metering problem. The third possible cause for zero consumption billings is tampering of the customer meter and/or AMR/AMI device, an activity that indeed is unauthorized consumption. Customer meter tampering might be controlled by locking devices that secure the covers of outdoor meter pits. Most AMR/AMI systems include alerts that flag tamper events on the meter or meter reading equipment and give the water utility immediate indication of unauthorized activity.

If the water utility has a significant number of accounts that register zero consumption for more than two consecutive billing cycles, then inspections of individual customer premises should be undertaken to uncover the reason for the unchanged water meter readings. These physical inspections are bottom-up auditing activities that locate apparent losses in an account-by-account manner. By physically inspecting a representative sample of these accounts, the utility manager can gather data to determine the percentage of zero consumption accounts occurring because of vacancy, meter/AMR failure, or tampering.

Similar bottom-up loss control activities can include the following:

- **Collect data on field reports of illegally opened fire hydrants.** The auditor should review opportunities for the unauthorized use of fire hydrants and ensure that a rational policy regarding fire hydrant use exists. The Loudoun County Sanitation Authority in Loudoun County, Va., developed a comprehensive policy and detailed procedures for fire hydrant usage that has allowed them to better balance the need for access to water supply versus protection of the water distribution system and water quality. Their efforts were well documented in AWWA's *Opflow* publication of October 2006 (Villegas 2006). Field data can show the extent to which these policies are violated. Actions to control such unauthorized usage may include the installation of fire hydrant locking devices, increased public

Figure 5-18 Public relations flyer cautioning communities about the impacts of unauthorized water consumption

Courtesy of New Jersey American Water Company

education functions, and the enactment of stricter penalties for unauthorized use of fire hydrants. Figure 5-18 illustrates an effective public relations flyer to communicate with customers the negative impacts of unauthorized consumption and utility policy.

- **Conduct random inspections after terminating service.** If utility policy allows customer water service to be terminated because of payment delinquency, followup random inspections should be conducted to ensure that customers have not reactivated their service illegally. If the water utility halts water service by closing a "curb stop" or valve in an outdoor meter pit or at the building property line, some unscrupulous customers may gain access to these valves and reopen them. Locking devices can deter these activities. AMI systems will register forward water usage at the time that this type of illegal activity occurs, allowing the water utility to respond quickly to this unauthorized consumption.
- **Identify meter/AMR tampering.** Theft of service is common in virtually all utility/services sectors, including electric, cable TV, water, gas, and other services. In virtually any water utility, there are certain customers that will tamper with meters and meter reading equipment to create an erroneously low measure of water consumption on their water bill. Tampering can be identified by review

Figure 5-19 Existence of a "cheater" or "jumper" pipe (top) that was illegally used to replace the top meter in the meter setter. In the lower part of this meter pit is a typical ⅝-in. residential meter.

of zero consumption accounts, as described above. Sometimes however, shrewd individuals will create a *low* consumption bill rather than a *zero* consumption bill, making it less likely to draw attention to the consumption history. Meters may be removed and installed backward for several days or weeks each month to reverse the consumption accumulation. Meters may be removed and replaced with a straight pipe ("jumper" or "cheater") for several weeks each month to obtain unmetered water for a portion of the billing period. Figure 5-19 shows a meter jumper pipe in place on a service in Morgantown, W.V. Careful inspection of billing records can identify suspicious consumption patterns that may identify tampering. Utility managers can schedule inspections of customer metering installations on a periodic basis to attempt to identify tampered meters. AMR and AMI systems with tamper alerts also provide evidence of equipment tampering and suspicious consumption, and may be the most reliable source of information on these activities.

- **Conduct periodic inspections for illegal bypass piping.** Many customers with large meter settings include unmetered bypass piping around the meter that can be used to maintain water service while the meter is periodically taken out of service for maintenance or replacement. By simply closing and opening certain valves, the customer can route water flow through the unmetered bypass line with little or no flow going through the metered line. Water utilities can schedule large meter installations for periodic inspections to identify cases of illegally opened bypass piping. Also it may be possible to lock valves in the closed position on bypass piping to prohibit tampering. The use and monitoring of water consumption output reports may show significant changes in water consumption patterns for given accounts, which can indicate that a bypass has been illegally opened. Imposing significant fines and penalties may also convince customers to avoid this illegal activity.
- **Inspect valves on interconnecting water systems.** Similarly to bypasses around meters, valves on water supply pipelines to neighboring water systems might be occasionally opened inadvertently or unscrupulously to cause unauthorized consumption. Water utility interconnections with neighboring water utilities are common. Many of these pipelines supply water on a continuous basis, but some interconnections exist for standby or emergency supply purposes. These latter connections normally exist with supply line valves closed until authorized for use during emergency or special conditions. If valves on these lines are inappropriately opened, water supply may be obtained by the receiving water utility in an unauthorized manner. It is not unusual for such connections to be unmetered

since they are not intended for continuous water supply. Valves on such interconnection pipelines should be inspected periodically to ensure that they are in the proper position. If unauthorized consumption is occurring on these interconnections, the water utility selling the water should consult its contract with the receiving water utility and determine what penalties might apply.

- **Conduct inspections to identify illegal connections.** Unfortunately, illegally installed connections into water supply piping are common throughout the world. In some parts of the world, it is not uncommon for water pipelines to be flagrantly excavated and tapped illegally with multiple lines. More often, illegal lines are not connected in such a blatant manner but exist more serendipitously. It is not unusual for unmetered fire connection piping to be tapped inside building premises. Sometimes this occurs inadvertently when contractors misidentify fire connection piping as the domestic water supply line. However, many such illegal service connections are installed purely with intent to obtain water without paying for the service. Since these illegal connections are visible inside of building premises, water utilities can schedule periodic internal inspections of building supply line and plumbing to identify such connections. These inspections might be combined with existing inspection activities, such as leak detection or cross-connection control inspections. This would minimize the need for additional resources to conduct the inspections. The "Criminal Prosecution of Unauthorized Consumption" sidebar describes the case of an illegal connection made to supply significant irrigation water to a golf course in Kansas City, Mo. In cases of hidden illegal connections, water utility managers may be able to discern the likelihood of suspicious supply if the consumption patterns for a given water user appear to be inordinately low for the class of service. This was the case in Kansas City. Once illegal connections are identified, the water utility must rely on its enforcement policies to invoke appropriate warnings and penalties to offending property owners to eliminate the illegal connection and pay any back charges that are due. Legal and/or criminal remedies may also be needed.

These are some of the actions that are typical of the bottom-up procedures utilities can undertake to quantify and control unauthorized consumption. Every water utility is unique, however, and certain circumstances may exist in a given system that allow for the possibility of unauthorized consumption. This is why it is worthwhile for utility managers to conduct a reasonable level of bottom-up auditing investigations to discern the extent of opportunities for unauthorized consumption to occur in their system.

Utility managers undertaking the water audit process for the first time may only have an approximate quantity to enter into the water audit for the unauthorized consumption component. Such a "rough guess" is sufficient to include in the water audit during its first several years. In this case, the data grading value for unauthorized consumption will be low: at a value of 3 or lower, typically. Alternatively, the auditor may apply the default value of 0.25 percent of the annual billed authorized consumption volume to obtain a reasonable quantity of unauthorized consumption in the absence of reliable data. Ultimately, however, the water auditor should undertake bottom-up auditing activities to obtain a more reliable measure of the unauthorized consumption occurring in the system. Clear policies, reliable means to detect unauthorized consumption, and ongoing bottom-up investigations are necessary for the water utility to grade the unauthorized consumption component at a level of 8 or higher.

For control of unauthorized consumption on a long-term basis, the water utility should employ effective policies and enforcement capabilities. This may require changes in existing regulations, statutes, or codes, or the creation of new ones. Implementing changes in these instruments can be politically sensitive and requires skilled effort over

Criminal Prosecution of Unauthorized Consumption in the Kansas City Water Services Department*

The Kansas City Water Services Department (KCWSD) is a large water utility that is active in controlling water losses and has placed particular emphasis on monitoring its operations for apparent losses. When proactively assessing the billing records of its large consumers, utility auditors took note of the billing records of a particular golf course as very suspicious. Golf courses rely on large volumes of water for irrigation. While some golf courses are supplied recycled water, KCWSD supplied this golf course from its potable water distribution system. This facility was expected to register high volumes of consumption during the irrigation season, but it routinely registered unusually small metered water consumption volumes. An inspection of the service line and metering installation found that an illegal connection, with a line valve, had been tapped into the primary water service connection piping to divert water—in unmetered fashion—to a pond on the golf course property. Water from the pond was used to irrigate the golf course.

Not only did KCWSD then work to halt the illegal use of water, but it followed with legal action that ultimately led to the owner of the golf club pleading guilty and being placed on four years of probation under the conditions that he repays the city $251,400 in four installments. The judge in the case left open the option to sentence the owner up to seven years in prison if the debt went unpaid. The golf course owner admitted that between 2003 and 2008, golf course employees routinely opened the valve on the illegal line to divert water supply to the pond. KCWSD initially placed a lien on the golf course and billed the owner $1.6 million in back charges for water services and fees. As part of the court rulings, KCWSD agreed to settle the claim against the golf course operator for the $251,400 amount.

This incident testifies to the significant extent to which water customers will go to take water unlawfully, and to the large volumes of water and revenue that can be lost. The volume of unbilled water taken over a period of five years was considerable and resulted in uncaptured revenue of several hundred thousand dollars per year to KCWSD. And this was just from a single customer! This event underscores the fact that water utilities are vulnerable to occurrences of unauthorized consumption and—like KCWSD—should take proactive steps to identify suspicious customer behavior and control the occurrence of unauthorized consumption to economic levels.

*Club and Resort Business 2009.

potentially long periods of time to orchestrate; however, a strong legal framework will ultimately allow the water utility to operate with sufficient enforcement powers to keep unauthorized consumption to an economic minimum.

DEVELOPING THE APPARENT LOSS CONTROL STRATEGY

Figure 5-20 is a graphic that represents a conceptual approach to loss control interventions applied to apparent losses. The center boxes represent three levels of apparent losses, as defined in the following list:

- The outer box perimeter represents the current volume of apparent losses listed in the water audit.
- The perimeter of the middle box represents the utility-specific target level for apparent losses. Conceptually, this is the economic level of apparent losses (ELAL) or the level at which the cost of the loss control efforts equals the savings garnered from the loss recovery. The ELAL represents a breakeven point, beyond which the effort to control apparent losses costs more than the likely recoveries of revenue.

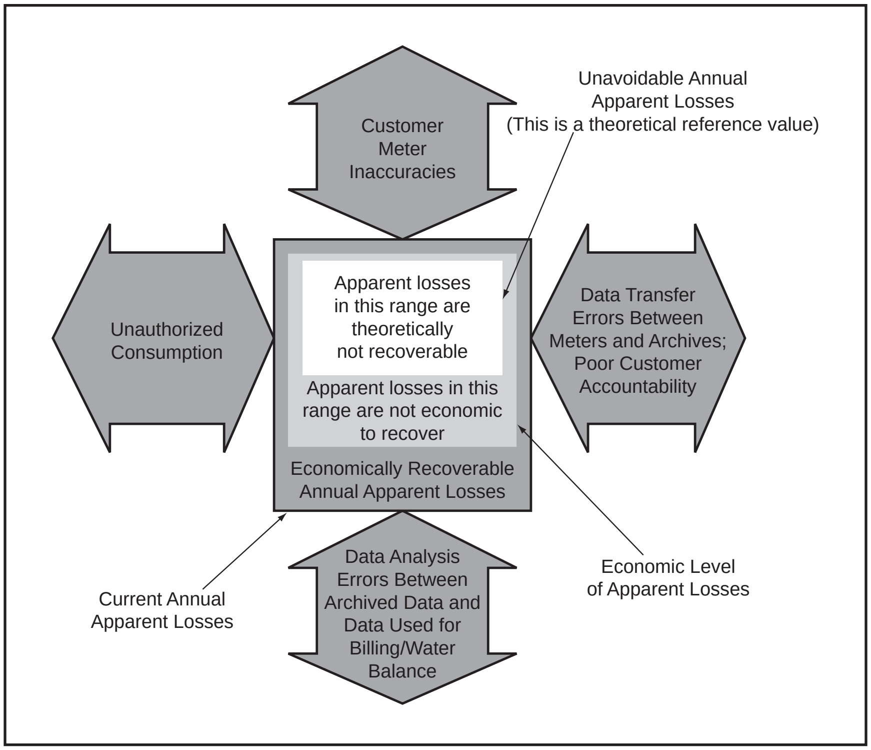


Figure 5-20 Four-pillar approach to the control of apparent losses

- The inner box is defined by the unavoidable annual apparent losses (UAAL) as the quantity representing its perimeter. This is a conceptual level of loss representing the lowest level that could be attained if all possible loss controls could be exerted. Unlike the unavoidable annual real losses (UARL) that has an established calculation, an established formula or reference value for the UAAL does not currently exist. Discussion on the means to develop a calculation for the UAAL has been underway for a number of years (Rizzo et al. 2007).
- The four arrows represent the mechanisms by which apparent losses occur. The dual directions of the arrows reflect the fact that by exerting control in each component of loss, the total annual volume of losses (outer box) can be reduced. The arrows also reflect that lack of control of these components results in the total volume of apparent loss increasing.

Controlling losses in almost any field of endeavor is an effort of diminishing returns, as many losses can never be completely eliminated. When losses are rampant, relatively large reductions can often be gained early in a loss control program; this is known as the *low-hanging fruit*. However, further loss reduction requires ever-greater cost and effort to recoup ever-diminishing returns. Figure 5-21 provides a cost curve for meter replacement, with points plotted at replacement frequency (years) and average cumulative consumption passed through the meters (MG, or million gallons). It can be seen that replacing meters at a high frequency results in less apparent loss as a result of meter inaccuracy. However, a high replacement frequency means higher replacement costs.

When setting an apparent loss reduction target, there exists a breakeven point beyond which the effort to control the losses costs more than the likely recoveries. In this case, further loss control effort is not economic to pursue. This is the ELAL or the optimum target of apparent losses to seek. The ELAL for customer metering inaccuracies is shown

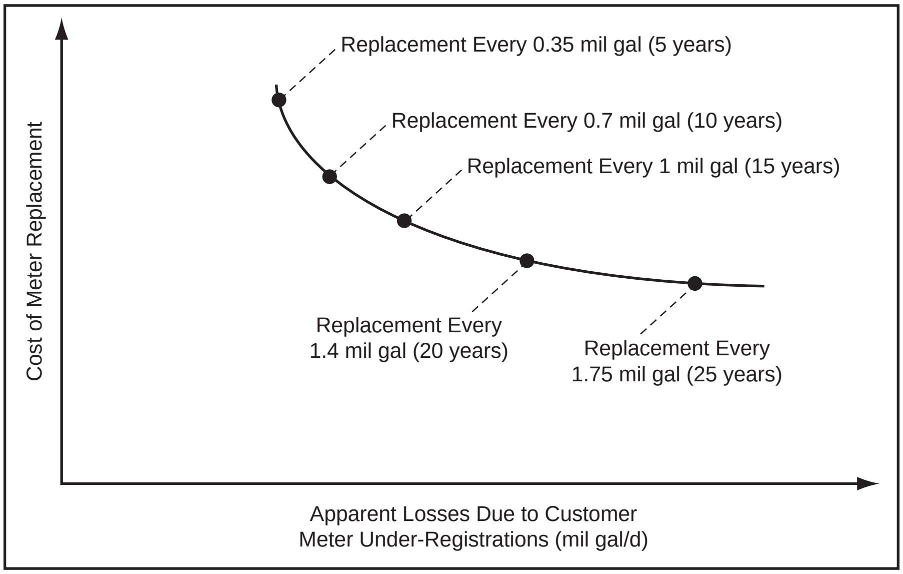


Figure 5-21 Cost curve for meter replacement program

Source: *AwwaRF 2007*

graphically in Figures 5-21 and 5-22. In Figure 5-22 the meter replacement cost curve from Figure 5-21 is matched against the cost recovery line, which reflects the savings generated by apparent loss recovery. A third curve is generated by adding the two values and plotting the summed values; thus a curve of total annual apparent loss cost is derived. The ELAL for apparent loss caused by meter inaccuracy is found by taking the level of loss at the minimum point of this curve, as shown in Figure 5-22. The optimum level of apparent loss reduction at the ELAL is determined by reading back off the apparent loss reduction cost curve. For apparent losses caused by customer metering inaccuracies, the optimum frequency of meter replacement can be determined by selecting the point on the meter replacement cost curve that matches the minimum point of the total cost curve.

The benefit–cost analysis for reducing meter errors should be sure to recognize significant costs where they exist, including administrative and billing personnel expenses to manage errors, refunds, and the cost to verify readings.

In generating a particular curve, the economic analysis should start with determining the volume and cost value of the most significant sources of apparent loss. For each apparent loss component, it is necessary to analyze the problem and determine why these errors are occurring. It is then possible to consider various solutions to reduce these losses. Possible solutions might range from improved auditing, new reports to identify these errors, or better training as low-cost endeavors, to full AMR/AMI system implementation or a new customer billing system at the opposite end of the cost spectrum. Solutions to reducing apparent losses caused by meter reading errors may range from better training for meter readers, improved auditing of meter readings, and improved software on handheld meter reading computers, to the implementation of a complete AMR/AMI system. The cost of each of these alternative solutions should be compared to the projected revenue recovery from the reduction in apparent loss, and the solutions ranked in terms of benefit–cost ratio. Only those solutions with a sufficiently attractive benefit–cost ratio or payback period should be included in the apparent loss control plan. Clearly, the scale and the shape of the cost curve for solutions to the various components of apparent loss could be very different and will vary from utility to utility. Until further research has been undertaken and standardized models or spreadsheets are available, it is up to each water

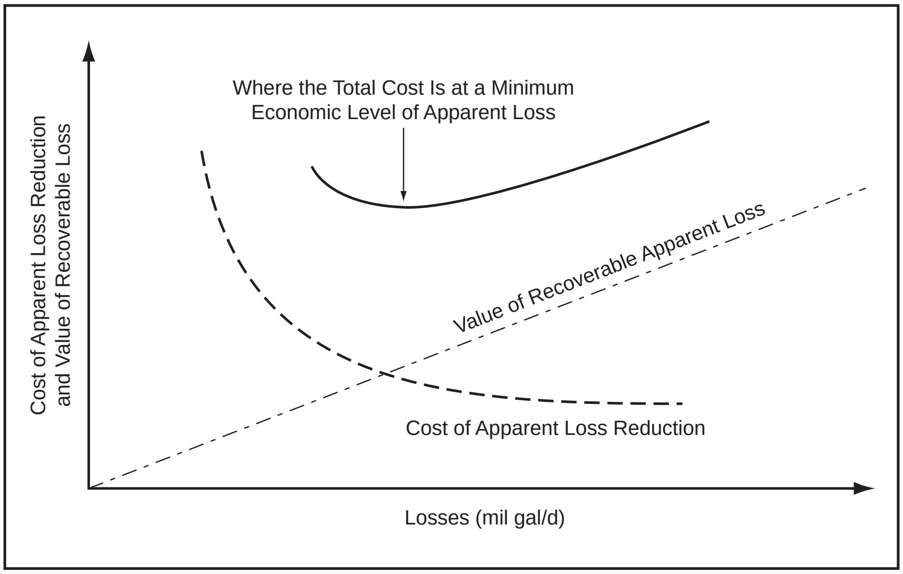


Figure 5-22 Economic balance for an apparent loss reduction solution

utility to develop appropriate utility-specific costs and cost curves for the various apparent loss components that they perceive to be significant.

The previous example illustrates two limitations in the current status of apparent loss target-setting. First, in applying the method using cost curves, considerable data on meter accuracy at varying meter consumption levels must be generated. This can be a complex and time-consuming undertaking. Second, separate cost curves must be developed for each of the components (and subcomponents) of apparent losses that are deemed significant: one for customer metering inaccuracies, one for meter tampering, one for unauthorized use of fire hydrants, and so on. Unfortunately, there is no single, composite ELAL for a water utility. There will be an ELAL for each apparent loss control solution considered, and the overall ELAL for the utility will be the sum of each solution to the different components of apparent losses selected. Therefore, the present means of rigorously developing the ELAL is a demanding task that cannot be executed without considerable data. At this time, discussion continues on the best means to develop a simpler, straightforward method of obtaining the ELAL.

Clearly, the current approach to identify the overall ELAL is time and resource intensive. However, apparent loss recovery can often generate considerable "new" revenue. Until a simpler method to calculate the ELAL is available, water utilities should undertake a cursory analysis of their apparent losses and identify approximate levels of desired apparent loss reduction. If a water utility is only beginning to audit its water supply, it is very likely that considerable apparent (and real) losses exist, and it will be economic to recover a relatively large volume of losses. In lieu of a complex apparent loss analysis, the following recommendations are reiterated as standard starting points for water utilities in apparent loss control:

1. Flowchart the customer meter reading and billing process. Understanding this process and identifying any lapses or loopholes that allow apparent losses to occur are fundamental to the management of all apparent loss components. Additionally, this exercise can be conducted largely in a desktop manner with limited resources and costs, and it may identify several loss components that can be quickly and inexpensively corrected by policy, procedural, or computer programming changes.

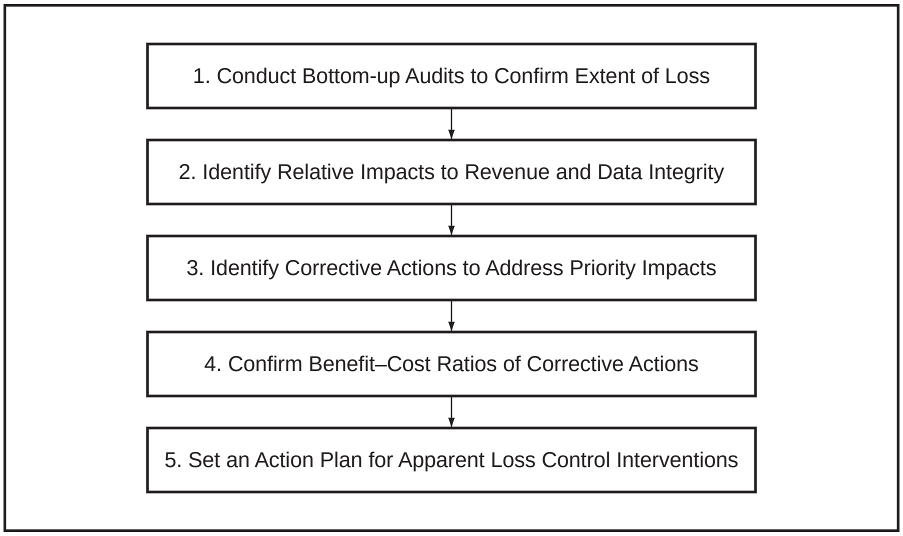


Figure 5-23 Steps to execute an apparent loss control strategy

2. Unless the customer meter population is very young and well documented, establish meter demographics reports and statistics, and perform annual meter accuracy tests on a sample of customer meters. This can be as few as 50 meter tests per year, with 25 randomly selected meters and 25 meters that have registered high cumulative consumption. Data from this testing will give a preliminary representation of the current accuracy status of the existing meter population, and the yearly trend will ultimately reveal the points at which meters lose accuracy significantly as a result of cumulative volumes passed through the meter.
3. Review customer billing records and consider data-logging 5–10 meters of the largest water-using customers to identify large water-using accounts that are underbilled because of inappropriate meter sizes or types.

The above first steps are manageable in terms of effort and expense, and can provide good data and possible recoveries that can get apparent loss control efforts started productively. Once water auditing has been performed for several years, additional bottom-up data will be available and a more robust assessment of existing apparent losses can be undertaken.

Figure 5-23 identifies a sequence of steps for executing the apparent loss control strategy after the initial top-down water audit has been compiled and bottom-up activities are launched. These steps, starting with the bottom-up auditing procedure, should be followed in sequence to ensure that intervention actions are economically justified, well planned and executed, and documented.

DEVELOPING A REVENUE PROTECTION PLAN TO CONTROL APPARENT LOSSES

The most significant impact of apparent losses for water utility managers is usually uncaptured revenue. The term *revenue protection program* is used to identify the host of procedures put in place to protect the utility's revenue base by controlling apparent losses. As previously noted, a number of distinct components and subcomponents of apparent losses occur in water utilities; therefore, a revenue protection program must be tailored to the individual needs of the water utility. The "Sample Revenue Protection Plan" sidebar shows an example revenue protection plan for CWC. Revenue protection plans should be developed by considering each of the three major components of apparent losses: systematic

Sample Revenue Protection Plan

Name of Water Utility: *County Water Company* Date: *07/10/2014*

I. Revenue Protection Plan

After completing County Water Company's (CWC's) first annual water audit (see Figures 3-4 through 3-8), the manager creates an ongoing revenue protection program that identifies causes of the most significant apparent loss components and launches efforts to reduce these losses to economic levels. After initial gains are evaluated, additional less-significant occurrences of apparent loss will be evaluated for reduction.

The CWC Water Audit quantifies apparent losses as follows:

• Residential meter under-registration	134.33 mil gal @	$529,932
• Industrial/commercial/agricultural meter under-registration	29.97 mil gal @	$118,233
• Systematic data transfer error	12.57 mil gal @	$49,589
• Systematic data analysis error	8.72 mil gal @	$34,400
• Data policy/procedure impacts	11.63 mil gal @	$45,880
• Unauthorized consumption (default 0.25% of water supplied)	11.00 mil gal @	$43,395
• Total Apparent Losses	208.22 mil gal @	$821,449

From this summary, the cost impact of customer metering inaccuracies is $529,932 + $118,233 = $648,165. This is equal to 6.75 percent of the total cost of running the system ($648,165/$9,600,000). The three subcomponents of the systematic data handling errors add to a total cost impact of $129,869 or 1.3 percent of the total cost of running the water system. Unauthorized consumption is believed to be a very minor occurrence in the CWC system and is estimated using the default value of 0.25 percent of water supplied. From the results of the water audit, the revenue protection plan should focus primarily on customer metering inaccuracies, with a secondary focus on systematic data handling errors. By following the recommended first step in addressing apparent losses, the manager of CWC plans to flowchart the workings of the customer billing system to ascertain the integrity of the customer consumption data and identify occurrences of systematic data handling errors.

II. Customer Billing Process Analysis

II-a. The manager assigns one CWC billing analyst to work part time over a period of two months, in conjunction with a billing system consultant, to perform an initial analysis of the customer meter reading and billing process. From the initial findings, any areas of apparent loss that are deemed to be readily correctable will be implemented. Such corrections are recognized as relatively minor procedural or programming changes, an example of which might be a programming lapse that inadvertently left a two-year-old housing development of 50 homes off of the meter reading/billing rolls. The cost of this effort is basically the cost of human resources to implement it.

II-b. Staffing costs, including wages and benefits for CWC personnel

Number of CWC Staff: 1	Cost, $/hr 33.50	$/d 268.00
Number of Consultant Staff: 1	Cost, $/hr 75.00	$/d 600.00

II-c. Duration

Days, per Project Task	Flowcharting/ Analysis	Corrections	Total Days	Total Project Costs, $
CWC Staff	14.00	4.00	18.00	4,824.00
Consultant	25.00	7.00	32.00	19,200.00
Total				24,024.00

III. Customer Meter Accuracy Testing

III-a. The water audit for CWC estimates that customer metering inaccuracies caused under-registered consumption worth $648,165 of revenue during the audit year. This amount represents the majority of the revenue recovery potential in CWC. During the water audit process, CWC undertook customer meter testing on a sample of meters: 50 random residential meters and 5 random large (industrial, commercial, and agricultural) meters. The analysis of the meter test results are shown in Tables 3.13–3.19. The findings of this meter testing were extrapolated to the entire meter population to determine an estimate of the entire apparent losses attributed to customer metering inaccuracies. Based on the value of this testing, the CWC manager continues such testing on an annual basis, both to continually gauge meter accuracy and to also observe the rate of long-term degradation in accuracy with increasing cumulative consumption. CWC does not have its own meter testing facility; therefore, it uses contracted testing services. The metering supervisor and one staff person will also participate by identifying meters for testing, rotating meters from customer properties, and performing the administrative and analysis work.

III-b. Staffing and testing service costs, including wages and benefits for CWC personnel

Number of CWC Staff: 2

Supervisor:	Cost, $/hr 35.00	$/d 280.00	# of days 3	Cost,	$840.00
Service Worker:	Cost, $/hr 27.50	$/d 220.00	# of days 15	Cost,	$3,300.00
Total				CWC Staff Cost,	$4,140.00

III-c. Estimated costs of meter testing program—55 annual meter tests

Meter Testing Services:	Cost, $/small meter	35.00	Cost for 50 meter tests,	$1,750.00
Meter Testing Services:	Cost, $/large meter	250.00	Cost for 5 meter tests,	$1,250.00
			Meter Testing Service Cost	$3,000.00

III-d. Total cost for annual meter testing program, $7,140.00

IV. Revenue Protection Program Summary

IV-a. The total cost of the two components of the initial revenue protection program:

Customer Billing Process Analysis:	$24,024
Annual Meter Testing Program:	$7,140
Total Revenue Protection Program Cost:	$31,164

IV-b. Economic level of revenue recovery

During the first year of the new revenue protection program, CWC anticipates spending $31,164 to launch the program. To recover the cost of this program, CWC would need to recover revenue equal to this amount. By applying the composite customer retail billing rate (see Figure 3-5) of $3,945/mil gal of customer consumption, an equivalent volume of consumption can be determined:

$$\text{breakeven recovery volume} = \frac{\$31{,}164}{\$3{,}945\ /\ \text{mil gal}} = 7.90\ \text{mil gal}$$

If CWC's initial revenue protection efforts recover merely 7.90 mil gal of consumption, the revenue protection program will have paid for itself in its first year of operation. This level is only 3.8 percent of the total apparent losses of 208.22 mil gal quantified in the water audit in Figure 3-5. Because apparent losses are valued at the customer retail rate, recovering these losses can be highly cost-effective. CWC has strong potential to more than recoup its first-year revenue protection program costs in its first year. If this level of revenue recovery is met or exceeded, CWC will be well on its way to creating a very cost-effective apparent loss control and revenue enhancement program.

data handling errors, customer metering inaccuracies, and unauthorized consumption. Data from the water audit should be evaluated to assess the relative impact that each component exerts on the water utility. In the CWC sidebar example, CWC estimates that very little unauthorized consumption occurs in its system, so this component is not included in its initial revenue protection program. Work in subsequent years should look into this occurrence, however.

The example shows that the cost impact in lost revenue to CWC caused by apparent losses is $821,449, which is 8.5 percent of the total annual operating cost of $9,600,000. In following with the previous recommendations, the manager determines to launch a revenue protection program that will analyze the customer billing process and institute annual customer meter accuracy testing.

The billing process analysis (flowcharting) is envisioned as a two-month project costing $24,024. This cost includes the analysis and any apparent loss corrections that can be immediately incorporated into the process. CWC conducted accuracy testing of a sample of customer meters during the compilation of its initial water audit and determined that it should continue testing a sample of meters on an annual basis to track the accuracy of the customer meter population and monitor degradation of accuracy over time. The projected cost of this effort is $7,140 to test 50 residential meters and 5 large meters.

The total first-year cost of the two-component revenue protection program is estimated at $24,024 + $7,140 = $31,164. By applying its composite customer retail billing rate of $3,945/mil gal, CWC need only recoup 7.90 mil gal of apparent loss to break even during the first year of program operation. This is only 3.8 percent of the total apparent loss volume of 208.22 mil gal quantified in the water audit. If each residential customer consumes 71,808 gal/year (8 ccf/month) of water, then the equivalent of recovering 110 missing accounts from the billing roles would meet the cost-effective breakpoint of 7.90 mil gal recovered. This is less than 1 percent of the total of 12,196 accounts in the customer billing system. It is evident that recovering losses valued at the customer retail rate can offer a very swift and high payback.

During the early phases of a revenue protection program, significant recoveries may be recouped with less costly programming and procedural refinements. However, as the program matures, the water utility will ultimately consider more extensive improvements to control the more subtle forms of apparent loss occurring in the system. Such efforts will require additional costs and may include replacement of large numbers of customer meters, installation of AMR/AMI systems, or implementation of a new computerized billing system. Chapter 8 gives guidance on water loss control program planning with consideration of long-term upgrades to the major systems and processes of the water utility that impact on apparent loss control.

SUMMARY

Apparent losses distort the measure of the volume of customer water consumption and cause water utilities a loss of revenue. Apparent loss control results in more accurate consumption data for the service population and gives a better portrayal of community water demand. This is particularly helpful in regions that have limited water resources and/or are encountering drought or water shortage. Controlling apparent losses, however, can be very cost-effective because initial corrections may require relatively little work with potentially high payback. It is often advantageous to target apparent loss control early in the water loss control program to quickly generate recoveries that can seed further loss reduction activities, particularly real loss reduction. Loss control is an endeavor of diminishing returns, but it is likely that many water utilities have significant apparent losses, which can be cost-effectively recovered to enhance the utility's revenue stream and further promote the water loss control program.

REFERENCES

AWWA (American Water Works Association). 2015. C703-15 *Standard for Cold-Water Meters—Fire-Service Type*. Denver, Colo.: AWWA.

AWWA (American Water Works Association). 2012. Manual M6. *Water Meters—Selection, Installation, Testing, and Maintenance.* Denver, Colo.: AWWA.

AWWA (American Water Works Association). 2013. C714-13 *Standard for Cold-Water Meters for Residential Fire Sprinklers in One- and Two-Family Dwellings and Manufactured Homes*. Denver, Colo.: AWWA.

AWWA (American Water Works Association). 2014. Manual M22. *Sizing Water Service Lines and Meters*. Denver, Colo.: AWWA.

AwwaRF (Awwa Research Foundation). 2007. *Evaluating Water Loss and Planning Loss Reduction Strategies*. Denver, Colo.: AwwaRF.

Club and Resort Business. 2009. Staley Farms GC owner pleads guilty to stealing water. 2009. www.clubandresortbusiness.com/tag/staley-farms-golf-club/ (accessed Sept. 14, 2014).

Davis, S.E. 2005. Residential water meter replacement economics. In *Water Loss 2005 Conference Proceedings, Halifax, Nova Scotia, Canada.*

Rizzo, A., M. Vermersch, S.G. St. John, G. Micallef, and R. Race. 2007. Apparent water loss control: The way forward. In *Water 21.* London: IWA Publishing.

Schlenger, D.L., D.M. Hughes, and A. Green. 2011. *Advanced Metering Infrastructure: Best Practices for Water Utilities*. Denver, Colo.: Water Research Foundation.

Thornton, J. 2002. Component analysis of apparent losses (non-physical losses). In *Proceedings, Technical Session on Promoting Progressive Approaches for Water Loss Control: AWWA, Distribution and Plant Operations Conference*. Denver, Colo.: American Water Works Association.

Villegas, S. 2006. Hydrant use: Balancing access and protection. *AWWA Opflow*, 32(10):24–26.

WRF (Water Research Foundation). 2011. *Accuracy of In-Service Water Meters at Low and High Flow Rates*. Denver, Colo.: WRF.

WSO (Water Systems Optimization). 2006. *Report on Technical Assistance to the Long-Term Water Loss Control Program of the Philadelphia Water Department for Fiscal Year 2006: July 1, 2005–June 30, 2006.*

Chapter 6

Understanding Real Losses: The Occurrence and Impacts of Leakage

As in chapter 4, which discusses apparent losses, this chapter addresses the question: What kinds of losses exist in drinking water utilities? It is known from the water balance in Figure 3-1 that water losses represent the water volumes that do not achieve beneficial use or cost utilities a portion of the revenue to which they are entitled. Water losses in drinking water utilities occur as two distinct types. *Apparent losses* are the nonphysical losses that occur when water is successfully delivered to the customer but, for various reasons, is not measured or recorded accurately. *Real losses* represent the physical losses of treated, pressurized water from the distribution system and are comprised of breaks and leaks from water mains and customer service connection pipes, joints, and fittings; from leaking reservoirs; and from reservoir or tank overflows. This chapter explains how real losses, particularly leakage, occur in water distribution systems. It also provides perspective on why leakage occurs, the causes and influencing factors. Lastly, it describes the significant impacts that real losses exert on the operations and finances of the water utility, and the unnecessary strain that they place on water and energy resources of the community and region. Various methods to cost-effectively control leakage are discussed in detail in chapter 7.

For most water utilities, leakage is the greatest portion of real losses. While tank overflows (Figure 6-1) are included in the definition of real losses, these events are typically infrequent and often visible; therefore, they are less likely to run unattended for extended periods of time unless the storage is underground. Even so, observant water operators performing usual checks generally discover this loss quickly. Given this, the content of this chapter focuses on leakage as the primary component of real losses.

Figure 6-1 Tank overflows are a component of real losses
Courtesy of R. McKenzie, WRP Pty Ltd.

THE HOW AND WHY OF LEAKAGE

Water that leaks from the water distribution system between source and customer occurs in all utilities—only the volume varies. The annual volume of leakage losses is the difference between the water supplied volume minus the sum of authorized consumption (billed and unbilled), apparent losses, and water lost to storage overflows. There are numerous types of leaks in water supply distribution systems, each with different typical ranges of flow. Leakage in water distribution systems can be attributed to the following (Lambert et al. 1998):

- Inferior or defective materials, whether of the pipes and jointing or in the bedding or support
- Pipe breaks resulting from poor workmanship or materials handling in pipe laying—unsupported lengths of pipe, stones in contact with pipes, non-adherence to required joint gaps, poor backfilling of trenches, excessive joint deflection, plastic pipe exposed to sunlight during storage, and similar occurrences
- Operational errors—excessive pressure, filling pipelines too rapidly, closing valves and/or hydrants too rapidly, incorrect operation (starting and stopping) of pumps, water hammer
- Corrosion—internal corrosion caused by aggressive water, external corrosion caused by insufficient protection of metallic materials from aggressive soils, groundwaters, or stray electric current
- Seasonally induced stresses—frost loading, soil expansion, thermal effects during extreme temperatures, including pipe expansion/contraction due to winter cold water in the pipe (from surface water sources—groundwater maintains a more constant temperature throughout the seasons)
- Poor quality of leak repair work
- Leaking fittings and appurtenances—valves, air valves, saddles, hydrants, leaking stuffing boxes, drain or blow-off valves that are closed but passing water
- Accidental or deliberate damage to water mains, hydrants, or other appurtenances; heavy traffic loadings; or careless construction activity over shallow water mains

- Changing stresses in the pipe environment: pipe installed in bygone eras met the design standards of the day. As fire protection became more important and systems grew, flow rates and pressure levels may have increased, placing greater loads on piping systems. Light vehicular traffic may have evolved to heavy truck traffic on roadways and greater stress on buried pipelines.

The total volume of leakage losses occurring in a particular water distribution system over a given period of time depends on

- the operating pressure in the piping distribution system;
- whether the geology, soil type, and road cover material allow water to be visible at the surface;
- the frequency and scope of active leakage control to detect, locate, and repair unreported leaks; and
- the integrity of the piping infrastructure and its degree of upkeep via best-practice rehabilitation and renewal programs.

The extent of the occurrence of leakage within a water utility depends on the

- characteristics of the water distribution system;
- importance attached to loss control by the water utility;
- way in which the distribution system is operated and maintained; and
- level of expertise and technology available within the utility.

It is evident that there are many factors that influence the level of leakage occurring in a drinking water utility. These factors can be aggregated to three primary categories:

1. The characteristics of the water distribution system
2. The stresses produced in the local environment—weather extremes as well as traffic, soil conditions, etc.
3. The level of proactive leakage management employed by the water utility

How much control can a utility operator exert upon the listed factors? Water system operators can exert change over the characteristics of the water distribution system, but major system changes (expansion, rehabilitation, and renewal) can only be accomplished on a long-term basis. Relatively little control of the second factor can be gained, which is dependent on the physical environment in which a utility is located. The weather, geologic conditions, or even traffic loadings cannot be controlled to any great extent. The last of these factors, proactive leakage management, is where the utility operator can exert the greatest day-to-day degree of control on the occurrence of leakage. While leakage in water distribution systems is inevitable, utility operators can employ successful methods to limit the extent of leakage and the volume of leakage losses.

THE EFFECT OF TIME ON LEAKAGE LOSSES

The volume of leakage losses in a distribution system over a year depends on the number of leaks occurring, their magnitude, operating pressure, and—perhaps most importantly—the total time that the leaks are permitted to run. Leaks left to run for long periods of time often account for the greatest volume of leakage losses in a water distribution system. While large, dramatic water main breaks (see Figure 6-2) wreak havoc and garner much

Figure 6-2 Large water main break

Figure 6-3 Small leak on customer service connection piping

attention, these events typically contribute measurable, but small, volumes of non-revenue water on an annual basis. Despite the large volumes of water spewing from a severe water main rupture, the disruptive nature of such events usually prompts a quick response by the water utility and a relatively speedy shutdown of the broken section of pipe. Because the run time of the break is often limited to a period of hours, the total volume of lost water from the event is contained.

Conversely—and surprising to many—numerous small, hidden leaks (see Figure 6-3) account for the greatest overall volume of leakage losses in a distribution system over the course of the year. In well-run systems, the greatest annual volume of real losses occurs from long-running, small-to-medium-sized leaks on customer service connections, except at very low densities of service connections (Brown et al. 2000). Although their leakage rates are low, small leaks often run undetected for long periods of time.

As depicted in Figure 6-4, the run time of leaks comprises three elements:

1. **Awareness time.** This is the time needed for a water operator to become aware that a leak exists, a parameter strongly influenced by the presence or absence of an active leakage control program.
2. **Location time.** This is the time taken to pinpoint the source of the leak once the operator is aware of its existence.
3. **Repair time.** This is actually the time to halt the leakage flow once the leak position has been identified. This is not just the time of the shutoff of the leakage flow, but all preceding time (while the leak is still running) needed to route the repair work order, schedule the repair, notify customers, and other activities, which can take days or weeks depending on the policies of the water utility and the severity of disruption caused by the leakage.

The influence of run time, as shown in Figure 6-5, is the primary factor in the volume of water lost to leakage over the course of a year (AwwaRF 2007). In systems with no active leak detection programs, the run time of hidden leaks is continuous until the leaks are detected by the water utility or an external party such as a customer, usually after a leak becomes evident through some form of damage or disruption that it is causing.

In many water systems, small leaks and breaks run for periods of weeks, months, or even years before they are discovered and repaired. Consequently, although the flow

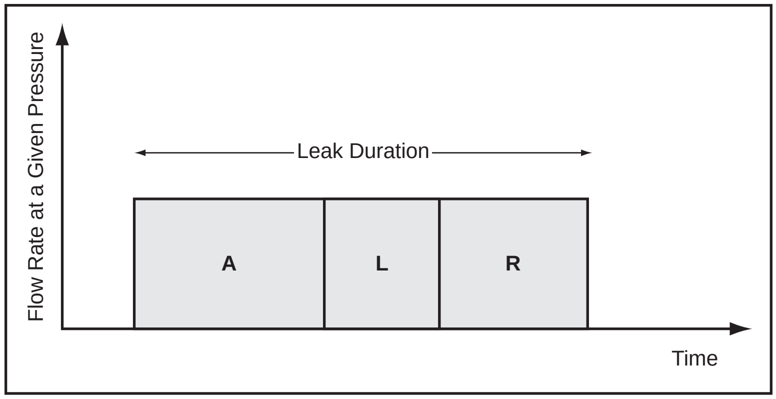


Figure 6-4 Time periods in the life of a leak: A–Awareness, L–Location, R–Repair

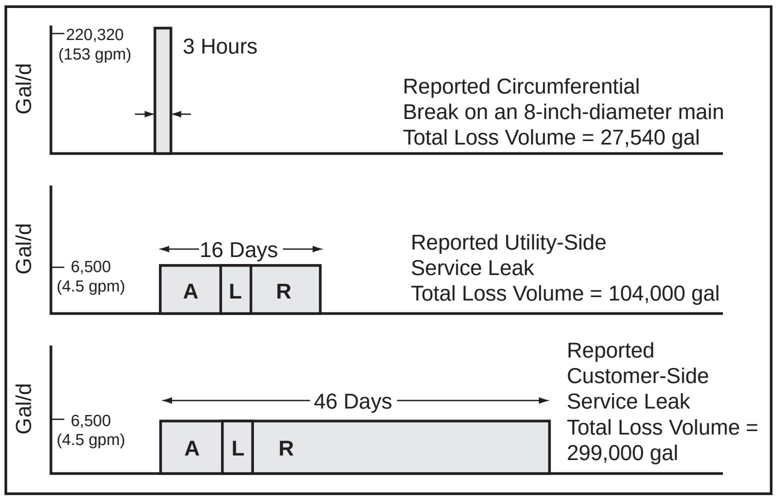


Figure 6-5 Example of various leakage types and impacts of time on the volume of loss

rate from such leaks may be relatively small, the annual volume of hidden leakage losses is usually a significant proportion of the total leakage volume and far exceeds the water lost in catastrophic, visible main break events. For illustrative purposes, the schematic diagrams shown in Figures 6-4 and 6-5 have been simplified into boxes that suggest distinct start and end times of leaks and a constant, linear leakage flow rate. In reality, the flow emanating from a leak varies over the life of the leak, usually starting at a small rate of flow and accelerating over time, perhaps with a notable rupture after leaking for some period of time. Figure 6-6 depicts a leak noise signature for a leak detected by a leak noise transmitter. The sound intensity correlates well with the leakage flow rate and shows how the rate varies and increases over time. The leakage pattern shown in Figure 6-6, nonetheless, further suggests the value that can be gained in minimizing leak run time to optimize water loss reduction.

CHARACTERIZING LEAKAGE EVENTS

Because leak run time is such a prominent factor in the occurrence of leakage losses, developing a strategy to minimize leakage run time is key to a successful leakage management program. The first phase of the response to a leak is the awareness time. To put into place

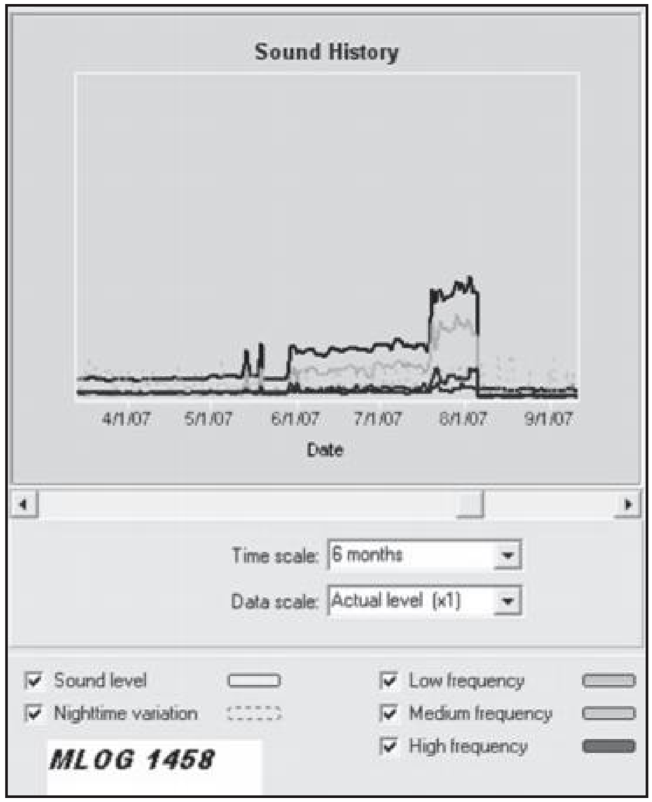


Figure 6-6 Leak noise signature of a leak showing increasing flow rate over time

Courtesy of American Water

mechanisms to become aware of leaks, it is necessary to know the different types of leakage that can occur in water distribution systems.

Leakage occurs in the following three distinct manners:

1. **Reported leaks.** These are leaks that are reported by customers, traffic authorities, or any other outside party because of their visible and/or disruptive nature. Also, those leaks detected by high flows and/or noticeable drops in water pressure in supervisory control and data acquisition systems can be categorized as reported leaks.
2. **Unreported leaks.** These leaks escape public knowledge and are only identified through the active leakage control work of the water utility. The leak detection survey (see chapter 7) is the most common means currently used in North America to identify unreported leaks. Unfortunately, many water utilities do not regularly perform proactive leak detection work.
3. **Background leakage.** These are the collective weeps and seeps at joint and fittings that occur at very low flow rates but may exist pervasively across the water distribution system, particularly if the piping and service connections are in poor condition. This type of leakage is not acoustically detectable, so it will not be addressed by conventional leak detection work. Background leakage can often be addressed by improved pressure management or by pipeline renewal. Background leakage can be quantified by using the step-testing technique in the distribution system (see chapter 7).

All drinking water utilities encounter reported leaks. Utilities whose only leakage control activity is to respond to reported leaks are operating a *reactive* leakage management program. Systems that additionally seek to identify unreported leaks and control excessive background leakage are operating a *proactive* leakage management program. For many utilities, most of the leakage losses over the course of a year occur from unreported leaks and/or background leakage. For those systems with a reactive leakage control policy, it is likely that they are controlling only a minority of the leakage occurrences in their distribution systems.

Because of the low-flow nature of its existence, background leakage defies detection through conventional acoustic means. The tiny weeps and seeps of background leakage are usually numerous and widespread in a given distribution system but are not readily detectable individually. In the past, those leaks falling under the heading of background leakage may have been viewed as *unavoidable* leakage, in the sense that it was not cost-effective to detect and repair them on an individual basis. However, the use of pressure management has emerged to challenge these notions and offer a successful means to reduce, though not eliminate, background leakage.

The concepts of awareness, location, and repair (ALR) times led to the development of *leakage component analysis* (LCA) as a powerful method for discerning leakage patterns in a specific water distribution system. Reported and unreported leaks have different ALR times based on the nature of the leakage occurrences and the leakage control mechanisms practiced by the water utility. Some examples are as follows:

- Visible water main breaks are the most recognized form of reported leaks and typically have very short ALR times (see Figure 6-5). Because of the disruptive nature of such events, they encounter an almost instantaneous awareness and location time, and a repair time of perhaps several hours to gain a shutdown of the broken section of pipe (recognizing that the actual pipe repair and restoration take more time).
- Unreported, or hidden, leaks on underground water mains and valves can have brief or lengthy awareness times (depending on whether proactive or reactive leakage management is employed) but will usually have brief location and repair times. Most utilities are capable of pinpointing and repairing such leaks expeditiously once they are aware of them.
- Unreported leaks on customer service connections may also have variable awareness times for the same reasons as stated above. A notable difference for these leaks is that they can also have variable repair times depending on the utility's policies. Many water utilities require their customers to arrange for repairs on sections, or the entire length, of their service connection piping. Such policies are inefficient leakage control mechanisms because many customers respond slowly in arranging for such repairs. Water utilities that conduct repairs on customer service connections or have programs to handle repairs can keep average repair times at a reasonable level, perhaps on the order of several days. For those systems that rely on customer-arranged repairs, the repair time can extend for weeks or months, with the unwanted consequence of mounting volumes of leakage losses, even after leaks have been identified and pinpointed.

Spreadsheet software models have been in use since the 1990s to model the leakage components occurring in water utilities and provide data to the water audit, although many of these have existed in proprietary packages offered by consultants. In 2014, the Water Research Foundation (WRF) and the United States Environmental Protection Agency (USEPA) sponsored a research project that developed standardized software tools that allow users to conduct a reliable LCA that permits water utilities to set a system-specific, cost-effective leakage management strategy. The project—titled *Real Loss Component Analysis: A Tool for Economic Water Loss Control* (WRF 2014)—is described in detail in chapter 7. In using LCA software, the operator gathers information on the occurrence and durations of leakage events. The input data includes noting whether or not the system operates a leak survey program; average repair times for different kinds of leaks, including customer service connection piping leaks; the number and types of leaks; and other information. From this analysis, predictions can be made to estimate the volume of leakage loss reduction that can be gained by a variety of refined leakage control activities. LCA is one of the powerful recent innovations developed to assist leakage management planning.

A FURTHER WORD ON CUSTOMER SERVICE CONNECTION PIPING LEAKAGE

In water utilities throughout the world, the majority of both leakage events and leakage volume losses occur on customer service connection piping, not on the water main piping of the distribution system. Several reasons for this exist. Distribution system piping often tends to be relatively uniform in its materials, design, and construction. Customer service pipes and the connections to the distribution mains have many more fittings, threads, and pieces that can fail and are often found to be much more variable in materials and installation practices. Different piping types have been employed over the years, from lead and galvanized iron in the past to copper and plastic pipes currently. Many service pipe materials, such as galvanized iron and polybutylene pipe, are prone to failure well before their water main material counterparts. Many utilities require work on distribution piping to be performed only by their personnel or a construction contractor selected and inspected by them. Conversely, they allow customers to hire independent contractors to install and repair service connection piping, typically without inspection. The quality of materials and caliber of workmanship can become suspect when many independent contractors work in unsupervised mode. Drinking water utilities can reduce the risk of customer service connection piping failures by establishing uniform quality standards for this piping, as well as sound installation and quality assurance procedures.

The primary factor in the high volume of leakage losses occurring on customer service connection piping leakage, however, is the type of repair policy employed by the water utility. It is common for many North American water utilities to require customers to not only own their service connection piping but to arrange for repairs of leaks found on at least a portion of their pipes. During severe drought in the United Kingdom in 1995–1996, the government regulator imposed a precedent-setting requirement on several water companies that were in the throes of water shortages, requiring them to execute repairs on known private customer service piping leaks that were running continuously while awaiting repair by the customer (Lambert et al. 1998). By implementing speedy repairs, the reduction in leakage losses was so dramatic that the regulator implemented a permanent requirement for all water companies in England and Wales to institute a policy for utility-implemented repairs of private service piping leaks. The result was to greatly reduce the run time of leaks that had already been detected and pinpointed. This major policy shift was notable by the fact that, after an initial backlog of leaks was addressed, the rate of occurrence of new leaks was found to be manageable for the companies, demonstrating that a proactive approach actually saves water and money for the utility as compared to the more reactive approach of customer-implemented repairs.

WATER PRESSURE AND LEAKAGE

Water pressure levels in distribution systems vary widely throughout all countries. Regulatory requirements and design guidelines also vary considerably. In some parts of the world, very low pressures (20 psi or less) are common, whereas in other parts, pressure runs at well over 100 psi, often in systems with hilly or mountainous terrain and varying topography. In parts of the developing world, some systems operate with *intermittent* supply, in which the distribution system is shut down and depressurized for portions of a week or month. This often creates considerable leakage and infrastructure deterioration, as well as a strong likelihood of water quality compromise. Although this type of operation certainly merits attention for improvement, the following discussion applies to systems with *continuous* supply and constant positive pressure, which includes North America and most of the developed world.

The AWWA Partnership for Safe Water Distribution System Optimization Program launched in 2011 as a means to promote water utility practices that optimize water conveyance operations. Pressure management is one of three focus areas of this program, along with maintenance of acceptable chlorine residual and controls to limit the number of water main breaks. The program's *Self-Assessment Guide for Distribution System Optimization* (AWWA Partnership for Safe Water 2011) referenced a reputable pressure standard by quoting the "Ten State Standards" (Water Supply Committee of the Great Lakes–Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers *Recommended Standards for Water Works* [GLUMRB 2007]) which stipulates that water systems "shall be designed to maintain a minimum pressure of 20 psi at ground level at all points in the distribution system under all conditions of flow." Additionally, the Ten State Standards specify that the normal working pressure in the distribution system should be approximately 60 to 80 psi and not less than 35 psi.

Systems with areas of pressure routinely falling below 35 psi may have difficulty providing reliable supply to buildings at higher elevations under all conditions and may struggle to fully meet local fire flow requirements. Systems with pressures notably above 80 psi may result in pressure-reducing valves being needed on customer service lines to prevent damage to customer plumbing, hot water heaters, and other customer devices. In the same vein, water distribution systems operating with pressure levels notably higher than 80 psi may encounter a greater opportunity for high leakage and rates of failure on water distribution piping. The AWWA Partnership for Safe Water *Self-Assessment Guide for Distribution System Optimization* flags water pressure levels above 100 psi as noteworthy.

The standard AWWA Water Audit Methodology described in chapter 3 includes several data inputs to the water audit, including the average water pressure level existing in the water distribution systems. As described in chapter 2 and appendix E, water audit requirements exist in a number of US state and regional water agencies. However, as of 2014, two water audit data collection efforts are notable in that they include a data validation process. Thus, the data from the water audits from these two initiatives can be viewed as graded reliably. The data were collected by the AWWA Water Loss Control Committee in its annual Water Audit Data Initiative and by the State of Georgia. Table 6-1 shows a summary of the average pressure values reported by 233 systems of varying size included in these efforts. Notably, the average of the average pressures was reported as 76 psi.

Since each water utility reported the average pressure across its distribution system, then it is likely in many cases that various sections of the distribution system reside at pressure higher than the average value. It is highly significant that 91 of the 233 systems (39 percent) reported average system pressures above 80 psi, at a composite average of 97.7 psi. These findings strongly suggest that water utilities with notably high pressure are quite common in North America. (This is not necessarily the case in other parts of the world, however.) None of the 233 systems reported an average pressure less than 35 psi.

Table 6-1 Assessment of average water pressure levels reported in validated water audits in North American water utilities*

Validated Water Audit Data Source	No. of Utility Audits	Average of All Pressure Values (psi)	No. of Utilities With Pressure Over 80 psi	Average Value for Those Systems With Average Pressure > 80 psi
AWWA WLCC 2013†	26	80	12	98.3
Georgia—Large Systems 2011‡	107	77	53	93.7
Georgia—Small Systems 2012‡	100	72	26	105.5
All Utilities	233	76	91	97.7

*Pressure values reported are the average pressure across the water distribution system.

†AWWA Water Loss Control Committee, Water Audit Data Initiative (WADI).

‡Georgia Department of Natural Resources, Georgia Environmental Protection Department, Georgia Watershed Protection Branch.

Thus, it is strongly surmised from the data that typical North American water utilities have been successful in designing and operating water distribution systems to meet general requirements to provide minimal pressure levels that exceed 35 psi as an average pressure level. However, since similar guidelines do not typically exist for maximal pressure levels, it is very likely that many North American distribution systems are operating with at least some portion of their distribution system at well over 100 psi. It stands that many of these systems have the potential to better manage these high or excessive levels of pressure for multiple benefits. In water distribution systems that are particularly pressure sensitive, such as those with very poor infrastructure condition and/or high background leakage, excessive pressures can exert a cost in terms of lost water from elevated leakage and water main break rates, as well as higher energy demands to pump water to higher pressures.

It is logical that the level of water pressure has bearing on the amount of water escaping from a leak in a pressurized pipe. Simply put, the higher the pressure, the greater the rate of water flow out of the leak. Yet, until relatively recently, pressure was not commonly analyzed for its effect on leakage in water distribution systems. The theory of fixed and variable area discharge paths (FAVAD) was developed in 1994 and has greatly advanced the understanding of pressure–leakage relationships for water distribution systems (May 1994). Prior to this theory, it was assumed that the amount of leakage through a fixed hole in a pipe varied according to the square root power of the pressure, implying that a 10 percent change in pressure will produce only a 5 percent change in the velocity of water leaving the leak. The FAVAD theory takes into account the fact that certain types of leaks, such as holes in metal pipes, will follow this fixed-path model and demonstrate the square root, or 0.5 power, relationship in the pressure–leakage calculation. This exponent variable is referred to as the N1 exponent. Certain other types of leaks, however, follow variable leakage paths (e.g., cracks in plastic pipe, whereby the size of the crack also increases with pressure). The pressure–leakage relationship varies up to a power of 2.5 in such cases. Background leakage typically has a FAVAD exponent of 1.5. Many distribution systems have a variety of leakage types occurring, and it is now common to assume a power of 1.0 rather than 0.5 for most systems. The FAVAD theory has brought about an objective method of analysis for the influence of pressure on leakage volumes and is becoming an effective tool to assist in developing the leakage and pressure management strategy.

High pressures can greatly exacerbate the rate of water escaping from active leaks, particularly if background leakage is a significant percentage of the total real loss. The Philadelphia Water Department reported sustained reduction in background leakage in a single district metered area (DMA) by employing advanced pressure management via a flow-modulated pressure management scheme (Kunkel and Sturm 2011). With a separate controller linked to a standard pressure-reducing valve, pressure is automatically and gradually reduced as flow declines with reduced nighttime customer consumption. Conversely, pressure is increased during the daytime hours when customer consumption increases, or when emergency supply (such as during a fire event) is needed. (See chapter 7 for additional information on this work.)

Studies have been underway to confirm the extent to which water main break and service leak frequency is accelerated where high pressure is encountered. Reducing excessive system pressure may also result in less damage to adjacent property and infrastructure during water main break events. Operating the distribution system at a steady level of pressure sufficient to sustain the desired level of service to customers, but not at excessive levels, can garner savings from leakage reduction and results in less stress on distribution system infrastructure. Studying the effects of pressure on leakage rates and infrastructure condition is a relatively recent undertaking, and additional work is needed to provide comprehensive conclusions on the techniques and benefits of pressure management. Because all water distribution systems are unique in their configuration and operation, each system must be assessed individually for the potential for improved pressure management. Benefits and results will vary and it is best to undertake a business case assessment of each proposed pressure management project before undertaking it.

In recognizing the pressure–leakage relationship and by employing new means to target its use for individual distribution systems, advanced pressure management has become a distinct tool in the control of leakage losses that are distinctly influenced by excessive levels of pressure. Particularly in addressing background losses that are, by definition, undetectable by traditional acoustic means, pressure management has become a highly cost-effective means to reduce leakage below what was previously viewed as unavoidable leakage. Establishing pressure management as a strategy in the leakage management tool box is one of the most effective innovations of recent years for utilities for whom it is an appropriate intervention. The technique of pressure management is discussed in detail in chapter 7.

LOCATING AND QUANTIFYING LEAKAGE

It has become essential for the utility operator to know where and how much water loss is occurring. Leaks have occurred in piped water systems for as long as these systems have been in existence. Historically, many water utility operators reacted to leaks only after they became visible, often causing disruption in the process. In recent decades, however, technologies have been developed to allow the operator to address leakage proactively, by detecting leaks while they are relatively minor and not evident from aboveground. These techniques provide operators with accurate means to pinpoint leak sources and measure quantities of water from leakage occurrences. Active leakage control methods employed by water utilities fall into two general categories:

1. **Acoustic techniques.** The sound of water escaping from the pressurized system is detected by sensitive listening devices. Leaks can be identified and pinpointed via these techniques, but the amount of water escaping from leaks cannot be quantified with great accuracy, and these techniques cannot detect background leaks, which are, by definition, undetectable by sonic methods.

Figure 6-7 Leak correlators have become a standard pinpointing tool of the leak detection squad in many water utilities

Courtesy of Fluid Conservation Systems

2. **Flow measurement techniques.** Water supplied throughout a distribution system can be measured at different points in the system and analyzed to infer and quantify the presence of one or more leaks across a given area by identifying flow quantities exceeding the normal water demand of the customer population. Flow measurement techniques have been refined to measure the presence of a relatively small leak in a specific area of the distribution system. In utilities with good leakage management, this technique can be used to monitor the emergence of new leaks as they occur. This method also quantifies leakage rates, which is data that can be fed back into the water audit to improve its reliability. However, this method cannot pinpoint the exact locations of individual leak sources.

Effective leakage management relies on the use of both techniques, and both have had considerable advancement in recent years.

Acoustic devices have been used to detect and pinpoint leak noises for hundreds of years. When water escapes from a pressurized pipeline, a characteristic and recognizable leak sound is generated in the pipe at the point of leakage. Such leak sounds can travel along the pipe in both directions and be detected at points remote from the leak. From early mechanical listening devices (sounding rods, geophones), leak noise detection advanced to devices using electronic sound amplification to better detect, filter, and discern leak noises. In the 1970s, leak noise correlators were invented to provide accurate pinpointing of leak sources. As shown in Figure 6-7, a leak correlator pinpoints the exact leak location by comparing leak noise sound waves from two sites that encompass the leak. Within several decades, the leak correlator became a fundamental tool of the leakage specialist.

More recently, leak noise loggers have been developed to not only detect leak noises but also record them over a fixed period of time. These units are designed to be deployed either permanently in fixed locations or rotated from site to site (the "lift and shift"

Figure 6-8 Leak noise loggers help to automate the leak survey process and provide consistent sounding capabilities for effective leak detection

Courtesy of Fluid Conservation Systems

method). The loggers are usually programmed to *awaken* during the quiet nighttime hours and record leak noises. The recorded sounds can then be downloaded and compared with other nearby loggers to detect the presence of leaks. Leak noise loggers can be deployed relatively easily and require less overall labor than traditional manual leak surveys. They are also useful in standing watch over sensitive or hard-to-access locations. Some leak noise loggers are currently used in tandem with correlating equipment to detect, record, and pinpoint leak sources. Figure 6-8 shows a typical installation of a leak noise logger deployed in a permanent location. Leak noise loggers properly stationed throughout an area can find leaks at fairly low flow rates. There is evidence that detecting leaks shortly after they emerge can reduce leakage significantly and limit the costs of repair, restoration, and damage. It is important to carefully develop the economic business case for the use of leak noise loggers since these are "smart" devices that can require frequent upgrades or replacement.

Acoustic devices are the primary tools of the leak detection squad. They allow crews to detect the presence of leak noises and pinpoint leak locations accurately and quickly. Leakage management programs cannot be effective without these instruments.

Although effective acoustic leak detection devices are commonly used, these devices do not measure the volume of water escaping from a leak or detect background leakage. Obtaining a measure of the volume of water lost from leaks is important to include accurate leakage quantities in the water audit and reveal leakage patterns in the distribution system. Making economically justifiable leakage intervention decisions also relies on knowing leakage amounts in given areas of the distribution system. Unless leak noise loggers are permanently deployed, acoustic devices cannot detect the rise in leakage as new leaks occur or as existing leakage worsens. Flow measurement, while not providing pinpointing capability, allows the operator to quantify individual leak flow rates or bulk leakage rates from multiple leaks existing in distinct areas of the distribution system.

The advancement of flow measurement in leakage analysis has brought about the ability to monitor wide variation in leakage quantities, down to the level of individual small leaks in well-run distribution systems. The approach to this method requires measurement of flows into DMAs or subsections of DMAs. DMAs are discrete areas of the distribution system that are sufficiently small (1,000–3,000 customer connections) to measure and segregate leakage flow rates from customer consumption rates. By limiting supply into the DMA to one or two water mains, daily and seasonal variations in flow can be accurately measured by meters placed on the supply mains. Supply flow rates during minimal consumption periods are analyzed because leakage rates exist at their highest proportion of the supply flow during these times. In many areas, customer consumption is minimal during nighttime hours; therefore, high night flows can infer the existence of leakage. However, in areas with continuous industrial consumption or dry regions or warm seasons with considerable nighttime irrigation sprinkler use, supply flows may actually reach their maximal levels at night. In such cases, careful scheduling must be utilized to assess flows during true minimal consumption periods. In areas of high industrial flows, analysis may be available only during scheduled shutdowns of industrial plant facilities. In dry regions, the use of landscape irrigation systems may be minimal during winter periods, and analysis can be performed during such times. Once minimal consumption periods are analyzed, flow trends can be monitored and economic leak detection intervention levels set, whereby leak pinpointing work is launched only when leakage rates in the DMA have risen to an established economic level.

Figure 6-9 illustrates the hierarchy of zoning—from supply zones to DMA and sub-DMA levels—that can exist to varying degrees in water distribution systems. The system comprises

- measurement at the source of the treated water supply or treatment works (water supplied);
- measurement of flow into supply or pressure zones, with geographic or hydraulic boundaries, usually 10,000–50,000 customer properties;
- flow monitoring into DMAs of 1,000–3,000 properties, with permanently closed boundary valves and one or more open supply mains feeding the DMA;
- small leak location areas within each DMA, of around 500–1,000 customer connections, where boundary valves remain open except during a leak location exercise such as a "step-test" (described in chapter 7); and
- individual customer meters, domestic, commercial, and industrial.

Sectoring the water distribution system by establishing pressure zones and DMAs has become common and, in some cases, required practice in water utilities in different countries of the world. It has become a highly useful technique for monitoring the occurrence of customer consumption and leakage, and providing quantities to these components. Guidelines for designing and implementing leakage monitoring zones (DMAs) are described in chapter 7. Employing sectoring methods such as DMAs in conjunction with geographic information systems (GISs) and making use of hydraulic models can allow for advanced analysis of customer consumption and leakage patterns. Operators may be able to identify leak clusters by reviewing flow and pressure data from specific DMAs, and viewing leak frequencies and categories spatially through the use of GIS software.

Considerable advances in flow metering and computing technology have given water utility operators the ability to discern the location and amount of leakage occurring in their water distribution systems. Misconceptions, such as the inability to measure leakage, have given way to effective technologies to identify and control leakage in a cost-effective manner.

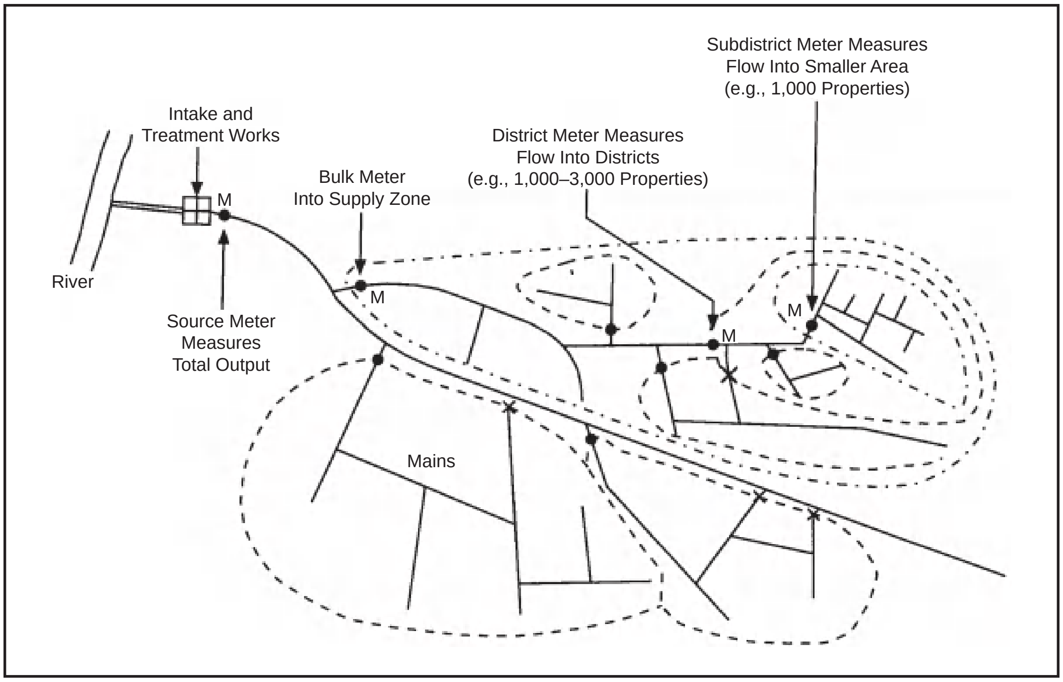


Figure 6-9 Distribution system flow metering and DMA design options

Source: *UKWIR 1999*

Generally, an acoustic leak survey and repair program forms part of a short- to medium-term leakage control program. Flow monitoring, DMA control, and pressure management form part of a medium- to long-term intervention. Infrastructure replacement completes the long-term program.

A potential new way of detecting leakage may emerge and become commercially viable. Leakage from pressurized systems creates a drop in pressure in the leakage pipeline. By employing accurate pressure sensors, likely as part of advanced metering infrastructure systems, sophisticated models may be employed to detect areas of emerging leakage by identifying trends of reducing pressure. This approach is not yet available in a widespread manner but has potential for the future.

THE IMPACT OF LEAKAGE

Although leakage from water distribution systems is labeled a loss, it should be recognized that the water cycle is a continuous process and leaked water is only lost in the sense that it has unintentionally escaped from the pressurized water distribution system. Water lost as leakage, like rain, percolates into the ground or enters breaches in sewers or stormwater collector systems, or other underground conduits. The negative effects that leakage imparts on society, however, are numerous, and can be identified as follows:

- High leakage losses indirectly require water suppliers to extract, treat, and transport greater volumes of water than their customers require. This results in unnecessary withdrawals from watersheds, possibly contributing to adverse environmental impacts.
- High leakage losses require larger infrastructure capacity than needed to meet customer demand, a compelling factor because infrastructure rehabilitation and renewal is of great concern. Infrastructure condition assessments should include

Energy Impacts of Water Loss

Water utilities are continuously consuming energy to treat and transport drinking water, a significant portion of which is lost to leakage. Excessive energy expended on leakage burdens energy-generating infrastructure, which often relies on large quantities of water in the generation process. It is estimated that water utilities consume from 2 to 10 percent of all power use in any country, and power can consume up to 65 percent of a water utility's operating budget (Crapeau 2000, Pelli and Hitz 2000). It has been estimated that, collectively, water utilities are the largest single user of electricity in the United States, consuming an estimated 75 billion kilowatts annually, or about 3 percent of all electric power generated in the country (Von Sacken 2001). It is possible that between 5 and 10 billion kilowatts of power generated in the United States is expended on water that is either leaked or not paid for by customers each year. In California, where many water supplies are transported great distances, water-related energy consumption consumes 19 percent and 32 percent of the state's electricity and natural gas, respectively. One large-scale water supply project alone uses 7–8 percent of all power in the state. This includes storage, delivery, and treatment of water, as well as energy used by customers to heat water and to supply water for landscape irrigation. Consequently, regulators agreed to divert some of the ample funding earmarked for energy conservation to water conservation in recognition that saving water means saving energy, and it all means saving money (CEC 2005). Many water utilities have found that reducing water demand by water loss control, water conservation, or reuse also results in significant energy savings.

A growing number of examples exist that provide proof that water savings from water efficiency improvements translate into energy savings. Two examples are given below.

The City of San Diego (Calif.) Water Department has achieved award-winning levels of energy reduction by managing its water demand. Each year, the department's water conservation program saves 30,000 acre-ft of water, which translates to 13 percent of the city's total water consumption. This reduction in water demand has resulted in electricity savings of more than 2 million kilowatt-hours and an annual cost savings of $191,000.

In a research vein, the California Public Utilities Commission (CPUC) authorized a significant project titled the Embedded Energy in Water Pilot Programs Impact Evaluation. Under this initiative, "California's largest energy Investor-Owned Utilities were directed to develop partnerships with water agencies, implement specific water conservation and energy efficiency programs, and measure the embedded energy savings. More specifically, the CPUC required the utilities to partner with water providers to implement jointly funded programs designed to conserve water, use less energy-intensive water or make delivery and treatment systems more efficient and thereby reduce energy used by water providers and wastewater treatment agencies" (CPUC 2011). A total of nine pilot programs were implemented by Pacific Gas and Electric Company, Southern California Edison (SCE), and San Diego Gas and Electric Company from July 2008 to December 2009. For each pilot program, water and wastewater savings were measured via direct metering or analysis of water utility bills, and embedded energy savings were either measured directly or estimated based on the energy intensities of the water and wastewater systems that serve the pilot participants.

The nine pilots included the use of low-flow toilets for single-family and multi-family housing, landscaping irrigation efficiency, improved industrial processes, cooling tower efficiencies, water pumping improvements, leak detection and repair, and several other programs.

The findings of the project reported that "SCE's Leak Detection program appears to offer the greatest energy savings potential (at relatively low cost) among all the Pilot programs. In particular, the energy savings documented in this report are based on leaks that were *actually* repaired during the program period; *potential achievable* water (and energy) savings were estimated to be much higher by the program implementation contractor" (CPUC 2011). The Leak Detection Pilot also saved the greatest quantity of water and was one of the most cost-effective of the pilots. It is evident from the results of this project that leakage reduction can provide multiple benefits, including potentially significant energy savings, and these savings may exceed the savings that could be gained from a variety of other water efficiency endeavors.

Achieving good water efficiency results in savings of two valuable resources: water and energy. And these reductions almost always result in cost savings for the water utility. Saving water and energy therefore make a good economic case for water utility managers, board members, or town councils.

an evaluation of leakage losses to distinguish that portion of infrastructure capacity that provides water to beneficial consumption versus the portion of capacity that exists merely to supply distribution system leakage. Improving the conveyance efficiency of distribution systems is an important part of any long-term water supply infrastructure improvement.

- High leakage losses are also a pertinent energy management issue. (See the “Energy Impacts of Water Loss” sidebar.)
- Leaks and breaks often cause considerable damage and increase liability for utilities.
- Leaks and breaks stress utility personnel. When operators are continuously responding to emergency leaks, routine maintenance is deferred, which can lead to other problems.
- Leaks and breaks may have a distinct effect on distribution system water quality as a potential source of contamination during low-pressure or backflow conditions.
- Significant volumes of leakage drain into community waste- or stormwater collection systems and are treated at the local wastewater treatment plant—thereby experiencing two rounds of expensive treatment without ever providing any beneficial use (Thornton et al. 2008).
- Unnecessary withdrawals caused by leakage may limit growth in a region as a result of restrictions on available source water and may be a source of conflict during water shortages or competing interests for limited water resources.

Other negative impacts exist from utility to utility, with unique issues possible in any water system. Associated with these issues are financial impacts. Any negative impact to the water utility or community carries a cost impact, although some of these may be difficult to quantify. It is important during the compilation of the water audit that costs be assigned to the various components of leakage identified by the audit. Leakage costs vary directly with the cost of the water in the community or region. If water resources are limited and the rates charged to customers are high, the costs associated with leakage will also be high. Leakage costs can also vary with time; if a water shortage develops as a result of drought or other reason, the cost of leakage lost from the system will likewise increase as the relative scarcity of the water increases. Costs include the short-term variable costs to treat and deliver water, but can also include long-term infrastructure, economic, social, or political costs. Leakage should be valued at customer retail cost if the utility is facing significant water resource limitations and implementing strict water conservation measures. In such cases, it can be argued that volumes of water from recovered leakage can be sold to current or future customers; therefore, the retail rate applies.

Leakage represents inefficiency in the process that a water utility uses to deliver water to its customers. Although there exist limits below which leakage recovery is not cost-effective, it is likely that many North American water utilities are operating with excessive levels of leakage that are cost-effective to recover.

REFERENCES

AWWA (American Water Works Association) Partnership for Safe Water. 2011. *Self-Assessment Guide for Distribution System Optimization*. Denver, Colo.: AWWA Partnership for Safe Water.

AwwaRF (Awwa Research Foundation). 2007. *Evaluating Water Loss and Planning Loss Reduction Strategies*. Denver, Colo.: AwwaRF.

Brown, T.G., D. Huntington, and A. Lambert. 2000. Water loss management in North America—Just how good is it? In *Proceedings, Technical Session on Progressive Developments in Leakage and Water Loss Management, Distribution System Symposium*. Denver, Colo.: American Water Works Association.

CEC (California Energy Commission). 2005. *2005 Integrated Energy Policy Report*. CEC-100-2005-007-ES. Sacramento, Calif.: CEC.

CPUC (California Public Utilities Commission). 2011. *Embedded Energy in Water Pilot Programs Impact Evaluation*. 2011. Final Report Study ID: CPU0053.01. Prepared for the California Public Utilities Commission Energy Division. Portland, OR: ECONorthwest. www.calmac.org.

Crapeau, M. 2000. Changing the face of the water industry. *Journal AWWA*, 92(11):60–66.

GLUMRB (Great Lakes Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers). 2007. *Recommended Standards for Water Works*. Albany, N.Y.: Health Research, Health Education Services Division.

Kunkel, G., and R. Sturm. 2011. Piloting proactive, advanced leakage management technologies. *Journal AWWA*, 103(2):62–75.

Lambert, A.O., S. Myers, and S. Trow. 1998. *Managing Water Leakage—Economic and Technical Issues*. London: Financial Times Energy.

May, J. 1994. Leakage, pressure, and control. In *BICS International Conference on Leakage Control Investigation in Underground Assets*. London: BICS.

Pelli, T., and H.U. Hitz. 2000. Energy indicators and savings in water supply. *Journal AWWA*, 92(6):55–62.

Thornton, J., R. Sturm, and G. Kunkel. 2008. *Water Loss Control*. New York: McGraw-Hill.

UKWIR (United Kingdom Water Industry Research). 1999. *A Manual of DMA Practice*. Report Ref. No. 99/WM/08/23. UKWIR.

Von Sacken, E. 2001. *Energy and Water Quality Management*. Update "Drinking Water Research." Denver, Colo.: Awwa Research Foundation.

WRF (Water Research Foundation). 2014. *Real Loss Component Analysis: A Tool for Economic Water Loss Control*. Denver, Colo.: WRF.

Chapter 7

Controlling Real Losses: Leakage and Pressure Management

Considerable advancement has occurred in the field of leakage management since the early 1990s, particularly in the understanding of the occurrence of leakage and in the innovation of new methods to economically control leakage losses. This chapter offers information on how to economically control leakage. It provides instruction on the most effective leakage management approaches available in a world of rapidly improving technology. The reader is urged to review chapter 6 prior to reading this chapter. Chapter 6 explains the nature and impacts of leakage in water distribution systems. Table 7-1 serves as a guide to employ a systematic approach to develop the leakage management strategy. Explanation of the steps in this approach is given throughout chapter 7.

This chapter presumes that the first three steps listed in Table 7-1 have been completed and that the water utility is now poised to develop its leakage management program. Continuing to Step 4 in Table 7-1, the water utility can focus on specific leakage reduction goals and methods to achieve them. A sample leakage management plan for the fictitious County Water Company (CWC) is included in this chapter.

Figure 7-1 illustrates how a combination of effective water distribution infrastructure management techniques can sustain a low-leakage, water-efficient distribution system. The outer box of this graphic represents the volume of current annual real losses (CARL), which can be reduced by applying the four pillars of leakage control in the most economic combination. All water utilities should employ some level of activity in each of the four pillars if leakage is to be maintained at economically low levels.

The key is to determine an initial leakage reduction target and then assign the most appropriate combination of the following four primary leakage control methods:

1. Active leakage control—identifying and quantifying existing leakage in the water utility transmission and distribution system, typically by performing acoustic

Table 7-1 Eleven steps for preparing a sustainable leakage management program

1. Identify a team that will take ownership of the program, and regularly assess progress and continually implement best management practices for leakage control (see chapter 8).
2. Compile the top-down water audit to quantify the initial real loss volume; assign a cost value to this volume of real loss (see chapter 3).
3. Validate the System Input Volume of the water audit by testing source/production flowmeters (see chapter 3 and appendix A).
4. Identify a preliminary target range for real loss reduction, noting the cost savings projected from the leakage reductions.
5. Quantify the component volumes of leakage (reported leaks, unreported leaks, and background leakage) by applying the leakage component analysis technique and/or minimum-hour flow measurements in pilot zones or district metered areas. (See "Leakage Component Analysis" section in this chapter.)
6. Assign costs to the individual component leakage volumes.
7. Compile the short-term plan for initial leakage reduction (the "low-hanging fruit") by identifying the leakage reduction methods and resources to achieve early success in meeting initial targets.
8. Implement the short-term plan and reduce leakage levels to short-term economic levels.
9. Review results and confirm assumptions; revise the plan as needed.
10. Recalculate the leakage component analysis based on any new assumptions.
11. Set goals for medium- and long-term reduction, including methods and targets.

leak detection surveys and continuous monitoring of flows into small zones or district metered areas (DMAs).

2. Optimized leak repair activities—ensuring timely and lasting repairs.
3. Pressure management—leakage levels can be improved or worsened solely by changes in the level of operating pressure.
4. System rehabilitation and renewal—all pipeline assets eventually reach the end of their useful life and must be rehabilitated or replaced if they are to continue to provide service.

Effective leakage management programs are developed by collecting data to identify the types and volumes of leakage losses occurring within the distribution system, the cost of water in the utility, and the costs of the appropriate techniques to reduce specific components of leakage. The Water Research Foundation (WRF) *Real Loss Component Analysis: A Tool for Economic Water Loss Control* (WRF Project 4372a; 2014a) was completed in 2014 and now stands as the standard approach to conduct a reliable leakage component analysis. This project created a free spreadsheet software tool (Leakage Component Analysis Model, or LCA Model) that water utilities can use to undertake a leakage component analysis and economic leakage evaluation. This enables utilities to plan cost-effective leakage control interventions via the first three leakage control methods mentioned previously. This LCA Model is described in detail in this chapter. The LCA Model and companion *Leak Repair Data Collection Guide* (WRF 2014b) can be downloaded for free from the WRF web site at www.waterrf.org.

QUANTIFYING REAL LOSSES IN THE WATER AUDIT

The center boxes shown in Figure 7-1 represent three levels of real losses.

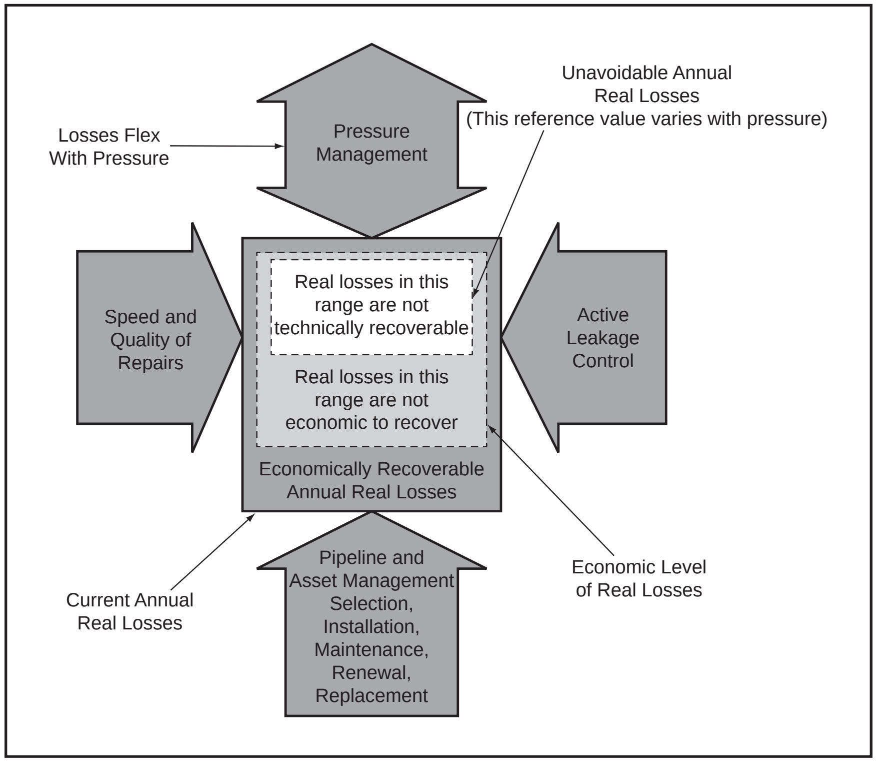


Figure 7-1 Four-pillar approach to the control of real (leakage) losses

1. The outer box represents the CARL, as quantified in the water audit.
2. The middle box perimeter is defined by the economic level of leakage (real losses), or ELL. Leakage cannot be economically reduced below this level because the cost of the leakage control measures will exceed the value of the water savings from the additional leakage reductions that are achieved.
3. The perimeter of the inner box is defined by the unavoidable annual real losses (UARL). This reference level is represented by a theoretical model of the lowest level of leakage that could be technically attained if all possible leakage control efforts could be exerted to reduce the losses. The derivation of the UARL calculation is given in Tables 3-22 and 3-23 and was developed with data from water utilities that have achieved excellent leakage control. The UARL is a reference level used to calculate the performance indicator infrastructure leakage index (ILI). Water utilities need not seek to establish their UARL level as their leakage target unless their water supply is very scarce, expensive, or both.

Controlling losses in most fields of endeavor is an effort of diminishing returns, where losses can never be completely eliminated. When losses are excessive, relatively large reductions can occur early in a loss control program at relatively little cost, that is, the “low-hanging fruit.” However, further loss reduction requires ever-greater cost and effort to recoup ever-diminishing returns. There exists a break point, beyond which the effort to control the losses costs more than the value of the recoveries. In this case, further loss recovery is not economically feasible to pursue. This level is the ELL, or the conceptual target level of real losses to seek. If a water utility has only just begun to audit its operations and has not employed active leakage control methods, it is likely that considerable leakage losses exist, and it will be economically feasible to recover a notable portion of those losses.

New leakage controls will likely generate considerable initial savings, but the water utility must then carefully project the additional loss recovery that is economical to pursue.

Several approaches have been developed to calculate the ELL. Early methods devised for this purpose were complex and required that considerable leakage reduction work be performed, along with rigorous analysis of detailed leak repair and cost data. A thorough discussion of this approach for economic target-setting is given in the WRF report *Evaluating Water Loss and Planning Loss Reduction Strategies* (WRF 2007a). More contemporary approaches have eased this process, however, by simplifying the calculations of components of the short-run ELL by rapid assessment of economic intervention parameters for the unreported real loss component of the ELL. Additional guidance is available in the LCA Model. Work continues by members of AWWA and the International Water Association (IWA) to refine the methods of determining economic leakage control by incorporating pressure management options and benefits into the ELL calculations.

If a water utility has not yet calculated its ELL, Table 7-2 provides preliminary target-setting guidelines. This table, which was first presented in a 2003 committee report (Kunkel et al. 2003) authored by the AWWA Water Loss Control Committee, suggests preliminary target levels using the ILI as well as water resource, operational, and financial considerations that utilities typically encounter. Although the ILI is structured to serve as a benchmarking indicator, water utilities working in the *early phases* of a program can use the ILI to set a *preliminary* leakage target. Once leakage control work launches and makes initial leakage reductions, the water utility should gather and assess the leakage data and employ the Op24 real loss performance indicator (see Table 3-24) to track its progress and set economically defined long-term targets. As the leakage management program moves forward—producing more extensive and reliable field data on leakage occurrences—the program can be refined to continuously employ the most strategic leakage reduction interventions. An example of the preliminary target-setting process for CWC is given in the "County Water Company—Preliminary Leakage Loss Reduction Target-Setting Analysis" sidebar. Finally, as an additional caveat, the ILI levels shown in Table 7-2 are now considered by many leakage control practitioners worldwide as very liberal, with ILI levels up to 8.0 as potentially tolerating too high a level of leakage. Many believe that lower ILI levels are more appropriate. The AWWA Water Loss Control Committee intends to investigate this further.

The ELL is dependent on the cost of water as well as the cost to locate leaks. The higher the cost of leaking water, the lower the level of the calculated ELL. The higher the cost of locating leaks, the higher the ELL. The more prone the system is to have leaks, the more intense the leakage management effort should be.

Once an initial target leakage reduction level is set, the auditor has an estimate of the potential cost savings to be recouped by the initial leakage control work. These potential savings can be weighed against the costs of the leakage controls to determine the appropriate leakage management plan. Ultimately, target-setting and loss control planning become an iterative process. Initial targets are usually revised after initial leak reduction activities are conducted, generating more reliable data on the types, quantities, and regions of leakage occurring in the water distribution system. It is therefore acceptable that initial leakage targets are approximate, but the target should be refined as the leakage control program develops.

Note: A reminder about real (leakage) loss costs. As described in chapter 3, real losses include water that has been extracted from a water source, treated, pressurized, and transported before being lost from the distribution system. The examples for CWC in Figures 3-5 and 3-6, and in the "County Water Company—Preliminary Leakage Loss Reduction Target-Setting Analysis" sidebar, value leakage losses at the variable production cost to treat (chemical costs) and deliver (pumping power costs) the next million gallons of water, which is $190/mil gal for CWC in these examples. Other short-term costs (liability, treatment residuals management, equipment wear and tear) many also be considered. In addition to these

Table 7-2 AWWA Water Loss Control Committee—preliminary leakage management target-setting guidelines

Guidelines for Use of the Infrastructure Leakage Index as a Preliminary Leakage Target-Setting Tool
(in lieu of having a determination of the system-specific economic level of leakage)

Target ILI Range	Water Resources Considerations	Operational Considerations	Financial Considerations
1.0–3.0	Available resources are greatly limited and are very difficult and/or environmentally unsound to develop.	Operating with system leakage above this level would require expansion of existing infrastructure and/or additional water resources to meet the demand.	Water resources are costly to develop or purchase. Ability to increase revenues via water rates is greatly limited due to regulation or low ratepayer affordability.
3.0–5.0	Water resources are believed to be sufficient to meet long-term needs, but demand management interventions (leakage management, water conservation) are included in the long-term planning.	Existing water supply infrastructure capability is sufficient to meet long-term demand as long as reasonable leakage management controls are in place.	Water resources can be developed or purchased at reasonable expense. Periodic water rate increases can be feasibly effected and are tolerated by the customer population.
5.0–8.0	Water resources are plentiful, reliable, and easily extracted.	Superior reliability, capacity, and integrity of the water supply infrastructure make it relatively immune to supply shortages.	Cost to purchase or obtain/treat water is low, as are rates charged to customers.
Greater than 8.0	While operational and financial considerations may allow a long-term ILI greater than 8.0, such a level of leakage is not an effective utilization of water as a resource. Setting a target level greater than 8.0—other than as an incremental goal to a smaller long-term target—is discouraged.		
Less than 1.0	In theory, an ILI value less than 1.0 is not possible for most systems.* If the calculated ILI is just under 1.0, excellent leakage control is indicated. If the water utility is consistently applying comprehensive leakage management controls, this ILI value validates the program's effectiveness. However, if strict leakage management controls are not in place, the low ILI value might be attributed to error in a portion of the water audit data, which is causing the real losses to be understated. If the calculated ILI value is less than 1.0 and only cursory leakage management controls are used, the low ILI value should be considered preliminary until it is validated by field measurements utilizing the bottom-up approach.		

*An ILI value less than 1.0 can be achieved in small, stand-alone systems of less than 3,000 service connections, and in flexible pipe (such as plastic) systems with high N1 values at pressures less than 40 psi (Lambert et al. 2014).

Source: *Kunkel et al.* 2003

short-term variable production costs, long-term costs may also apply for the leakage losses. Because real losses represent volumes of water taken from a source that do not generate a benefit, these losses could also be assessed costs relating to their environmental, economic, and social impacts. Reducing leakage could mean lesser withdrawals from a river that could improve in-stream flows, benefiting aquatic life, recreation (boating, fishing), or economic development (industrial, residential, waterfront amenities, etc.).

Additionally, if the water utility's supply infrastructure is close to its capacity in meeting normal daily supply needs, leakage reduction may provide the added benefit of avoiding expansions to a water treatment plant or pumping infrastructure. Such costs could be considerable and justify more significant leakage reductions than those suggested merely by the variable production costs. A water supplier's capital improvement plan should be consulted for scheduled investments in capacity expansion. Some of these projects might be deferred or downsized if leakage losses were to be reduced. When the scheduled and deferred investment scenarios are compared on a present value basis, the difference can be added to the value of real water losses.

County Water Company—Preliminary Leakage Loss Reduction Target-Setting Analysis (from data in Figures 3-5 and 3-6)

From the water audit data shown in Figures 3-5 and 3-6 in chapter 3, County Water Company (CWC) was found to have current annual real losses (CARL) of around 737 mil gal for the 2013 audit year. Its unavoidable annual real losses (UARL) calculates to be 83.7 mil gal. This represents the theoretical low level of leakage that could be achieved in the CWC distribution system if all possible leakage management technologies could be applied. The infrastructure leakage index (ILI) for CWC is calculated as 737/83.7 = 8.8, and the cost impact of the real losses is 737 × $190/mil gal = $140,000 in production costs for 2013. To develop a preliminary leakage loss reduction target, a three-step process is offered:

Step 1. Evaluate the current ILI value: Refer to Table 7-2 to assess the current ILI value, and identify whether the current level of losses, as reflected by the ILI, is acceptable under the circumstances encountered by the water utility. The ILI value of CWC is 8.8. Table 7-2 advises that water utilities should not operate with leakage losses greater than those that translate to an ILI greater than 8.0. Because CWC has an ILI of 8.8, it should seek to reduce its current leakage level.

Step 2. Identify a preliminary target ILI range from Table 7-2 based on the water resources, operational, and financial considerations: Based on the circumstances under these three categories, compare the conditions of the water utility to find the description that most closely represents the conditions in the water utility. CWC is a small but growing water utility servicing a semi-rural area that is experiencing a moderate population growth as the rural demeanor (small farming operations) is transforming into a larger residential community. As small farms with independent wells are replaced by new housing developments with water main connections, CWC is adding customers to its water distribution system. CWC is located in a region that receives less than 20 in. of rain per year. Its primary water source is a small mountain reservoir located 25 miles from the CWC water treatment plant. Several surrounding water utilities with growing populations also rely on water supplied from this reservoir, which is managed by a regional water authority. The growing utilization of supply from this reservoir is recognized by the water resource regulatory agency, and it has advised the regional water utilities to heighten their water efficiency programs as a means of sustaining supply amid growing customer populations. The CWC water distribution system is approximately 45 years old and is beginning to show evidence of deterioration, with an increasing number of main breaks and service leaks, believed to occur as a result of years of deferred maintenance of its largely metallic distribution system. In analyzing the boxes in Table 7-2, the general manager for CWC determines that the conditions described in the mid-level ILI range of 3.0–5.0 most closely apply to the conditions at CWC because of its water resources, operational, and financial circumstances. In this instance, a moderate level of leakage can be tolerated (ILI 3.0–5.0), but CWC is operating well above this range with an ILI of 8.8. The variable cost of water is considered to be $190/mil gal for variable power and treatment costs.

Finally, another situation for consideration is that of a water utility facing constrained water resources, with water restrictions in effect. In this case, leakage losses should be valued at the customer retail rate (same as apparent losses) because the reduction of these losses could result in the sale of like volumes of water to customers, thereby easing the severity of the restrictions or allowing projected new development to occur. These long-term costs can be difficult to quantify but should be taken into consideration if any of these conditions exist for the water utility.

ACTIVE LEAKAGE CONTROL (FINDING LEAKS BEFORE THEY FIND YOU)

New losses are continually occurring in a water distribution system; therefore, loss reduction activities should be designed to both reduce existing leakage levels to economic levels and to sustain the lower leakage levels to the greatest extent possible. To define

County Water Company—Preliminary Leakage Loss Reduction Target-Setting Analysis (continued)

ILI	Real Loss Volume (mil gal/year)	Annual Real Loss Cost	Potential Savings (current costs minus this ILI cost)	ILI	Real Loss Volume (mil gal/year)	Annual Real Loss Cost	Potential Savings (current costs minus this ILI cost)
1.0	83.7	$15,900	$124,100	7.0	586	$111,300	$28,700
2.0	168	$21,800	$108,200	8.0	670	$127,200	$12,800
3.0	251	$47,700	$92,300	8.8	737	$140,000	Current level
4.0	335	$63,600	$76,400	9.0	753	$143,100	(–$3,100)
5.0	419	$79,500	$60,500	10.0	837	$159,000	(–$19,000)
6.0	502	$95,400	$44,600				

Step 3. Identify a range of cost consideration for the target ILI range from Table 7-2: The above table lists ILI, real loss volumes, and cost impacts for ILI increments from 1.0 (technical minimum) to a value of 10.0. The cost of lost water at various ILI values is calculated by multiplying the equivalent leakage volume at the given ILI value by $190/mil gal. For ILI values of 8.0 or less, the savings amounts shown represent the amount of annual money that can be saved if the current leakage was reduced to a level equivalent to the respective ILI value. If leakage were to rise—as it will if no active leakage control is exerted—then additional loss costs (shown in parentheses as negative savings) will be incurred. In Step 2, a preliminary ILI range of 3.0–5.0 was selected, which translates to the following:

ILI = 5.0
Real (leakage) loss reduction = (737 – 419) = 318 mil gal
Potential savings from leakage reduction ≈ $60,500

ILI = 3.0
Real (leakage) loss reduction = (737 – 251) = 486 mil gal
Potential savings from leakage reduction ≈ $92,300

To achieve an ILI value of 5.0, CWC would need to reduce its CARL of 737 mil gal to a level of 419 mil gal, or a reduction of 318 mil gal. However, for CWC to economically break even in its loss reduction work, it should not spend more than $60,500 because this is the level of payback that will be recouped by the leakage reduction. Similarly, to achieve an ILI of 3.0, CWC should not spend more than approximately $92,300 to achieve a reduction of around 486 mil gal. By employing this assessment, CWC has now identified a preliminary leakage reduction target range of values that reveal cost savings that can be weighed against potential leakage control options.

This type of analysis, while not detailed, is a quick and useful means to set a preliminary leakage reduction target range and develop an initial budget justification. CWC can now move forward to develop the leakage control program by evaluating various leakage control methods within the budget of the utility. An evaluation of the ultimately designed CWC leakage management program cost-effectiveness is explained in detail throughout this chapter.

the most appropriate leakage management strategy, the nature and scope of the leakage events occurring in the water distribution system must be understood. It is best to establish short-, medium-, and long-term interventions designed to sustain the benefits of the leakage management program. In addition to leakage program guidance offered in this chapter, Table 8-1 also provides instruction in setting these goals.

As discussed in chapter 3, water auditing occurs at three levels of refinement, and these levels can also be applied to the assessment of real (leakage) losses:

1. **Top-down approach—**the initial desktop process of gathering information from records, procedures, data, and other information systems.
2. **Leakage component analysis—**a technique that models leakage volumes based on the nature of leak occurrences and durations.
3. **Bottom-up approach—**validating the top-down results with actual field measurements and data, such as leakage losses calculated from integrated zonal or DMA minimum-hour flows, or temporary deployment of acoustic monitors to evaluate what potential there may be to reduce leakage with a monitoring program. Background losses can be quantified in this approach by conducting step testing in small zones, which is described in the "Zone or DMA Flow Measurement and Analysis to Quantify and Manage Leakage Volumes" section.

The top-down water balance method of identifying real loss volumes is very useful for a quick, broad look at entire system performance or for a look at volumes of real loss for distinct regions within a utility system. However, the top-down approach does not produce a sufficiently detailed analysis of the separate components and volumes of real loss. Ultimately, the water auditor can better validate and improve the accuracy of the water audit when it is augmented by LCA, bottom-up field measurements, or both of these assessments.

Leakage Component Analysis

After the CARL has been estimated from the top-down water audit, it is recommended to attempt to broadly quantify the components of leakage—reported leakage, unreported leakage, and background leakage—to understand which components are the greatest portions of the CARL and how these losses occur. LCA requires more data than the top-down water audit approach, but it is still largely a desktop exercise; therefore, it is not as resource intensive as the bottom-up assessment, which requires hydraulic measurement equipment to be used in the water distribution system.

The three components of leakage loss occur in different manners, and specific tools are needed for the most successful intervention. Figure 7-2 illustrates the three types, or components, of real losses—reported leakage, unreported leakage, and background leakage—and the appropriate activities to control them. LCA also relies on the assessment of the average durations in the life of a leak, namely, the *awareness* period, the *location* period, and the *repair* period. These "ALR" periods are shown schematically in Figure 6-4 with an example given in Figure 6-5, along with discussion in chapter 6. Breaking down the water utility's annual leakage (CARL) into its component quantities of reported, unreported, and background leakage, and assessing their average ALR period is the fundamental approach of the LCA. Additionally, leakage events can be categorized as those occurring on water mains, mains fittings, and service connections.

Having an estimate of the individual volume components of CARL is important because certain leakage strategies are effective only for certain types of leakage. For example, background leakage is, by definition, undetectable by acoustic leak detection methods. If a system incurs high amounts of background leakage as determined by step testing (described later in this chapter), acoustic leak detection surveys will not be effective in detecting this leakage. However, pressure management is a very effective tool to reduce background leakage.

LCA builds logical estimates of leakage volumes by assessing the types of leakage events typically encountered in the system and analyzing them using specific leakage flow rates and response times to those events, along with average pressures and other readily available data. The sum of the estimates is then compared to the CARL identified in the top-down analysis and the two models are calibrated.

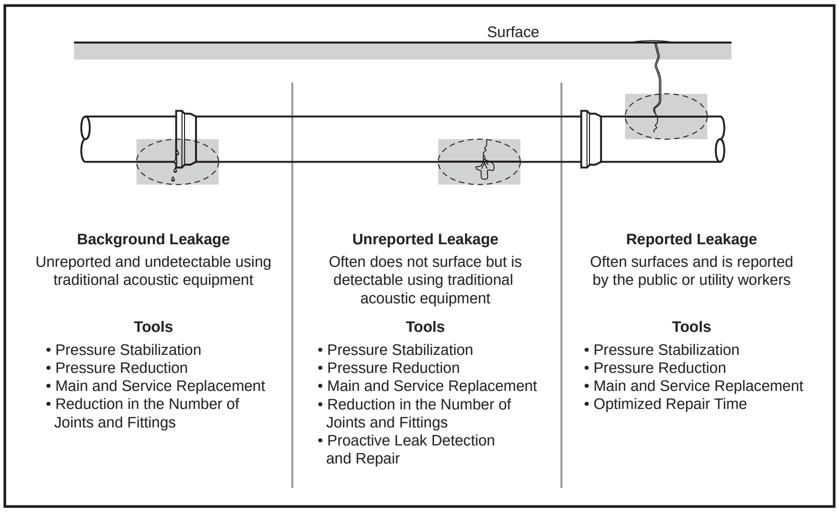


Figure 7-2 Components of leakage and appropriate intervention tools

Source: *Tardelli Filho 2004*

The importance of reliable distribution system failure data collection. The reliability of the LCA is only as good as the quality and completeness of the water system failure event data collected by water utility staff. Numerous research projects have found that the terminology used by water utilities for documenting what should be generically considered as pipe *failures* is highly inconsistent. The terms *leak*, *break*, and *burst* are all used throughout the industry but have many different interpretations/definitions depending on the water utility. For example, some utilities categorize a *break* as a failure event of significant nature that requires immediate action, and the term *leak* is used for less significant pipe failures that do not require immediate response. What one utility might call a "break," another water utility might call a "leak." WRF Project 4372a, however, set forth a standardized terminology that water utilities can employ consistently to document failure events. These definitions should be followed to input the failure data consistently into the LCA Model developed as part of WRF Project 4372a (WRF 2014a).

In addition to the inconsistent use of terminology in the water industry, many water utilities fail to document all of the failure events occurring in their systems. Some utilities collect data on break events, but not leak events. Some may document events on paper records that cannot be easily incorporated into computer analysis. To conduct a reliable LCA, every failure event on the transmission system, distribution system, and on service connections needs to be consistently documented. Acknowledging the need for consistent leak repair data collection, WRF Project 4372a also developed a companion spreadsheet—the *Leak Repair Data Collection Guide* (WRF 2014b)—to give water utilities a means for consistent documentation of water system failure events. This tool is also a free product available to water utilities to employ to ensure consistent data collection. The primary worksheets of this tool are shown in Figures 7-3 through 7-6 and are discussed briefly here.

The forms shown in Figures 7-3 through 7-6 include standardized terminology that is shown in Figure 7-3 with options that are displayed in drop-down menus in the data entry columns (labeled Failure 1, Failure 2, etc.) in Figures 7-4 through 7-6. Figure 7-3 includes the listings of all possible data entry classifications that are included in the drop-down menus of the other three spreadsheets. By limiting the data entry to the options in the drop-down menus, the water utility will be able to analyze a consistent grouping of failure types occurring in the water utility. Since the LCA should be conducted for the same annual period as the water audit, data collected using the *Leak Repair Data Collection Guide* (WRF 2014b) should encompass one full year's data before conducting the initial LCA.

Mains - Drop Down Menu Sources For Macro — *Note: This page is linked to the macro to fill the drop down lists on the other worksheets* — **WRF Project 4372**

Failure Event Type	Network Category of Failure	Failure Event was reported/detected by:	Nature of Failure	Piping Material at Location of Failure	Suspected Cause of Failure	Soil Condition at Location of Failure	How was failure repaired?
Reported	Transmission	Leak Detection Crew	Circumferential Crack	Cast Iron	Corrosion	Compacted Sand	Replaced section of pipe
Unreported	Distribution	Leak Detection Service	Longitudinal Crack	Ductile Iron	Thermal effects (cold, heat)	Clay	Repair Clamp
		Customer	Blow Out	Steel	Poor materials	Ash/Corrosive	Plug
		Meter Reader	Pin Hole	Pressuized Concete Cyliner Pipe	Poor installation	Rubbish/Poor Quality Fill	Welded a patch
		Sewer Inspection	Split Bell/Joint	PVC	Excessive pressure/surges	Flowable Fill (Cementious Material)	Rehabilitated pipe joint
		Other	Joint Leak	HDPE Pipe	Improper operation	Rock	Other Repair
			Other	Asbestos Cement	Third party damage	Other	
				other	Other		

Service Connection - Drop Down Menu Sources For Macro

Failure Event Type	Service Connection Ownership Where Service Leak Occurred	Failure Event was reported/detected by:	Nature of Failure	Piping Material at Location of Failure	Suspected Cause of Failure	Soil Condition at Location of Failure	How was failure repaired?
Reported	Utility	Leak Detection Crew	Circumferential Crack	Copper	Corrosion	Compacted Sand	New Service Connection
Unreported	Customer	Leak Detection Service	Longitudinal Crack	PVC	Thermal effects (cold, heat)	Clay	Replace Section
		Customer	Service Connection Saddle Leaking	Galvinized Iron	Poor materials	Ash/Corrosive	Fixed Meter Leak
		Meter Reader	Pin Hole	Lead	Poor installation	Rubbish/Poor Quality Fill	Other Repair
		Sewer Inspection	Meter Leak	other	Excessive pressure/surges	Flowable Fill (Cementious Material)	
		Other	Joint Leak		Improper operation	Rock	
			Other		Third party damage	Other	
					Other		

Mains Fittings - Drop Down Menu Sources For Macro

Failure Event Type	Type of Appurtenance in Failure	Failure Event was reported/detected by:	Nature of Failure	Piping Material at Location of Failure	Suspected Cause of Failure	Soil Condition at Location of Failure	How was failure repaired?
Reported	Blow-off	Leak Detection Crew	blow-off left (partially) open		Corrosion	Compacted Sand	Plug
Unreported	Hydrant	Leak Detection Service	packing leak on valve		Thermal effects (cold, heat)	Clay	Welded a patch
	Air Valve/Tap	Customer	leak at tapping point		Poor materials	Ash/Corrosive	Replaced fitting
	Valve	Meter Reader	leak at hydrant base		Poor installation	Rubbish/Poor Quality Fill	Leak repair (repacked, etc)
		Sewer Inspection	hydrant stripped open and running		Excessive pressure/surges	Flowable Fill (Cementious Material)	Other Repair
		Other	packing leak		Improper operation	Rock	
			Other		Third party damage	Other	
					Other		

Figure 7-3 WRF Project 4372a, *Leak Repair Data Collection Guide*—data selection options

Source: *WRF 2014b*

Although not included in the tools issued under Project 4372a, additional field information on leaks can include photos of excavated piping that is experiencing leakage. With the prevalence of mobile devices and Internet connectivity, great opportunity exists to photo-document leaking pipelines, fittings, and service connections. These images can be employed to assist the evaluation of failure trends, serve as evidence in liability claims, and promote better maintenance and repair techniques.

Leakage component analysis example. The detailed methodology of the standard LCA is conducted in the following three steps and illustrated in the example for CWC given in a series of sidebars (see the "County Water Company—Conducting a Leakage Component Analysis to Quantify Individual Leak Types and Evaluate Economic Intervention Frequency" sidebars, Parts 1 through 6).

Step 1. Quantify current reported leakage (CRL). The annual volume of CRL can be assessed by summing the product of each reported break and leak per year by the flow rate of the leak (adjusted for pressure) and by the run time of each leak. This can be simplified by applying the following equation:

$$\text{annual CRL} = \text{sum of } [(\text{NLr})(\text{QLr-ave})(\text{Tave})] \tag{7-1}$$

Where:

NLR = number of annual reported leak and break events on water mains and customer services ("reported" leaks/breaks are those events where water surfaces and the event are reported)

QLr-ave = average flow rates for reported leaks/breaks at the current average system pressure. See Tables 7-3 and 7-4 later in this chapter to identify flow rates for various leak/break types.

Tave = average run time, the sum of the average awareness, location, and repair times assigned to each leakage type (see Figure 6-5). Separate calculations should be made for different sizes of mains and for service connections.

Water Main Failures			WRF Project 4372	
	Water Distribution System Failure Tracking for:	*(Input Utility Name)*		
	Year or Period:			
		Unique ID# for failure or work order	Failure 1	Failure 2
Minimum Required Information	Failure Event Type	*Reported - from complaints Unreported - from proactive leak detection*		
	Network Category of Failure	*Distribution Systems Transmission System*		
	General Location of Failure Event	*For Example - Street Intersection*		
	Size Information	*Size of Main At Failure Location*		
	Failure Event Reported	*Date*		
		Time		
	Failure Event Pinpointed	*Date*		
		Time		
	Failure Event Contained/Valved-off/Repaired	*Date*		
		Time		
Additional Information for Reliable Leakage Component Analysis	Detailed Failure Event Information	*Failure Event was reported/detected by:*		
		Nature of failure		
		Piping Material at location of failure		
		Age of piping at location of failure		
		Average Pressure at Failure Location		
		Suspected cause of failure		
	Detailed Location Description for Failure	*Street Address*		
		Nearest House Number		
		GIS Coordinates (X)		
		GIS Coordinates (Y)		
	Additional Failure Event Information	*Soil condition at location of failure*		
		How was failure repaired?		
		Estimated Cost to repair failure (labor/materials/equipment/restoration of excavation and pavements)		
		Comments		
		Estimated Leak Flow Rate (using AWWA M36 recommended flow rates)		
		Estimated Leak Flow Rate (using utility specific estimations/measurements)		

Figure 7-4 WRF Project 4372a, *Leak Repair Data Collection Guide*—water main failures data worksheet

Source: *WRF 2014b*

Mains Fittings Failures			WRF Project 4372	
	Water Distribution System Failure Tracking for:	*(Input Utility Name)*		
	Year or Period:			
		Unique ID# for failure or work order	Failure 1	Failure 2
Minimum Required Information	Failure Event Type	*Reported - from complaints Unreported - from proactive leak detection*		
	Type of Appurtenance in Failure	*Blow-off, Hydrant, Air Valve/Tap, Valve*		
	General Location of Failure Event	*For Example - Street Intersection*		
	Size Information	*Size (if applicable)*		
	Failure Event Reported	*Date*		
		Time		
	Failure Event Pinpointed	*Date*		
		Time		
	Failure Event Contained/Valve-off/Repaired	*Date*		
		Time		
Additional Information for Reliable Leakage Component Analysis	Detailed Failure Event Information	*Failure Event was reported/detected by:*		
		Nature of failure		
		Piping Material at location of failure		
		Age of piping at location of failure		
		Average Pressure at Failure Location		
		Suspected cause of failure		
	Detailed Location Description for Failure	*Street Address*		
		Nearest House Number		
		GIS Coordinates (X)		
		GIS Coordinates (Y)		
	Additional Failure Event Information	*Soil condition at location of failure*		
		How was failure repaired?		
		Estimated Cost to repair failure (labor/materials/equipment/restoration of excavation and pavements)		
		Comments		
		Estimated Leak Flow Rate (using AWWA M36 recommended flow rates)		
		Estimated Leak Flow Rate (using utility specific estimations/measurements)		

Figure 7-5 WRF Project 4372a, *Leak Repair Data Collection Guide*—water mains fittings failures data worksheet

Source: *WRF 2014b*

Service Connection Failures			WRF Project 4372	
	Water Distribution System Failure Tracking for:	(Input Utility Name)		
	Year or Period:			
		Unique ID# for failure or work order	Failure 1	Failure 2
Minimum Required Information	Failure Event Type	Reported - from complaints Unreported - from proactive leak detection		
	Service Connection Ownership Where Service Leak Occurred	Utility Maintained Section Customer Maintained Section		
	General Location of Failure Event	For Example - House Address		
	Size Information	Service Connection Size		
	Failure Event Reported	Date		
		Time		
	Failure Event Pinpointed	Date		
		Time		
	Failure Event Contained/Valve-off/Repaired	Date		
		Time		
Additional Information for Reliable Leakage Component Analysis	Detailed Failure Event Information	Failure Event was reported/detected by:		
		Nature of failure		
		Piping Material at location of failure		
		Age of piping at location of failure		
		Average Pressure at Failure Location		
		Suspected cause of failure		
	Detailed Location Description for Failure	Street Address		
		Nearest House Number		
		GIS Coordinates (X)		
		GIS Coordinates (Y)		
	Additional Failure Event Information	Soil condition at location of failure		
		How was failure repaired?		
		Estimated Cost to repair failure (labor/materials/equipment/restoration of excavation and pavements)		
		Comments		
		Estimated Leak Flow Rate (using AWWA M36 recommended flow rates)		
		Estimated Leak Flow Rate (using utility specific estimations/measurements)		

Figure 7-6 WRF Project 4372a, *Leak Repair Data Collection Guide*—customer service connection failures data worksheet

Source: *WRF 2014b*

In the LCA Model, failures (breaks and leaks) are categorized into three broad types: failures that occur on the primary water main piping, failures on customer service connection piping, and failures on mains fittings or appurtenances attached to water mains, including fire hydrants, valves, and air valves or taps. The "Reported Failures" section of the model features a standardized calculation of the real loss volume (following Eq. 7-1) stemming from failure events reported to the utility. Reported failures are defined as events that are brought to the attention of the water utility by the general public or other parties as a result of either water showing on the ground surface or other visible places, generally as customer complaints, and often causing some level of disruption or damage.

An example of the calculation of the annual value of CRL for CWC is given in the "County Water Company—Part 1" sidebar.

Step 2. Quantify current unreported leakage (CURL). The annual volume of CURL can be assessed by summing the product of each unreported leak that was found through proactive leak detection per year by the flow rate of the leak (adjusted for pressure) and by the run time of each leak. The CURL is calculated using the same principles as used for calculating CRL, and the LCA Model performs this calculation. Since CWC did not undertake any proactive leak detection during 2013, the total volume of leakage stemming from CURL in this example for CWC is zero. Utilities with a proactive leak detection program would account for the annual volume of leakage abated via this program. The data can be entered into the LCA Model and the CURL calculated by the LCA Model.

Step 3. Estimate the unavoidable background leakage and target background leakage. This is done in two tasks that are explained as follows:

- Task 1: Calculate the unavoidable background leakage (UBL) for the system.

  Equation 7-2 calculates the UBL (Lambert 2009).

County Water Company—Part 1. Conducting a Leakage Component Analysis to Quantify Individual Leak Types and Evaluate Economic Intervention Frequency

From the water audit data shown in Figures 3-5 and 3-6 in chapter 3, County Water Company (CWC) was found to have current annual real losses (CARL) of 737 mil gal for the 2013 audit year. Its unavoidable annual real loss (UARL) calculates to be 83.7 mil gal. This represents the theoretical low level of leakage that could be achieved in the CWC distribution system if all possible leakage management technologies could be applied. The infrastructure leakage index (ILI) for CWC is calculated as 737/83.7 = 8.8.

Figure 7-1 shows that four means exist to reduce the annual volumes of reported, unreported, and background leakage in the CWC distribution system; with an ILI as high as 8.8, it is likely that reductions can be achieved using all four approaches. To assist in targeting priorities, CWC performed a leakage component analysis utilizing the LCA Model as follows.

Step 1. Quantify the current reported leakage (CRL): During the 2013 audit year, CWC encountered 182 reported failure (break/leak) events. These events were recorded by CWC's work order management system. Utilizing the LCA Model, the total volume of real losses stemming from reported failures (leaks and breaks) was calculated.

As shown in Figure 7-7 based on the work order management records, the reported failure events are summarized by mains size. In addition, the average awareness duration and duration for location and repair/shutoff of the failure are entered. The LCA Model then calculates the total volume of real losses stemming from CWC's reported failure events (the user also has the option to enter utility-specific leak flow rates, an option not shown in Figure 7-7). In CWC's case, reported mains failures were responsible for 12.01 MG (million gallons) of real losses in 2013.

In addition to the reported mains failures, CWC also had 102 reported failures on service connections. A total volume of 6.89 MG of real losses were caused by reported failures on service connections. Figure 7-8 provides the results as calculated by the LCA Model.

The total volume of CRL was 18.9 MG (12.01 MG + 6.89 MG) for CWC in 2013, which is a small fraction of the CARL volume of 737 MG as calculated by the annual water audit (see Figures 3-5 and 3-6).

$$\text{UBL (thous gal/d)} = [(0.20 * Lm) + (0.008 * Nc) + (0.34 * L_c)] \times (Pav/70)^{1.5} \quad (7\text{-}2)$$

Where:

Lm = total length of water mains (miles)

Nc = number of service connections (main to curb stop)

L_c = total length of private service connection piping owned by the customer, curb stop to customer meter (converted to miles) = Nc * Lp (see Figures 3-13 to 3-15)

Pav = average system pressure (psi)

Equation 7.2 is rigorous in quantifying a minimal level of background leakage that can fairly be said to be "unavoidable" in the context of the significant (and likely not cost-effective) efforts needed to reduce below this level. The example UBL calculation for CWC is shown in the "County Water Company—Part 2" sidebar. The UBL value is indicative of a well-maintained infrastructure, subject to intensive and efficient active leakage control. It further serves as a point of reference for calculating the target background leakage level, as discussed in the text that follows.

Mains by Size	Number of Leaks & Failures per Year	Length of Main	Failure Frequency	Average Failure Flow Rate @	Average Pressure	N1 (Leakage-Pressure Exponent) Value	Average Failure Duration			Average Annual Loss per Failure	Total Annual Loss
			(number / 100miles / yr)	70psi			Average Awareness Duration	Average Duration for Location and Repair/Shutoff Failure	Total Duration		
		miles		(gpm)	(psi)		(days)	(days)	(days)	(MG)	(MG)
Diameter 2"	1	-	-	13.90	65.0	0.50	1.00	1.00	2.00	0.04	0.04
Diameter 3"	-	-	-	13.90	65.0	0.50	-	-	-	-	-
Diameter 4"	34	-	-	44.00	65.0	0.50	1.00	2.00	3.00	0.18	6.23
Diameter 6"	39	-	-	92.00	65.0	0.50	0.50	0.50	1.00	0.13	4.98
Diameter 8"	5	-	-	92.00	65.0	0.50	0.50	0.50	1.00	0.13	0.64
Diameter 10"	1	-	-	92.00	65.0	0.50	0.50	0.50	1.00	0.13	0.13
Diameter 12"	-	-	-	222.00	65.0	0.50	-	-	-	-	-
Diameter 14"	-	-	-	222.00	65.0	0.50	-	-	-	-	-
Diameter 16"	-	-	-	222.00	65.0	0.50	-	-	-	-	-
Diameter 18"	-	-	-	222.00	65.0	0.50	-	-	-	-	-
Diameter 20"	-	-	-	222.00	65.0	0.50	-	-	-	-	-
Diameter 24"	-	-	-	222.00	65.0	0.50	-	-	-	-	-
Diameter 30"	-	-	-	222.00	65.0	0.50	-	-	-	-	-
Diameter 36"	-	-	-	222.00	65.0	0.50	-	-	-	-	-
Diameter 42"	-	-	-	222.00	65.0	0.50	-	-	-	-	-
Diameter 48"	-	-	-	222.00	65.0	0.50	-	-	-	-	-
Diameter 54"	-	-	-	222.00	65.0	0.50	-	-	-	-	-
Diameter 60"	-	-	-	222.00	65.0	0.50	-	-	-	-	-
Diameter >60"	-	-	-	222.00	65.0	0.50	-	-	-	-	-
Other Diameter			-	-	65.0	0.50	-	-	-	-	-
SUB-TOTAL REPORTED FAILURES ON MAINS											12.01

Figure 7-7 LCA Model: Leakage losses stemming from reported failures on primary water main piping in County Water Company

Service Connections by Size	Number of Failures per Year	Total Number of Service Connections	Failure Frequency	Average Failure Flow Rate @	Average Pressure	N1 (Leakage-Pressure Exponent) Value	Average Failure Duration			Average Annual Loss per Failure	Total Annual Loss
			Number of Failures per 1000 Service Connections	70psi			Average Awareness Duration	Average Duration for Location and Repair/Shutoff Failure	Total Duration		
				(gpm)	(psi)		(days)	(days)	(days)	(MG)	(MG)
Services < 1"	-	-	-	6.90	65.0	0.50	-	-	-	-	-
Services >= 1"	102	-	-	13.90	65.0	0.50	1.00	2.50	3.50	0.07	6.89
SUB-TOTAL REPORTED LEAKS ON SERVICE CONNECTIONS											6.89
GRAND TOTAL REPORTED FAILURES											18.90

Figure 7-8 LCA Model: Leakage losses stemming from reported failures on customer service connections in County Water Company

County Water Company—Part 2. Conducting a Leakage Component Analysis to Quantify Individual Leak Types and Evaluate Economic Intervention Frequency

For CWC, the UBL can be estimated by using established values for three distribution system components: leaks on water mains, service connection sections (utility responsibility), and service connection sections (customer responsibility). See Tables 3-20 and 3-21 for the derivation of these values. The standard values are set at 70 psi, so these values must be pressure corrected for CWC's pressure level of 65 psi. The N1 exponent is taken as 1.5, reflecting that leakage rates are somewhat more likely to increase with increasing pressure (variable path) than a fixed path with an N1 of 1.0. (See the "Water Pressure and Leakage" section in chapter 6.)

UBL (thous gal/d) = $[(0.20 * Lm) + (0.008 * Nc) + (0.34 * Lc)] * (Pav/70)^{1.5}$

$= [(0.2 * 256) + (0.008 * 12{,}196) + (0.34 * 41.6)] \times (65/70)^{1.5}$

$= [51.2 + 97.6 + 14.1] \times (0.93)^{1.5}$

= 162.9 × 0.893 = 145 (thous gal/d) or 53 mil gal/year

Note: Lc = [(12,196)(18)]/5,280 ft/mi = 41.6 mi

- Task 2: Calculate the target background leakage (TBL) by using a multiplier called the infrastructure condition factor (ICF).

  Not all infrastructure meets the assumed criteria for the UBL equation. Different systems have varying characteristics including age, makeup of pipe materials and fittings, and pressure variability. The ICF expresses the ratio of the TBL to the previously calculated UBL. The TBL is then defined as follows: TBL can be estimated by multiplying the calculated UBL by an ICF, where

$$\text{TBL (thous gal/d)} = \text{ICF} * \text{UBL} \qquad (7\text{-}3)$$

Where:

$$\text{ICF} = \text{TBL/UBL} \qquad (7\text{-}4)$$

that leads to Eq. 7-5 (substituting for UBL in Eq. 7-2):

$$\text{TBL (thous gal/d)} = \text{ICF} * [(0.20 * \text{Lm}) + (0.008 * \text{Nc}) + (0.34 * \text{Lc})] * (\text{Pav}/70)^{1.5} \qquad (7\text{-}5)$$

The ICF can be estimated or calculated in several ways. The methods below are listed in order of decreasing effort but also decreasing reliability.

- **ICF Method A:** Perform comprehensive leak detection and repair in discrete zones or DMAs representative of the system as a whole. Using minimum-hour leakage assessments, obtain a direct measurement of the background leakage (via the minimum-hour analysis method described later in this chapter in the “Zone or DMA Flow Measurement and Analysis to Quantify and Manage Leakage Volumes” section) immediately after a “find and fix” sweep of an active leak detection program. This value can be taken as the TBL, and the ICF will be the ratio of the TBL over the value of UBL calculated using Eq. 7-2. This method requires the greatest amount of work and can be employed only by utilities that employ extensive leakage management programs. It is typically used to refine earlier estimates of the ICF.
- **ICF Method B:** Perform a pressure step test. This can only be used for systems with rigid (metal) piping. In a zone or DMA supplied by a single main, when the minimum-hour (night) flow has stabilized, decrease the inlet pressure in several 30-minute steps by incrementally closing the inlet valve. Strive to obtain 3 to 4 “step” drops in pressure/flow without starving the zone’s demand to unsafe levels. The inflow data, together with pressures measured at the location representative of the average pressure occurring in the DMA, the average zone point (AZP), can be used to calculate the ICF.
- **ICF Method C:** Using sensitivity analysis, estimate the best case/worst case values of the ICF from LCA and use the average. The best case is to assume that an ICF of 1 is achievable in the short term (but this would only be realistic if the ILI was very low, less than 1.5). The worst case is to assume that after deducting the calculated reported and economic unreported leakage (EUL) volumes from the CARL, all of the remaining real losses are attributable to background leakage, and therefore the ICF needs to be calculated accordingly. The portion of unreported leakage in a water utility that can be cost-justified to identify and repair is known as the EUL level. At the early stage of setting short-run ELL targets, a “middle of the road” approach might be to calculate the two extreme values for ICF and to assume the average of these two values.

County Water Company—Part 3. Conducting a Leakage Component Analysis to Quantify Individual Leakage Types and Evaluate Economic Intervention Frequency

CWC does not have sufficient leakage repair data to use the more refined methods of estimating its infrastructure condition factor (ICF) to quantify background leakage, but recognizes the benefits of attempting a systematic approach to setting the ICF. CWC therefore uses ICF estimation Method D, taking the ICF to be approximately equal to the ILI when the target leakage levels have been achieved. In CWC's case, the target ILI is assumed to be **4.0** (midway in the range 3 to 5 discussed in the "County Water Company—Preliminary Leakage Loss Reduction Target-Setting Analysis" sidebar earlier in this chapter).

The LCA Model provides a method of calculating the target/current background leakage volume for any given utility. The user can choose to select an ICF value based on average infrastructure age or based on one of the four ICF estimation methods explained previously. CWC has selected an ICF based on Method D and has entered the ICF of 4 in the LCA Model entry field. The resulting total volume of background leakage for CWC is 210.34 MG as calculated by the tool (see Figure 7-9). It is important that CWC updates the ICF value as more leak detection and repair data becomes available and they are able to employ one of the more reliable ICF estimation methods.

County Water Company—Part 4. Conducting a Leakage Component Analysis to Quantify Individual Leakage Types and Evaluate Economic Intervention Frequency

Component Analysis Summary

The results of the leakage component analysis for CWC are summarized by the LCA Model in a worksheet as shown in Figure 7-10. Out of the total real loss volume of 736.50 MG as calculated by the annual water audit (see Figures 3-5 and 3-6) the leakage component analysis reveals that about 210 MG occurs as background leakage and about 19 MG occurs from reported failures. The leakage component analysis results indicate that about 507 MG are due to leaks/failures that are currently running undetected. This illustrates that, while reported leaks can be disruptive and garner much attention, overall they normally do not account for a major portion of the annual volume of real loss since they are quickly detected and repaired. Hidden, unreported leaks that are left to run continuously, and undetectable background leakage, often account for a major portion of the CARL in a water distribution system.

- **ICF Method D:** Assume the ICF will be equal to the ILI value when the target leakage levels have been achieved. However, if leakage varies widely across the entire distribution system, as is often the case in large systems, the system-wide average ILI may not be representative of the ILI in specific zones or DMAs where the specific ILI is much higher or lower than the average ILI (WRF 2007b). (See the "County Water Company—Parts 3 and 4" sidebars.)

Step 2: BACKGROUND LEAKAGE ON MAINS AND SERVICES

Instructions: The background leakage volume from mains and service connections will be automatically calculated after selecting one of the default Infrastructure Condition Factors (ICFs) based on infrastructure age or after a utility-specific ICF has been selected and entered in cell P43. The level of background leakage tends to increase with infrastructure age and is higher for systems with higher pressure. The volume of background losses is generally a significant component of the total real loss volume, at times up to 50% of the total volume of real losses. Overestimating (ICF used in model is too high) or underestimating (ICF used in model is too low) the background leakage volume might lead to a real loss control strategy that is not truly optimized. Selecting the ICF based on general age of the distribution network should only be seen as a starting point. It is strongly recommended that over time a utility-specific ICF is assessed and confirmed through field tests using one of the recommended approaches outlined in AWWA Manual M36.

						Pressure Corrected Calculation	
System Component	Units	Quantity	Component UARL Values (gal/unit/d/psi)	Infrastructure Condition Factor	Average Pressure (psi)	N1 (Leakage-Pressure Exponent) Value	Annual Volume (MG)
Mains	miles	256.3	2.87	4.0	65.0	1.5	67.25
Services—Main to Curb Stop	number	12,196	0.112	4.0	65.0	1.5	124.91
Services—Curb Stop to Meter	miles	41.6	4.78	4.0	65.0	1.5	18.17
					Total Background Leakage on Mains and Services		**210.34**

Select Infrastructure Condition Factor (ICF) based on age of distribution network

- ○ ICF 1 for System Age <50 years — 1.0
- ○ ICF 1.5 for System Age 50–70 years — 1.5
- ○ ICF 2.5 for System Age >70 years — 2.5

OR

- ◉ Enter ICF values assessed through implementing the approaches outlined in AWWA Manual M36 — 4.0

Figure 7-9 LCA Model: Background leakage volume calculation for County Water Company

SUMMARY: REAL LOSS COMPONENT ANALYSIS				
System Component	**Background Leakage (MG)**	**Reported Failures (MG)**	**Unreported Failures (MG)**	**Total (MG)**
Reservoirs	—	—	—	—
Mains and appurtenances	67.25	12.01	—	79.26
Service connections	143.09	6.89	—	149.98
Total annual real loss	210.34	18.90	—	229.24
Real losses as calculated by water audit				736.50
Hidden losses/unreported leakage currently running undetected				507.26

Figure 7-10 LCA Model: Component analysis summary for County Water Company

THE ECONOMICS OF LEAK DETECTION

In addition to knowing how leak detection works, it is important to assemble a cost-effective basis to define the size, schedule, and functions of the leak detection program. The costs to create an in-house leak detection program with staffing or to contract leak detection services are a worthwhile investment but should be planned carefully.

Most water loss financial models, including the ELL approach and the benefit–cost ratio approach (both topics discussed in this chapter), rely on the same assumptions regarding targeted leak detection work, or a leak detection *intervention*. These assumptions are listed below.

1. Each leak detection intervention work conducted during a cycle should abate all unreported leaks and bring the leakage down to the same level where only background leakage remains.
2. The leakage rate is assumed to increase at a constant rate between interventions as new, unreported leaks gradually emerge. This is the rate of rise (RR) of leakage.
3. The cost of a leak detection intervention is the same, regardless of the leakage level.
4. Shortening the leak detection interval between interventions means more leakage found and abated but more money spent on reducing that leakage. Lengthening the leak detection interval means less money spent on leak detection but more money spent treating and pumping water that ends up wasted as leakage. Designing a cost-effective program means finding the right balance of leakage reduction and savings from leakage abatement.

Economic Intervention Frequency for Proactive Leak Detection

Figure 7-1 shows active leakage control as one of the four pillars of intervention that water utility managers can exert to reduce current leakage levels. Active leakage control provides for proactive surveillance of unreported leaks, or those that are not visible from aboveground but that can be quantified by continuous flow monitoring in DMAs or detected through proactive leak detection techniques. These approaches are detailed in the "Zone or DMA Flow Measurement and Analysis to Quantify and Manage Leakage Volumes" and "Acoustic Leak Detection" sections, respectively. In North America, acoustic leak detection is carried out by many water utilities that schedule crews to perform periodic leak soundings (leak surveys or interventions) of water distribution system infrastructure to identify unreported leaks. However, the use of zone or DMA flow measurement is still a new concept to most North American water utilities, although it is employed by a number of progressive water utilities.

The work to create a methodology and equations to calculate the economic intervention frequency was carried out and published by Lambert et al. in several technical papers, including the paper by Lambert and Fantozzi (2005) titled "Recent Advances in Calculating Economic Intervention Frequency for Active Leakage Control, and Implications for Calculation of Economic Leakage Levels." This work is included in the following discussion.

A preliminary schedule for acoustic leak detection surveys or zone measurement, including an appropriate annual budget for active leakage control interventions, can be assessed using three parameters:

1. The variable cost of real losses, CV (in dollars per thousand gallons, or $/thous gal).
2. The cost of a leak detection survey intervention, CI (in dollars per mile of mains, excluding repair costs). Note that the repair costs are excluded to keep the economic assessment limited to the leak detection work only. Per Lambert et al. (1998), "the cost of repairing each leak—however large or small its flow rate—may not vary greatly if excavation is required." This point generally holds true for leakage in the unreported, or hidden, phase, not larger disruptive reported leaks or breaks. The protocol to keep leakage repair costs out of the leak detection economic assessment was established in the seminal report, *Managing Leakage—Report C: Setting Economic Leakage Targets*, one of the earliest treatments of leakage economics (UKWIR/WRc 1994). This does not mean that water utilities should ignore tracking of repair costs; it merely means that repair costs do not factor into the determination of the economic intervention frequency (EIF), which is the leak detection inspection interval that is economically optimal in searching for unreported leaks.
3. The average rate of rise (RR) of unreported leakage (thous gal/mi of mains/d/year). Note: These units are more fully interpreted as "thousand gallons per day, per mile of mains, per year."

If no leak detection and repair activities have been previously conducted, an approximate estimate of the RR can be calculated from the rise in real losses from annual water audits conducted over several years. If the utility has previously conducted leak detection and repair work, the RR can be assessed from the numbers and flow rates of unreported breaks and leaks found, divided by the time period between leak surveys.

The appropriate level of intervention to control unreported real losses (URL) can be evaluated in terms of determining the frequency at which leak surveys are economically effective. This is proportional to the square root of the cost of the leak survey (CI) and inversely proportional to the square root of the variable cost of real losses (CV)—the

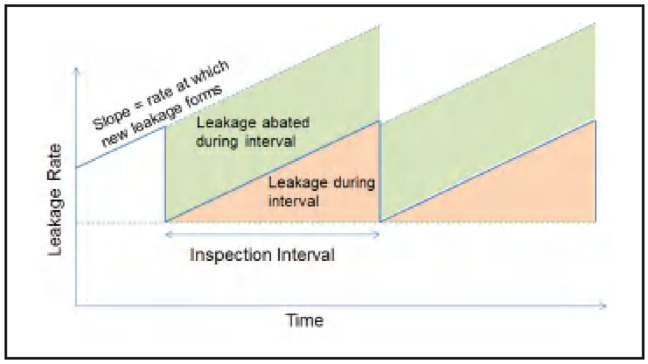


Figure 7-11 Rate of rise of leakage and changing leakage levels with an active leak detection program

higher the cost of water, the shorter the survey frequency. It is also inversely proportional to the square root of the rate of rise of unreported leakage from year to year (RR)—the more rapid the increase in unreported leakage between surveys, the shorter the EIF.

Changes in leakage due to leak detection interventions. It is important to recognize how leakage levels reduce due to successful leak detection interventions or, conversely, grow due to the lack of proactive leak detection. Rounds of leak detection work throughout a distribution system should produce a reduction in leakage according to the previously mentioned four assumptions and as illustrated in the schematic graphic of Figure 7-11. In this graphic, it is shown simplistically that, left unchecked, unreported leakage levels grow over time according to the RR represented by the diagonal slope of the sawtooth triangles in the graphic. Unreported leakage can be brought down to the background level of leakage after an effective leak detection survey, as shown by the vertical line of the sawtooth triangles in Figure 7-11.

Under this model, illustrated in Figure 7-11, there are two quantities of leakage volumes during the leak detection interval:

1. The water volume that occurs as *leakage during interval* due to the emergence of detectable leaks during each cycle. The volume of the *leakage during interval* is the area of the triangle in Figure 7-11 across the inspection interval, and can be calculated as ½ the base of the triangle multiplied by the height of the triangle:

   leakage during interval = ½ inspection interval × leakage eliminated (7-6)

2. The *leakage abated during interval* is the water volume that would have been lost due to detectable leaks during this cycle, had the leak detection work at the beginning of the cycle not occurred. This leakage volume is represented by the parallelogram in Figure 7-11. This volume of *leakage abated during interval* is in fact the amount of water that was recovered by this intervention, and is the area of the parallelogram, which can be calculated as the base times the height:

   leakage abated during interval = inspection interval × leakage eliminated (7-7)

This approach is a standard economic optimization. It recognizes that both water wasted due to leakage and money spent reducing leakage have cost impacts to the water utility and seeks to find the inspection interval that minimizes these costs. This approach actually calculates the financially optimal intervention interval, or leak detection cycle:

$$\text{costs per cycle} = \text{CI} + (\text{leakage during interval} \times \text{CV}) \tag{7-8}$$

$$\text{costs per cycle} = \text{CI}+ ((\tfrac{1}{2}\ \text{inspection interval} \times \text{leakage eliminated}) \times \text{CV}) \tag{7-9}$$

Since leakage is assumed to rise at a steady RR, the leakage eliminated can be calculated:

$$\text{leakage eliminated} = \text{inspection interval} \times \text{RR} \tag{7-10}$$

$$\text{costs per cycle} = \text{CI} +((\tfrac{1}{2}\ \text{inspection interval}^2 \times \text{RR}) \times \text{CV}) \tag{7-11}$$

The total costs of leakage and leak detection can then be expressed as an annual cost:

$$\text{costs per year} = \text{costs per cycle} / \text{inspection interval} \tag{7-12}$$

Although all of the calculations are not shown here, these equations can be expressed as costs per year (instead of per cycle) and then solved to calculate the inspection interval at which these total costs per year are minimized, which is the EIF. To make this equation usable in a practical manner, particular units need to be applied to each variable and a unit conversion coefficient applied. Using units typically applied in North America, this can be expressed mathematically as

$$\text{EIF (months)} = [0.789*(\text{CI}/\text{CV})/\text{RR}]^{0.5} \tag{7-13}$$

Where:

EIF = economic intervention frequency (measured in months)
CI = leak intervention costs (measured in \$/mi of mains surveyed for leakage)
CV = water value (measured in \$/thous gal)
RR = rate of rise (measured in thous gal/mi/d of mains/year)

A utility that runs leakage interventions at the EIF is spending the minimum possible sum of costs on leak detection and costs attributable to water wasted due to leakage. Running interventions less often than the EIF means that the utility is spending excessive money from water lost to leakage. Conversely, running interventions more often than the EIF means that the utility is spending more money than it can recoup in reduced leakage.

The economic percentage (EP%) of the system to be inspected annually (assuming a continuous program) is the inverse of the EIF:

$$\text{EP\% of system to be surveyed} = (100\% * 12)/\text{EIF} \tag{7-14}$$

The appropriate annual budget for intervention (ABI) is then the cost to survey the entire system for unreported leakage multiplied by the economic percentage of system to be surveyed:

$$\text{average ABI} = \text{cost of leak survey (CI)} * \text{EP\% of system to be surveyed} \tag{7-15}$$

The calculated economic unreported leakage (EUL) expressed in units of thousand gallons is the ratio of the annual budget for leak detection intervention to the variable cost in real losses:

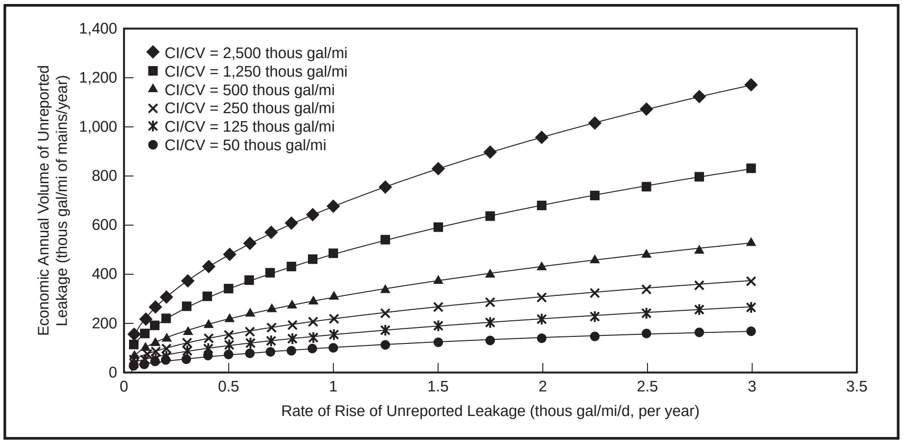


Figure 7-12 Economic unreported real losses for regular survey

Courtesy of Veritec Consulting Inc. and ILMSS Ltd.

CALCULATION OF ECONOMIC INTERVENTION FREQUENCY FOR PROACTIVE LEAK DETECTION			
	System Characteristics		
	Total Length of Mains	256.3	miles
	Number of Service Connections	12,196	
	Service Connection Density	47.6	conn./mile main
	Average System Pressure	65.0	PSI
	Water Balance Results		
TBL	Current Annual Background Leakage	210.34	MG/Yr
CRL	Real Losses from Current Reported Leakage	18.90	MG/Yr
UL	Unreported Failures Identified Through Existing Proactive Leak Detection Program	-	MG/Yr
	Hidden Failures/Unreported Failures not Identified or Captured by Current Leakage Management Policy	507.26	MG/Yr
CARL	Current Annual Real Losses	736.50	MG/Yr
UARL	Unavoidable Annual Real Losses	83.69	MG/Yr
	Infrastructure Leakage Index (ILI) [CARL/UARL]	8.8	
	Variable Cost of Real Losses		
CV	Variable Production cost (applied to Real Losses)	0.19	$/per kgal
		190.00	$/MG
CI	Cost of comprehensive leak detection survey (excluding leak repair cost)	250.00	$/per mile
		64,063	$/for entire system
RR	Average Rate of Rise of Unreported Leakage	0.78	kgal/mile of mains/day in a year
		0.20	MG/day in a year
	CI/CV	1316	kgal/mile
EIF	Economic Intervention Frequency [0.789 * (CI/CV)/RR] ^0.5	36	months
		1,109.7	days
	Economic Intervention Frequency - Average Leak Run Time	554.8	days
	Economic Percentage of System to be Surveyed per Year	33	%
ABI	Average Annual Budget for Intervention (Proactive Leak Detection)	21,072	$/year
EUL	Economic Unreported Real Losses	110,904	kgal/year
		111	MG/year
	Economic Infrastructure Leakage Index (ILI)	4	
PRL	Potentially Recoverable Leakage (CARL-CRL-EUL-TBL-UL)	396	MG/year

Figure 7-13 Economic intervention frequency for proactive leak detection

Source: *Water Research Foundation Project 4372a, Leakage Component Analysis Model*

$$\text{EUL} = \text{average annual budget for leak detection intervention/CV} \qquad (7\text{-}16)$$

Figure 7-12 shows the relationship between rate of rise of unreported leakage, RR (x-axis), the ratio CI/CV (curved lines), and the economic annual volume of unreported real losses, EUL (y-axis). To use this graph, the rate of rise (x-axis) should be estimated, CI/CV should be calculated to identify the appropriate curved line, and the EUL annual volume can be read on the y-axis. Similar graphs are available to predict the EIF, the EP% of

County Water Company—Part 5. Conducting a Leakage Component Analysis to Quantify Individual Leakage Types and Evaluate Economic Intervention Frequency

CWC calculated the economic intervention frequency (EIF) for active leak detection utilizing the LCA Model, which employs Eq. 7-13. The three parameters necessary to calculate the EIF for CWC (or any given system) are as follows:

1. The variable cost of real losses, CV (in dollars per thousand gallons, or $/thous gal).

CV = $0.19/kgal

2. The cost of a leak detection survey intervention, CI ($/mi of mains, excluding repair costs). The current cost for the leakage survey—conducted once every five years—is $64,000, which translates to a cost of $250 per mile of mains.)

CI = $250/mi of mains

3. The average rate of rise (RR) of unreported leakage (thous gal/mi of mains/d/year). CWC does not operate an ongoing active leakage control program; instead it hires a leak detection contractor to survey the entire water distribution system for leakage once every five years. Between leak surveys, CWC responds reactively to reported leaks and breaks as they are called in. The unreported leaks and breaks that are typically found during the interventions every five years total around 1 mgd. The average flow rate of unreported leaks locatable by survey in the five-year period is taken as one half this five-year finding, which is 0.5 mgd or 183 mil gal/year. The economic intervention equations 7-13 to 7-16 can now be used to check if the frequency of the five-year survey and repair interventions are economic and to calculate the economic intervention parameters for this type of survey. The implied average RR of 0.2 mgd each year is 200,000/256 mi = 0.78 thous gal/mi of mains/d/year.

RR = 0.78 thous gal/mi of mains/d/year

The results (see Figure 7-13) indicate that the economic frequency of leak survey and repair intervention should include 33% of the system each year. This will require three years to complete the entire system instead of the five-year interval currently used by CWC. It would be preferable to increase the active leakage control annual budget (excluding repair costs) from an equivalent of $12,800 per year ($64,000/5) to $21,072 per year, and target around one third of the system to be checked each year.

The economic intervention equations clearly demonstrate that, as variable cost of water increases, the EIF and the economic unreported leakage volume will decrease, indicating that more frequent leak survey and repair interventions are justified. Likewise, if the annual budget for intervention and economic percentage both increase, the average run time of unreported leaks and breaks reduces and the total volume of real losses for the year decreases.

system to be surveyed each year, and the ABI (Lambert and Lalonde 2005). Alternatively, the LCA Model can be used to determine these parameters, and this output of the model is shown in Figure 7-13. The calculations for the example of CWC are shown in the "County Water Company—Part 5" sidebar.

Finally, an equation for potentially recoverable leakage (PRL) is given below:

$$PRL = CARL - CRL - EUL - TBL \tag{7-17}$$

This equation is employed in the "County Water Company—Part 6" sidebar for the example of CWC. Options for consideration in creating a comprehensive leakage management plan for CWC are also discussed in the sidebar.

Equations 7-13 through 7-16 are used to give a quick estimate of the four parameters for economic intervention (EIF, EP%, ABI, and EUL) and these equations are built into the LCA Model, which can easily calculate these parameters. This approach can also be used to identify whether the current annual budget and frequency of leak surveys are appropriate.

The Benefit–Cost Ratio Approach

Another approach often applied to leakage economics is the ratio of benefits to costs, where the benefits are the leakage avoided due to the program, and the costs are the leak detection program costs. Although this approach appears to have advantages of greater simplicity in use, it also has certain limitations that the user should understand before applying its results. These cost and benefit parameters can be described according to the following equations:

$$\text{costs per cycle} = \text{leak intervention costs} \tag{7-18}$$

$$\text{benefits per cycle} = \text{leakage abated during interval} \times \text{water value} \tag{7-19}$$

It is important to ensure that the leakage abated during interval (which is the water that would have been lost had the intervention not taken place, see Figure 7-11) be used as the benefit and not the leakage during interval, or the leakage that emerges after the leakage detection work. This is an easy error to make, as both can be referred to as "water lost"; however, one is actually a cost (leakage during interval), and the other (leakage abated during interval) is a benefit.

$$\text{benefits per cycle} = \text{inspection interval} \times \text{leakage abated during interval} \times \text{water value} \tag{7-20}$$

The benefit-to-cost ratio is calculated as

$$\text{benefits/costs} = (\text{inspection interval} \times \text{leakage abated during interval} \times \text{water value}) / \text{leak intervention costs} \tag{7-21}$$

A word of caution is needed when considering use of the benefit–cost ratio. Benefit–cost ratios are useful in confirming that the benefits of a program at least match the costs. They cannot, however, be used to define the ideal program. Benefit-to-cost ratios will always be increased by lengthening the inspection interval, but a higher benefit–cost ratio doesn't necessarily maximize net benefits.

Consider the utility having two options:

A. Spending \$10,000/year to yield a \$50,000/year savings (a 5:1 benefit–cost ratio).

B. Spending \$25,000/year to yield a \$100,000/year savings (a 4:1 benefit–cost ratio).

The utility would see a better benefit–cost ratio under option A (5:1 vs. 4:1), but option B will yield a larger net benefit to the water utility (\$75,000 vs. \$40,000).

The approach to calculating the EIF, as detailed in this section, alternatively yields the intervention frequency (and associated leakage level) that yields the maximum net benefit to the utility.

County Water Company—Part 6. Conducting a Leakage Component Analysis to Quantify Individual Leakage Types and Evaluate Economic Intervention Frequency

Based on the results of the leakage component analysis and calculation of economic intervention frequency (EIF), CWC estimates that around 396 mil gal of real losses could be potentially recovered by proactively surveying about one third of the system every year.

Currently, CWC's leakage management practices are largely reactive and focus almost entirely on reported leaks and main breaks. However, the initial component analysis shown in the "County Water Company—Part 1" sidebar finds that the current reported leakage (CRL) is only 18.9 mil gal/year, which is just 2.6 percent of the current annual real losses (CARL) of 737 mil gal. With the current schedule of active leakage control surveys only once every five years, the unreported leakage is around 183 mil gal/year, but the EIF analysis shows this should be reduced to around 111 mil gal/year, if the leakage survey frequency was increased to approximately once every three years. The analysis estimates target background leakage (TBL) (assuming an infrastructure condition factor, ICF, of 4) as 210 mil gal or around 28 percent of the CARL. This leaves 396 mil gal/year as the first estimate of potentially recoverable leakage (PRL), or about 54 percent of the CARL.

The economic intervention analysis shows that more frequent leak surveys are justified. However, provision for flow monitoring in discrete zones or district metered areas would improve the targeting of areas for active leakage control interventions. Continuous flow monitoring in discrete zones, as detailed in the next section, can shorten the awareness time for unreported leaks and reduce the annual losses from unreported leakage. A more structured and continual active leakage control program will enable CWC to reduce and sustain an economically lower level of leakage. Many good active leakage control options exist for CWC to evaluate.

The significant quantities of background leakage and PRL suggest that CWC could also benefit from optimization of distribution system pressures, which will reduce flow rates of all existing leaks, in addition to reducing the frequency of new leaks, rate of rise of unreported leakage, and repair costs. A number of pressure management improvements are relatively inexpensive and can be feasibly implemented on a short-term basis. Other techniques require the installation of pressure-reducing valves and are considered medium- to long-term improvements. Upgrading the distribution system via replacement or rehabilitation will also reduce background leakage. This option, however, requires the longest time frame to implement. It is also the most costly option and therefore should ideally be pursued when water distribution piping assets have reached the end of their useful services lives.

FLOW MEASUREMENT AND ANALYSIS TO QUANTIFY AND MANAGE LEAKAGE

The most accurate means to quantify the individual components of leakage in a water distribution system is to obtain detailed measurements of water flow and pressure. This is also the most resource intensive (costly) of the three methods, because it requires that areas of the distribution system be isolated by closing valves and installing flowmeters on one or more water mains supplying the DMA.

Monitoring flows in discrete areas or zones of the water distribution system offers several advantages to the water utility in optimizing its water supply efficiency. To best present the principles for design and operation of DMAs, guidelines from the publication *A Manual of DMA Practice* (UKWIR 1999) are discussed below with some changes to take into account the distribution system characteristics prevalent in North America.

Sectorizing parts or all of the water distribution system can provide many advantages in controlling water losses, managing pressure, and sustaining distribution infrastructure. However, each zone or DMA must be carefully engineered to serve its purpose while providing reliable water supply for all customer uses. A variety of factors need to be considered in the design. For example, distribution systems that exist in a grid and those with water storage tanks may present challenges when designing an effective DMA. Careful planning is required to avoid unintended consequences, such as supply restriction or adverse water quality effects. Still, thousands of distinct zones and DMAs have been successfully implemented in many countries, helping to provide highly efficient water service.

Principles of DMA operations. Many water utilities segment their water distribution systems into numerous distinct pressure zones to balance supply needs with optimized pumping configurations. This is particularly true in hilly or mountainous terrain where elevation varies widely, or in less populated, widespread areas where separate populated areas result in discrete pumping systems. The primary concept and advantage of DMA monitoring is to isolate and monitor a small area of the distribution system with supply flows into the DMA of sufficient scale so that flows can be analyzed to distinguish components of normal consumption from leakage rates. Although flow monitoring in DMAs does not provide the ability to pinpoint individual leaks, it gives the important capability of obtaining a quantity of the collective leakage occurring within the DMA, and it allows the measure of background leakage to be distinguished from unreported leaks. Well-managed DMAs also serve as early warning systems of newly rising leakage and can alert the operator when to optimally schedule leak detection interventions.

The technique of flow measurement to infer leakage volumes requires metering and tracking of flows that supply sections of the water distribution system. The design of such a leakage monitoring system for active leakage control has two goals:

1. to divide the distribution network into a number of zones or DMAs, each with a defined and permanent boundary, and appropriately sized so that flows can be regularly monitored, so that the level of normal consumption can be segregated to quantify the flow rate of unreported leakage by analyzing flow patterns during minimum consumption periods of the day; and
2. to manage pressure in each district or group of districts so that the network is operated at the optimum level of pressure, thus inhibiting the rise of new leaks and minimizing pressure transients that cause ruptures, while potentially reducing background leakage. These areas are referred to as pressure managed areas (PMAs).

Therefore, it follows that a leakage monitoring system will comprise a number of districts where flow is measured by permanently installed flowmeters. In some cases, the flowmeter installation will also be accompanied with a pressure-reducing valve (PRV) in series on the supply main. Depending on the characteristics of the water distribution system, a DMA will be

- supplied via a single supply main or multiple feeds;
- a discrete area (i.e., no flow into adjacent DMA);
- an area that cascades into an adjacent DMA; and
- a DMA with multiple feeds to provide emergency supply but secondary feeds are generally not open except in extraordinary circumstances.

DMAs enable a water utility to quantify the current level of leakage in a discrete area and to consequently prioritize its leak detection activities, sending leak detection crews into those DMAs when leakage rates rise appreciably, and deferring crew action as long as leakage rates remain contained. By regularly monitoring DMA inflows into a well-managed zone, the operator can identify the occurrence of new leaks and breaks by the rise in flow during the minimum hours of consumption. This information enables a utility to intervene and repair the leaks once the action level of leakage is reached and avoid expending leak detection crew time when the presence of excessive leakage is not indicated.

DMA planning considerations. Many factors should be considered when planning a DMA, including the following:

- *The target volume and cost of leakage to be reduced.* Does the preliminary target or economic level of leakage calculation indicate that a sufficient return on recovered leakage will exist to justify the expense to establish the DMA? Preliminary measurements can be gathered using temporarily installed flowmeters to determine which areas indicate high leakage levels. A pilot DMA employing permanent metering can be implemented at reasonable cost to give a better indication of the feasibility of using DMAs on a wider scale across the distribution system.
- *Size, by geographical area and number of customer service connections.* The DMA size is typically expressed in number of customer service connections. The size of a typical DMA in urban areas varies between 500 and 3,000 connections (WRc 1994).

The size of an individual DMA will vary, depending on several local factors and system characteristics, such as

- the estimated level of economic leakage reduction in the region of the system;
- geographic/demographic factors (e.g., urban, rural, or industrial areas);
- a previous leakage control technique (e.g., former flow measurement areas);
- individual water utility preference (e.g., identifying customer service connection leaks, ease of leak survey deployment);
- hydraulic conditions (e.g., limitations in closing valves, low pressures, local standards of service);
- minimum flow and pressure, as well as fire flow requirements; and
- the ability to maintain adequate water quality when employing additional closed valves.

DMAs in dense urban areas (e.g., inner cities) may be larger than 3,000 connections because of high housing density. The number of DMA connections may vary in rural areas, as rural DMAs may consist of a small population center or may encompass a cluster of centers (small number of connections but large geographical areas). If a DMA is larger than 3,000 connections, it becomes difficult to distinguish small leaks (e.g., service connection pipe leaks) from minimum-consumption-hour flow data, and location takes longer, therefore the DMA is less effective.

As a general guideline, DMAs can be grouped according to size in three categories:

1. Small: <1,000 connections
2. Medium: 1,000–3,000 connections
3. Large: 3,000–5,000 connections

Ultimately the configuration of the distribution system will play the largest role in determining the size of the DMA, based on factors including the following:

- Type of consumers (industrial, multifamily, single family, commercial, etc.)
- Variation in ground level
- Targeted final leakage level
- Minimum flow and pressure requirements for fire flow, insurance, and meeting levels of service
- Looping and redundancy considerations of the piping grid
- Hydraulic considerations. The location of service connections serving large or special-needs customers—buildings such as hospitals, schools, etc.—should be examined for special hydraulic considerations. If the proposed DMA includes several large and sensitive customers, special attention should be given when selecting the inflow location. If it is not possible to meet flow and pressure requirements when supplying through only one inflow, it is necessary to identify a second metered inflow water main into the configuration of the DMA.
- Water quality considerations. Creating a DMA involves closing valves to form a boundary. This creates more dead ends than would normally be found in a fully open system. Consequently, the potential for water quality degradation from flow disturbance (initially) and stagnation (eventually) may occur. The greater the number of closed valves in a DMA, the greater the care that should be exerted in designing water quality safeguards. Conversely, the creation of a DMA allows the water utility to focus more specifically on the management of valves, fire hydrants, pressure levels, and water quality than in a typical open system. Water utilities are often hard-pressed to actively manage system valves, and many valves are overlooked for maintenance, hence failing to operate in times of emergency such as water main breaks. Good valve exercising and management practices can be incorporated into DMA efforts to provide proactive management of these often neglected assets. Water utilities operating multiple DMAs often have better valve management than those not employing DMAs. Water quality sampling and assessment should be conducted during the planning and implementation phases of the DMA, as well as routinely during the DMA operation. This will give the utility operator the opportunity to proactively build any needed water quality controls into the design of the DMA. Good water quality can be maintained by properly configuring the boundary or performing periodic flushing.

The planning phase aims to configure desired portions of the distribution system into suitably sized DMAs. Initially, small-scale distribution mains maps should be used to outline provisional DMA boundaries using local knowledge of the distribution grid and hydraulic data (pressure and flow) to obtain the desired flow monitoring capability and to identify potential trouble spots to be managed in the DMA design. Calibrated hydraulic models can be used to simulate prospective DMAs and verify that pressures will be adequate during peak and emergency conditions.

DMA design considerations. Many North American utilities have basic pressure control zones established. This is the fundamental level of good pressure management. Some of these existing pressure zones, particularly in small, rural utilities, may be sized appropriately to serve as a DMA, and only metering need be established. Other larger pressure zones might be segmented into several separate DMAs, so new boundaries need to be established by closing valves. It is fortuitous for the operator to assess existing boundary valves in pressure zones and adapt them into the DMA design scheme where possible. Several DMA design considerations should be reviewed, including the following:

- In general, a boundary should be plotted to fit the broad design DMA objective but also to cross as few mains as possible, following the "line of least resistance" by using natural geographic and hydraulic boundaries, such as park land, railroads, or existing pressure zone boundaries. This minimizes the cost of installation, operation, and maintenance.
- In larger systems, DMAs are typically established in a small region of the local distribution grid, and, to the extent possible, transmission mains and larger distribution mains should be excluded from the DMA to avoid costly meter installations and, more importantly, to improve the accuracy of flow information. Likewise, transmission mains supplying water tanks should be avoided in larger systems because additional balancing of flows noting the effect of changing storage volumes must be conducted, and the fill/drain cycle of tank operations must be unhindered.
- Where the DMA boundary crosses a water main, a valve is closed or a meter is installed so that all flow at the boundary crossing, either into the DMA or into an adjacent DMA, is continuously monitored. Most DMAs use one or two meters, with all other main crossings employing closed valves.
- The DMA boundary should be configured so that existing valves designated to be closed and serve as boundary valves are located on smaller mains. This will help to avoid the creation of dead ends.
- A closed PRV or check valve can be configured as a boundary valve in place of a closed gate valve, and a PRV can be set to open during periods of low pressure in the DMA. During emergencies such as a large water main break or a heavy fire flow drawn from fire hydrants, low pressures may occur in the DMA. This standby feed senses the low pressure and automatically opens, thus serving as an automatic emergency supply main.
- Potential locations of unacceptably low pressure or flow should be identified during the preliminary design phase and design adjustments made when the potential for reduced service is identified. If a hydraulic model exists, it may be used to identify potential problems in advance of DMA construction.
- Once the general configuration is determined, a series of initial or baseline measurements and data collection should be undertaken to document system conditions prior to any modifications. These activities should include collecting pressure data at key and critical locations in the new DMA area. Pressure data loggers can be attached to fire hydrants to obtain 24-hour profiles. Water quality samples should be gathered and analyzed to determine the water quality status prior to the implementation of the DMA. Maintenance and customer complaint histories should be reviewed to assemble the history of water main breaks and leaks, valve and fire hydrant problems, low pressure or water quality complaints, and any other pertinent conditions in the proposed DMA. It is essential in judging the ultimate success of the DMA that good baseline data be collected and ultimately used for comparison of system performance once the DMA is established.
- To be economically justified, the water utility should carefully tabulate the costs of all efforts associated with the DMA. Only with representative cost data can an accurate economic analysis be conducted.

Where a large proportion of the flow entering a DMA passes out again to other parts of the system, the accuracy of the flow measurements may be inferior to those of a discrete DMA. This is because changes in inflow and outflow could imply large changes in DMA demand and in fact could be solely caused by compounded metering inaccuracies.

Analysis of DMA data relies on observation of minimum consumption-hour conditions. During the minimum consumption period when legitimate demand is at a minimum, the proportion of leakage to total inflow is at its greatest. Legitimate customer consumption during the minimum consumption hours should be measured or estimated. Advanced metering infrastructure (AMI) systems give the capability of gathering continuous detailed customer consumption data at short time intervals. Subtracting customer consumption from the total inflow gives a reliable estimate of the leakage in the DMA. For many areas, minimum consumption and flow conditions occur during nighttime hours; however, this may not be the case if the DMA includes large, continuous consumers, such as industrial plants, or if the DMA includes customer irrigation systems operating during nighttime hours in warm weather seasons.

An exact count of customer service connections is not necessary at the design stage, as long as the relative size guideline of 500 to 3,000 connections is met. An accurate count of properties is essential later when the system is operated to calculate minimum-hour consumption and quantify leakage. If a water distribution system hydraulic model exists, the number of properties may already be known. If not, the best source of property information is from a geographic information system (GIS), public online mapping, billing records, postal-code information, municipal parcels, or a street-by-street survey.

Sizing and locating the DMA meters. Once the general boundary configuration is determined, the operator should identify an appropriate location on the appropriate inflow water main. Flow and pressure measurements can be gathered by using instruments installed on a temporary basis. Temporary metering can be provided by installing an insertion flowmeter, or the inflow main can be excavated to apply a clamp-on ultrasonic meter. Once the temporary metering device is installed, the boundary valves should be closed and flow and pressure measured in the DMA for at least one 24-hour period. Obtaining flow and pressure measurements provides useful information about the maximum and minimum flow ranges occurring in the DMA and enables the designer to make accurate predictions about the absolute maximum and minimum flow ranges that are expected. These flow ranges lead the designer to the optimum size of the inflow piping, meter, and bypass piping (if this arrangement is used to provide two supply flow ranges: routine and emergency demand). A large-scale plan (1:400 or 1:1,000) should be used for site selection, so that details of the line of the inflow supply main and the position of valves, bends, connections, and obstructions can be clearly seen. Valves and bends can cause inaccuracies to the flow readings from some meters. It is important to site such meters on a straight length of main, as free as possible from obstructions, such as bends or butterfly valves in the pipeline. It is recommended to follow manufacturer guidelines in spacing meters between upstream and/or downstream obstructions, typically quoting the distance in terms of several pipe diameters. Meter data can be data-logged in the meter chamber and periodically collected locally, or it may be continuously transmitted to a central supervisory control and data acquisition (SCADA) system. Once the preliminary flow and pressure measurements are complete, the location of the permanent supply inflow meter should be confirmed. It is best to site this meter in a chamber to allow workable access; however, in some cases, congestion of utility infrastructure will cause a site to be unworkable and require either the meter location to be moved, or in extreme cases, the boundary to be redesigned. In the latter case, it will be necessary to return to the DMA planning stage.

The designer should identify the location of the critical point (CP), which is the location of lowest pressure in the DMA. Similarly, the average zone point (AZP), or the location most representative of the average pressure across the DMA—should be determined based on sampling of static pressure levels from fire hydrants or from the hydraulic model. The CP is significant in the DMA design process because supply infrastructure is usually sized to provide a minimal level of pressure and flow at the CP under emergency conditions. The AZP is an important reference value for the DMA. The AZP should be chosen on a pipeline in the mid-region of the zone, not near the perimeter. It should not be located on the smallest sized piping, or the largest piping, if possible. The selected location should have an average pressure that is close to the average pressure in the DMA. The "Determining Average Operating Pressure" sidebar, Tables 3-20 and 3-21, and Figure 3-16 in chapter 3 provide a method for calculating the average pressure in a portion of a distribution system that could be a DMA. Data on system operating pressures and hydraulic gradients under varying demand conditions (diurnal, seasonal) are needed to anticipate the effects of distribution system capacity for fire-fighting flows and normal service in areas of higher elevation. Pressure data are often collected at the CP and AZP, and these locations are monitored closely as the DMA is implemented and initially calibrated. Access to an appropriately calibrated computer hydraulic model of the proposed DMA and adjacent areas is helpful for this purpose.

Consider system changes required for DMA installation, like the number of new valves required, installation of flowmeters, PRVs, chambers, and so forth. The configuration of the distribution network pump system and location of pumping stations and water tanks need to be carefully assessed and included in the planning stage. When selecting the meter locations, it is necessary to size the primary inflow main to accurately measure the routine daily flows, not peak flows from fire-fighting demands, main breaks, and so on. Oversized flowmeters may experience low-velocity flows that fall below the accuracy limits of the flowmeter. Accurate measurement of the minimum period flow into the zone is crucial information for DMA monitoring and analysis. To provide the capability to supply flows for peak needs, the routine feed can be configured on smaller bypass piping around a larger supply main. A check valve or PRV on the larger supply can be triggered to open to provide high flows during an emergency event. Such an arrangement is schematically shown in Figure 7-14.

The feasibility of providing electric power supply at the meter location needs to be assessed and taken into consideration at the planning stage. If power is not available, battery-powered flowmeters and related equipment can be specified. The depth of mains, pipe material, age, and pipe condition need to be assessed at the potential meter location. It is also necessary to assess accessibility, traffic conditions, need for special permits, or environmental impacts to perform construction work. Conflicts with other utilities (electricity, telecommunications, etc.) should be identified and addressed in the design phase.

Constructing the DMA. To isolate the DMA, it is necessary to inspect all boundary valves and ensure that they are functional and provide a watertight closure. Defective valves, or those that "pass" water should be repaired or replaced, or the boundary of the DMA moved to the next nearest operational valve. The operator should install pressure loggers at the CP and AZP and collect data for several days before closing the boundary valves. Pressure loggers should also be installed near critical customers in the DMA. Comparing the data with the pressure values recorded after the DMA is isolated gives a profile of pressure changes to be encountered in operating the DMA and helps to identify problem locations. If an unacceptable pressure reduction occurs in operating the DMA, it may be necessary to revise the DMA design to provide sufficient pressure within the DMA.

Once boundary valves are closed, a pressure drop test should be conducted to ensure that the DMA is hydraulically tight. During this test, the pressure is dropped within the DMA in various steps by operating the valve controlling the inflow to the provisional DMA. To avoid a disruption of service, such tests can be conducted during the minimum consumption period. The minimum consumption period occurs during 1 a.m. and 4 a.m. in many communities. However, the growing use of irrigation systems operating at night by timer control means that the minimum consumption may not always occur during the nighttime hours. This period needs to be adjusted to take into account local differences in demand patterns. The pressure reductions should be in the range of 10–15 psi down to the

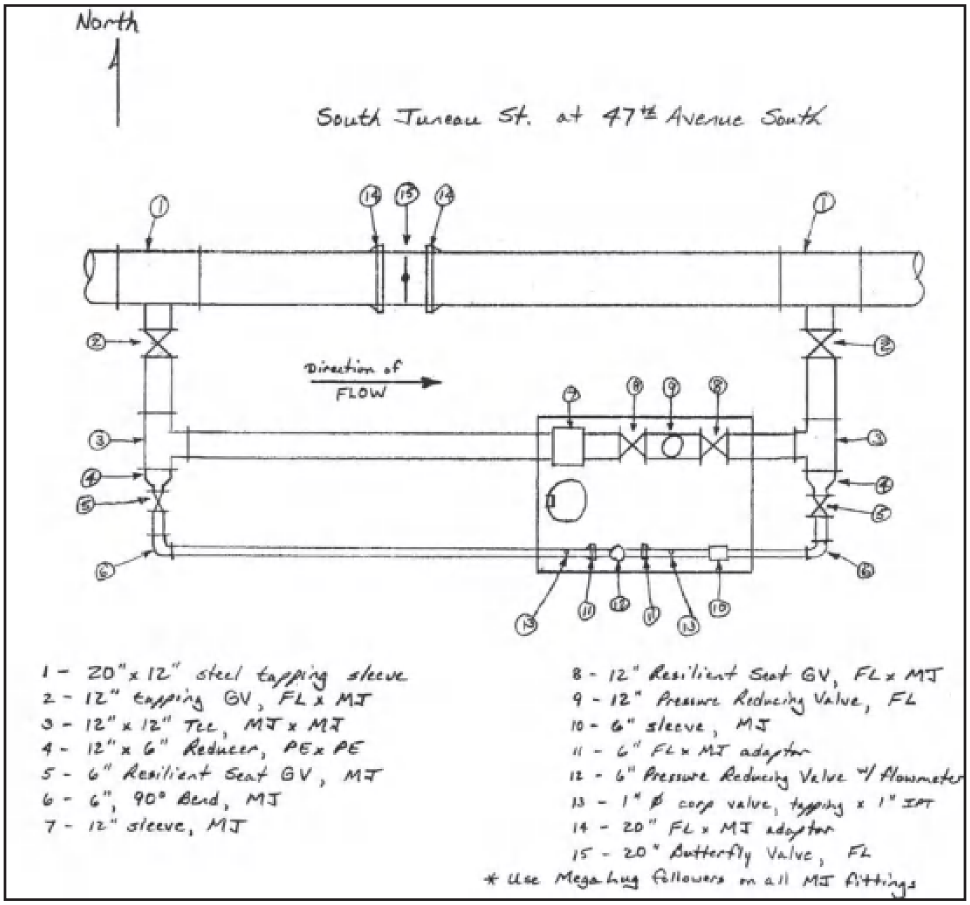


Figure 7-14 Preliminary design sketch for pressure management PRV chamber with bypass

Courtesy of Seattle Public Utilities

pressure where the minimum required pressure at the critical zone pressure point is set. To monitor whether or not the DMA is hydraulically discrete, several pressure loggers can be installed outside the DMA boundaries prior to the test. These boundary loggers will record changes in pressure related to pressure drops created within the DMA in case one or more valves are passing and the DMA is not hydraulically discrete. During the pressure drop test, pressure inside the DMA should drop as the supply is reduced. Pressures should not drop so low that service is disrupted, however, and the test should be completed within 30–45 minutes to limit the period of low pressure. If the inflow supply is reduced and the DMA pressure fails to drop, it is likely that one or more boundary valves are open or not holding tightly and are allowing flow from the neighboring grid to pass into the DMA. Again, these valves must be repaired or replaced, and the DMA confirmed to be hydraulically tight, before continuing with the DMA work.

After determining that the DMA boundary is hydraulically intact, the operator should confirm that the DMA supply can meet peak demands. High flow conditions can be created by opening a boundary valve to a neighboring lower pressure zone or DMA, thereby creating an additional flow demand through the subject DMA. Alternatively, one or more fire hydrants can be opened to simulate fire-fighting conditions. The utility should log or monitor pressures at the CP and sensitive customer locations during such testing. If the pressure drops incurred during the peak flow conditions are unacceptable, the DMA design should be revised with one or more additional inflow mains created to adequately supply peak-level flows. After the successful completion of these initial tests, the total inflow to the DMA has to be monitored over several days under normal operation. The inflow data is needed to determine the selection of an appropriate flowmeter.

DMA flow data analysis. DMA leakage trends can be identified by analyzing DMA flow patterns. In most water distribution systems, flow follows a repetitive diurnal pattern, peaking at certain times of day and minimizing at other times. During periods of relatively consistent customer consumption and leakage, a repetitive, characteristic pattern can be discerned. As leakage rates rise, an increase in the minimum-hour flow conditions can be observed. A gradual rise in minimum-hour flows over periods of days or weeks gives a good indication that new leaks have developed. A target level of minimum-hour consumption can be established. When minimum-hour flows reach or exceed this level, leak detection personnel should be sent into the DMA to survey the grid to pinpoint leaks and arrange for repairs.

Step tests. The term *step test* has been used to describe two types of testing techniques that can be conducted in the zonal or DMA structure. Each test method employs an incremental reduction, in a step fashion, in either the water supply to a DMA or the scale of the DMA by sectioning it to a smaller size by closing valves within the DMA. While the term *step test* is used for either test, these methods serve different purposes and each has considerations in use.

- **Pressure step tests to quantify background leakage.** This test is conducted by reducing the supply to the DMA by incrementally throttling the closure of a valve or PRV on the sole supply main to the DMA in a similar manner to the pressure drop test described earlier in the "Constructing the DMA" subsection. Three or four incremental reductions in supply should be conducted with gaps of at least 15 minutes between step reductions. Pressure should be reduced approximately 10–15 psi (or as much as can be tolerated) in predetermined steps for each increment. Flow and pressure should be recorded at the start of the test and at each reduction. The profile of the graph created by this test follows the shape of steps. The reduction in flow into the DMA relative to the drop in pressure is characteristic of the relation of background leakage to unreported leakage in the DMA. However, this test is valid for fully metallic piping systems where leak detection and repair has been conducted to eliminate unreported leakage.

  Pressure must be measured at the AZP during this test. A plot of the data can be used to determine the ratio of background leakage to unreported leakage. In this way, the pressure step test is an important tool in setting the leakage management strategy because the amount of background leakage influences the degree to which pressure management should be employed. Pressure step tests often must be conducted at night or during other low-water-demand periods, because these tests require working pressures to be lowered notably such that customer service may be disrupted for approximately 1 hour. The pressure step test is a more rigorous version of the pressure drop test described earlier in the "Constructing the DMA" subsection.
- **Flow step tests to localize leakage.** This technique attempts to identify a region of a DMA where leakage is occurring. If leakage is suspected as a result of high minimum-hour flows, this method isolates the leakage by segmenting the DMA in a step fashion. Valves inside the DMA can be used to create a new temporary boundary that shrinks the DMA or zone by one quarter or one third of its size. If the flow drops notably by more than the reduction of the zone size, it can be surmised that the majority of the leakage exists in the area that was isolated from the DMA.

> In North America, this test was often applied in temporary DMAs, or Pitometer districts, named after the company that, in the early 1900s, pioneered the use of commercial Pitot rod flow measurements. This test can be successful in narrowing the region in which leakage is occurring and is relatively straightforward to conduct in the DMA structure. However, flow step tests can be subject to an inherent flaw in that pressure also changes when the zone reduction is implemented. Without adjusting for the pressure change, the test might give misleading results. DMAs are useful in large part because flow and pressure patterns can be observed for seasonal variations and other supply fluctuations. A zone with high background leakage will be very sensitive to pressure changes, and higher pressures from the zone reductions may cause the leakage rates to change in the area being reduced. Often pressures rise as the DMA is further reduced in size, giving the indication that the majority of leakage is located in the segment closest to the supply main.
>
> Caution should be taken in conducting a flow step test by monitoring pressure at the supply point and other points in the DMA to see that undue pressure changes are not occurring, which could make the test results unreliable.

A major advantage of DMA technology is the ability to closely monitor a discrete, manageable area of the distribution system. By gathering data from the DMA on a continuous basis, the operator gains, over time, a solid understanding of the hydraulic performance of the zone. Deviations from normal flow patterns—caused by leakage, main breaks, fire flows, and so on—stand out and provide the operator with the capability to respond strategically to an event.

DMA summary. Installing DMAs requires careful design and planning to establish a proactive mechanism to monitor flows and infer leakage rates. DMAs provide the capability for routine monitoring of flows and leakages rates, and serve as an alert to the water utility to launch leak detection surveys when leakage volumes rise above an economic threshold. This improves the traditional means of scheduling leak surveys based on fixed time intervals. By applying pressure management controls in the DMA, the rate of rise of new leaks can be slowed and water main breaks inhibited. In an open system, leakage reduction often results in pressures gradually rising, which causes new leaks to form. Hence, an endless cycle of leak development occurs. Pressure management can prevent this by holding pressures at stable levels even as leakage rates are reduced. DMA monitoring is an effective method of both quantifying leakage and identifying the sections of the system where the leaks are occurring with greatest prevalence.

Acoustic Leak Detection

Acoustic leak detection is the technique of pinpointing the location of unreported water-distribution-system leaks via the sounds that they generate and is an essential part of an effective active leakage control program. All drinking water utilities should employ some form of regular leak detection, either provided by their own staff or contracted services. Acoustic leak detection is the most common technique in use in the drinking water industry. It is best to have leak detection activities occurring on a regular basis. Traditional approaches use crews surveying portions of the distribution system on a set frequency. These approaches provide a basic level of active leakage control that has worked well for many water utilities. However, as discussed in the assumptions listed earlier in "The Economics of Leak Detection" section earlier in this chapter, the longer the interval between leak surveys, the greater the likelihood that new, unreported leaks will emerge and run at length before being detected during the next leak survey. Progressive approaches, however, detect newly emerging unreported leaks sooner. Acoustic leak detection is most commonly used to pinpoint leaks during scheduled leak surveys, or as alerted by permanently installed leak noise loggers or high flows during minimum consumption periods in DMAs. The function of leak detection only identifies leak sources, however, and it must be complemented by effective repair or rehabilitation activities if leakage volumes are to be reduced.

Acoustic leak detection is the most common means of pinpointing individual unreported leaks and uses mechanical and electronic listening equipment to detect the sounds of leakage. Pressurized water forced through a leak loses energy to the pipe wall and to the surrounding soil area. This energy creates audible sound waves that can be sensed and amplified by electronic transducers or, in some cases, by simple mechanical devices. The sound waves are evaluated to determine the exact location of the leak. Most leak detection programs function by listening for leak sounds from outside of the piping by gaining access to place sensors on valves, fire hydrants, or other visible piping access points. Techniques also exist to sense leaks from probes traveling inside active water piping.

Although acoustic leak detection surveys are the most common way to detect unreported leaks, this technique has limitations. Conducting active, acoustic leak detection is difficult in high noise areas, such as heavily trafficked streets, and can suffer from interference from pumps, electric transformers, and other noisy equipment inside buildings. Hence, many water utilities deploy leak survey crews during quiet nighttime hours to perform surveys in areas of high daytime traffic. Acoustic leak detection can also be compromised by noise from continuous customer water use or water passing nearly closed valves, creating a sound that is very similar to leaks. Acoustic leak detection is complicated when multiple leaks exist within close proximity in a small area of the distribution grid. Repeat leak surveys are often needed after each leak repair is completed to pinpoint the additional leaks. Without DMA or other metering, acoustic leak detection does not provide the ability to quantify leakage flow rates to a good degree of accuracy, and acoustic leak detection does not detect or quantify background leakage, the tiny weeps and seeps at pipeline joints, which are, by definition, sonically undetectable.

Acoustic leak detection has some means to inhibit new leaks, typically by eliminating those leaks that could undermine the bedding soil support of nearby existing piping. However, acoustic leak detection combined with the other activities shown in Figure 7-1 provides the most effective results. For example, pressure management reduces background leakage rates and inhibits the formation of new leaks by removing excessive pressure. Because of the limitations of acoustic leak detection noted above, water utilities should employ an active leakage control strategy that includes appropriate combinations of flow measurement (DMAs), acoustic leak detection, pressure management, and system renewal to obtain the most effective results.

Principles of acoustic leak detection. The principles of acoustic leak detection must be understood to achieve success in pinpointing water system leaks. The following factors can affect leak sounds:

- **Pressure.** It is usually necessary to have a water pressure of at least 15 psi to employ acoustic leak detection successfully. Higher pressures tend to make a stronger leak sound.
- **Pipe material and pipe size.** Acoustic techniques can be used on pipe and fittings of any material. Because nonmetallic materials such as plastic pipe are much weaker sound conductors than metallic pipe, a closer test interval is required when searching for leaks on nonmetallic pipe. See Figure 7-15 for typical sound velocities in pipelines of different materials.
- **Soil type.** The type of soil greatly influences the amount of sound transmitted to the surface. Empirical observation indicates that sand is normally a good conductor of sound whereas clay is a poor conductor.

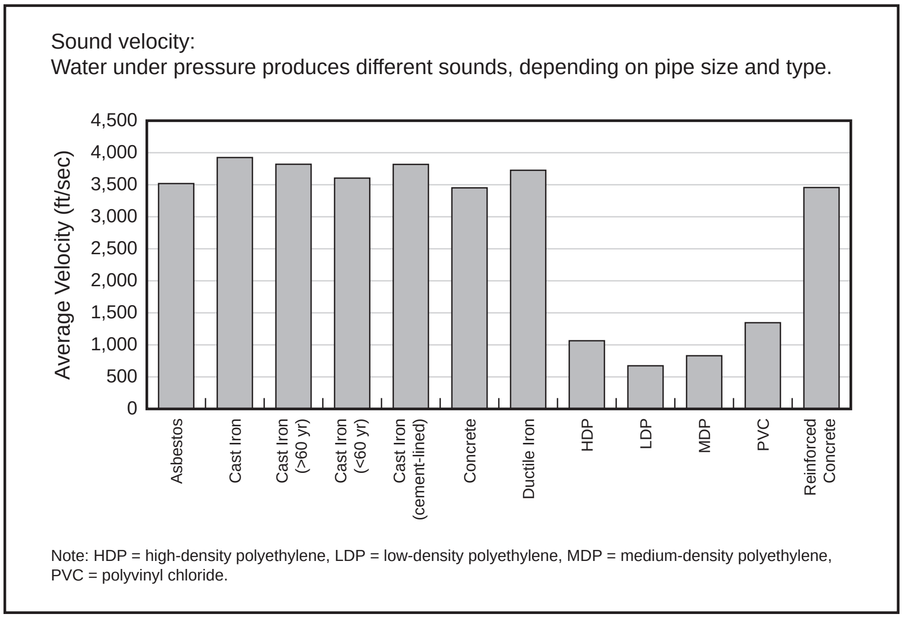


Figure 7-15 Leak sound velocities in pipelines of different materials

Source: *Titus et al.* 2013

- **Ground cover/surface type.** The type of surface on which the sounding instrument is placed also influences how the sound travels. Grass or sod tends to insulate and muffle sounds, whereas asphalt and concrete are good resonators providing a uniform sounding surface.

Types of leaks located by acoustic leak detection. Leakage in water distribution systems occurs as reported leaks or breaks, unreported leakage, and background leakage. Because reported leaks are visible and background leakage is, by definition, sonically undetectable, acoustic leak detection strives primarily to locate unreported leakage, which accounts for the majority of leakage losses in many water distribution systems. Unreported leaks typically occur as follows:

- **Detectable leaks on water mains** ranging from a low of 1 gpm to more than 1,000 gpm. Leaks on water main piping can occur as a result of corrosion that usually originates as small leaks but can grow to large leaks. Splits at bells of piping can occur as a result of excessive pressure, improper installation, defective joint material, settlement, and overloading. Joint leaks can occur because of corrosion, improper installation, improper materials, or overloading. Slow-developing main leaks (usually corrosion holes and joint leaks) have the potential to remain unreported because they can create subsurface paths for leaking water to travel. Alternatively, such leaks can undermine pipe support and lead to a larger pipe failure.
- **Detectable customer service connection piping leaks** ranging from a low of 0.5 gpm to more than 15 gpm, and are caused by the same factors as main leaks. Customer service connection piping leaks account for the greatest number of unreported leaks in many water utilities and often account for the greatest volume of annual real losses. Many water utilities have policies that require their customers to arrange for leak repairs occurring on certain sections of their service connections. Such policies tend to produce a delay in repairs and add to the quantity of current losses because many customers are unprepared to respond quickly, and service connection leaks run for excessive durations.

- **Detectable distribution system appurtenance leaks** occurring on valves, fire hydrants, air valves, and other system appurtenances, and can range from less than 1 gpm to 500 gpm. Higher volume leaks or those visible on fire hydrants often become reported leaks, but many small leaks remain unreported leaks for long durations. Leaks may also occur in system appurtenances, such as pressure-reducing valves, pressure-sustaining valves, pressure-relief valves, altitude-control valves, blow-offs, and related components of the distribution system. These leaks may occur as a result of malfunctions such as loose packing on valves or from operational problems such as pressure surges and fire hydrants that are closed too quickly.
- **Detectable customer meter leaks** near the meter box ranging from less than 1 gpm to 10 gpm. Leaks may be caused by loose spud nuts on the meter, loose packing nuts, damaged or broken angle stops, broken or damaged couplings, broken meters, or damaged or broken meter yokes.
- **Detectable premise plumbing leaks** on the customer side of the water meter ranging from less than 1 gpm to 15 gpm. Current industry standards for customer water meters specify accuracy levels down to ¼ gpm, a flow rate too high to identify very small leaks such as slight toilet flapper valve leaks. These leaks may be caused by holes or breaks in customer service connection piping, inefficient hose-bib or shutoff valves, holes or breaks in interior plumbing lines, or leakage inside plumbing fixtures; toilet leaks are very common. Because many of these leaks occur downstream from customers' meters, this leakage may be metered and result in a higher bill to the customer. Unfortunately, many very low flow leaks may not register on customer meters, and this waste of water may go undetected if not actively monitored. Note: Premises plumbing leaks are not included in the annual water audit since the customer meter is the terminus of the data tracked by the audit. However, the above information provides useful insight into the occurrence of such leaks since leak detection personnel will often detect the sounds of these leaks and must be able to distinguish them as being on customer-owned piping or utility-owned piping.
- **Miscellaneous leaks** occurring as a result of excessive pressure, settlement, overloading, improper installation, improper materials, and improper operation of components or appurtenances that are part of the water distribution system.

Acoustic leak detection equipment. A variety of equipment exists for purchase or as part of service contracts in the commercial marketplace. Mechanical listening equipment such as listening rods and geophones (operating like a physician's stethoscope) are still in use, but the most effective tools are electronic listening and pinpointing devices, such as ground microphones, amplified listening devices, leak noise correlators, leak noise loggers, and inline sensors. Water utilities can choose to employ many of these tools in various combinations to develop an effective leak detection capability that best suits their situation. Leak detection consultants maintain a range of this equipment in their "tool box." A description of some of the most notable equipment is given in the following subsections.

Simple leak noise probes. The fundamental instrument for leak noise surveys is an instrument that uses a probe that conveys sound to the user audibly or through a monitor or both. The original units were brought right to the ear to listen for the leak. Probes were brought into contact with part of the water system by direct contact if practical. Today's units convey to devices that have amplifiers, and they feature insulated headphones and filters to screen out selected frequencies. Many units have readout devices to provide a visual measure of the noise (and cover frequencies outside human hearing). A variation of the probe is a ground microphone that is placed on a flat surface to carry sound without direct water system contact.

Leak noise correlator. This device is accurate in pinpointing many leak locations by analyzing leak sounds (including those that may be inaudible to the human ear) that travel through the water column and along the pipe wall. These sounds can be sensed from aboveground by placing sounding sensors on valves, hydrants, and curb stops. Operators can also make direct contact with exposed mains or probe rods touching water mains through holes drilled in the street. Where taps are available, a hydrophone can be used to make contact with the water directly, offering improved sensitivity. This technology typically consists of a leak noise correlator unit (a receiver and processor) and two sensors (transducer or hydrophone depending on the application) with radio transmission capability that can pinpoint leaks in pressurized water piping through the use of the correlator to analyze leak sounds traveling along the pipe wall and water column inside the main.

The leak correlator is essentially a two-channel microprocessor that measures the time delay of a leak noise registered at two contact points on the water main. Although the characteristics of the leak sounds vary because of such factors as pipe material, diameter, size, nature of the leak orifice, system pressure, ground conditions, and other factors, the leak sound velocity (V), or speed with which the leak sound travels along the pipe, remains constant.

To use the leak correlator, the leak sound must be detectable at two or more contact points, and certain information must be entered into the correlator, including the distance along the pipe between the contact points, the pipe material, and size (diameter) of the pipeline. Sufficient pressure must exist in the pipeline to generate a detectable sound from the leak. Two sensors, connected to and powered by portable transmitters, are attached to the selected contact points. The leak sound, picked up by the sensors, is then transmitted to the correlator by a radio.

By obtaining leak sounds at two points on either side of a suspected leak, the correlator analyzes the leak sounds and, knowing main characteristics that are input by the operator, determines the exact location of the leak between the two sensors. A schematic of this is given in Figure 7-16 where the leak is on a main between two sounding points, A and B, at a distance D apart. The leak correlator is positioned at a location C somewhere between A and B. In this example, the leak is at a point roughly halfway between C and B. L is defined as the distance between the correlator location C and the leak source. The leak correlator determines the delay in arrival time taken by the leak sound to travel from C to A, the distance N. This delay is the time difference Td for the leak sounds to reach A versus its arrival time at B. Referring to this schematic,

$$D = 2L + N \qquad (7\text{-}22)$$

Substituting velocity V multiplied by time difference Td for N,

$$D = 2L + VTd \qquad (7\text{-}23)$$

The value D is measured in the field and velocity V is either selected from the leak correlator's memory or can be computed manually by the operator. The difference in arrival time Td of the leak sound at A and B is automatically established by the correlator through the cross-correlation process. In this instance, the difference is directly related to the sound velocity of the pipe under investigation. The leak location results appear on the correlator's display, or results can be printed. All findings can be downloaded for historical storage and comparisons with other correlations. The operator then measures the indicated distances from the contact points to pinpoint the exact leak location.

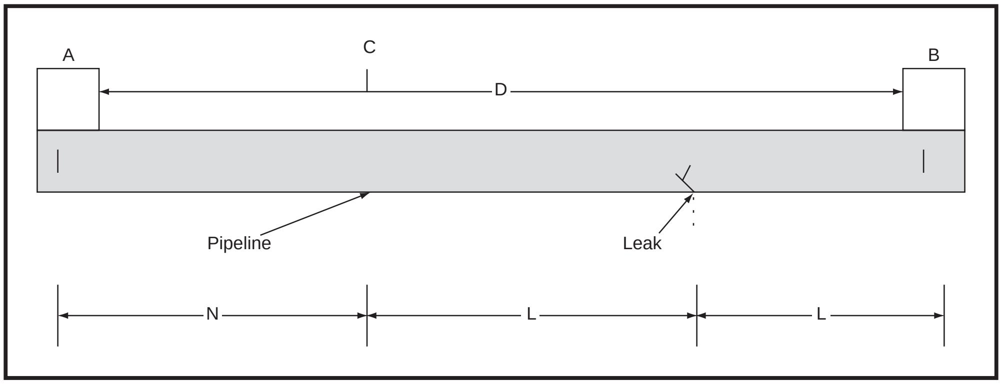


Figure 7-16 Determining the position of a leak using a leak noise correlator

Modern leak noise correlator systems are very portable and user friendly in the field. A typical complement of correlator equipment may include

- a laptop or personal digital assistant with internal rechargeable power supply, display screen, internal preamplifier, two-channel internal radio receiver, and stereo headphones;
- two electronic amplifier outstations with internal rechargeable power supply, internal radio transmitters, sensors, and headphone connections;
- battery charger kit;
- headphones; and
- manual and test tape with stereo lead.

Commonly available accessories include

- cases for carrying items and added protection,
- sensor attachment accessory kit,
- portable electronic survey tool,
- measuring wheel,
- hydrophone sensor package,
- stereo recorder with harness,
- leak noise recordings for training purposes,
- ground-microphone system,
- printer, and
- pipe locator.

The leak noise correlator is used to confirm the presence of a leak and pinpoint its location, both for surfacing and non-surfacing leaks. It is used before excavating pipes to conduct leakage repairs. The correlator method does not rely on the presence of surface sound as does the ground-microphone method. Common noise interference, such as wind, traffic, and ambient system noise, has less of an impact on the leak correlator. The depth of the main, type of cover, and surface conditions are generally not factors to be considered.

Leak noise correlator technology does require an accurate breakdown of the size and types of pipe material between the correlation units. Best practice is to use both the leak noise correlator and ground microphone to pinpoint the leak location as precisely as possible. The ability for sound to travel long distances is attenuated in a large-diameter pipe; thus, contact points for correlators sensors may need to be spaced at smaller intervals than a specific pipeline alignment configuration may have available. This may require excavation of the pipeline to make direct contact with exposed piping or probe rods touching water mains through holes drilled in the street. Most leak noise correlators are limited to sensors spacings of approximately 1,500 ft, although some models designed specifically to address the challenges of large-diameter piping quote allowable spacings of up to 5,000 ft. If multiple leaks are present within the bracketed area, the correlator may only detect the larger leak, and additional leak correlation will be necessary after the initial leak is abated. The presence of air pockets within the bracketed area of a pipeline (more likely in large-diameter piping) may reduce the reliability of the correlation.

In existence since the 1970s, correlators were expensive in their early years of development and were affordable mostly to large water utilities and leak detection consultants. Technology has advanced in recent years, competition among manufacturers has increased, and equipment prices have moderated. This equipment is now within budgetary reach for many water utilities and is one of the fundamental tools of the leak detection program. Efforts are underway to advance correlator technology to include pipe wall assessment functionality that may be capable of determining the average pipe wall stiffness across the bracketed area using the speed of sound. This average pipe wall stiffness can then be used to calculate the average minimum wall thickness of the bracketed area.

Leak noise monitors. Leak detection equipment manufacturers have developed units that can be deployed in the field and take the place of sending staff into the field to monitor data. Leak noise monitors have distinct advantages over conventional leak surveys. The units are programmed to listen to the quietest noise level of the night period where a leak survey crew listens only momentarily when some noisy activity may be occurring. The leak noise monitor units are generally strategically placed to ensure full coverage of the system where the leak survey crew may struggle in the nighttime hours to access adequate points or listen at many more locations than might be necessary. A drawback to leak noise monitors is that there are other sources of noise that can resemble leaks (termed *false positives*), and field staff will not always find a leak when dispatched to investigate. The use of leak noise correlators is still generally required to confirm a leak, but the area of investigation is usually a small area, perhaps 500 feet from the monitor. The class of this equipment is broken into two categories, leak noise loggers and leak noise transmitters, described in the following sections.

Leak noise data loggers (LNLs). LNLs sense and record sounds emanating from water distribution system piping, allowing operators to analyze sounds to detect and pinpoint leaks. LNLs can be used to conduct leak surveys by deploying them at various locations within the distribution grid and setting them to “awaken” during night or low-noise times of the day to continuously listen and record leak sounds (see Figure 6-8). The statistical variance of this noise is determined by the presence or absence of leakage. The noise signature obtained at each monitoring point confirms the presence or absence of leakage and indicates the relative location. In addition to use in leak survey work, LNLs can also be deployed to “stand watch” over sensitive or hard-to-access locations. Some LNLs have capabilities to integrate with leak correlators and are thereby able to gather sounds from multiple loggers and correlate to pinpoint leak locations.

The development of LNL technology is an important innovation in automating the leak detection process. LNLs provide uniform listening, sound recording, and analysis, greatly reducing human error associated with manual sounding methods. LNLs can reduce the worker-intensive process of manually sounding distribution system appurtenances. They can greatly reduce the need for crews to work at night, at times in unsafe locations, to gather leak sounds during low-noise periods. LNLs can be readily deployed in groups that are installed in valve boxes or other system access points at varying intervals up to approximately 1,500 ft. The area can be surveyed by gathering sounds, downloading the data, and correlating to pinpoint leaks. The LNLs can then be relocated to the next area designated for survey. This method is commonly referred to as "lift and shift." In this way, a relatively small number of LNLs can be purchased to outfit a leak survey team.

LNLs can also be deployed on a permanent basis. LNLs might be deployed permanently on critical infrastructure or other important/sensitive buildings to detect newly developing leaks quickly. Some water utilities have installed LNLs on a permanent, widespread basis throughout major portions of their water distribution system.

LNLs can create cost efficiencies by reducing the labor involved in conducting leak surveys. Instead of a crew of two to four employees sounding individual appurtenances, one or two employees can install LNLs relatively quickly in the same survey area and return the next day to download and analyze data. Leak noise correlator teams can then be dispatched to the areas that indicate leak sources. LNLs also provide greater consistency in sounding for leaks. Whereas manual leak detection relies heavily on the sound detection capabilities of individual team members, LNLs provide consistent sounding capabilities that can be assessed objectively. A slightly higher skill level may be required when analyzing data generated from LNLs, so the labor trade-off may be somewhat offset by the need for additional training for the analysis of the LNL findings.

Leak noise transmitters (LNTs). Several automatic meter reading and advanced metering infrastructure (AMR/AMI) manufacturers are making available (with or without connecting water meters) fixed-network and mobile AMR/AMI systems to send data that can be received and analyzed with software back in the office to identify potential leak locations. Fixed-network solutions offer the capability of next-day leak surveys while AMI systems provide possible feedback through data logging on a periodic basis without going into the field. The leak noise candidates identified in the LNL and LNT do identify leak noise sources but, in the absence of correlating, can also identify locations that emit false positives. This requires periodic field visits to perform leak noise correlation at such locations; the frequency of visits tends to diminish as a history of day-to-day leak noise is built and understood.

Economics of leak noise monitors. The economics for the use of leak noise monitors should be considered by the leak detection manager when planning the use of this method. Labor savings alone will often offer cost-effective advantages for leak noise monitors over manual leak detection surveys. If permanent deployment is considered, the economic return should be closely evaluated because dozens to thousands of devices might be deployed depending on the size of the system and the planned objectives. Large-scale deployment therefore will require a large initial investment.

The decision to install many units across a system for an extended period should consider the useful life of the equipment and its effectiveness. Factors to consider include expected battery life, the robustness of the equipment in its working environment, and the frequency of needed hardware and software upgrades. Like many new technologies, the design of the equipment is evolving rapidly and costs could drop in the future. If leakage is modest, the rate of rise of leakage is low, or leakage is believed to consist largely of background leakage or rapidly surfacing large breaks, this would not be an appropriate technology to employ. A description of the use of a system of leak noise transmitters in a water utility is given in the "Utility Case Study for the Use of Correlating Leak Noise Transmitters" sidebar.

DMAs offers an opportunity to quantify leakage where leak noise monitors do not. Typically, individual leaks can be quantified by using an estimation calculation that factors in the pressure and the size of the opening during repair. Nevertheless, there have been documented cases of effectively reducing leakage from such programs. Success is

Utility Case Study for the Use of Correlating Leak Noise Transmitters

Faced with high imported water costs, the Olivenhain Municipal Water District (OMWD), located near San Diego, Calif., has taken a proactive approach to leak detection. The financial impact of real losses in the distribution system costs the OMWD hundreds of thousands of dollars annually, so early awareness of newly emerging leaks is a key part of the OMWD's effort to control real losses. The OMWD has deployed correlating radio leak noise loggers in many areas of its distribution system. These loggers monitor and analyze noise characteristics within the pipe network and can detect and identify the presence and location of a leak.

Once the logger has detected noise that could indicate a leak, the precise position of the potential leak can be pinpointed between the two logger units. Not only does the logger get "leak/no-leak" data, but it is also able to ascertain the frequency of the suspected leak noise. This process allows the user to determine whether the noise is that of a leak or a false positive. This additional data also allows the user to pinpoint exactly the location of the leak in preparation for excavation. The data retrieved from each logger unit is automatically archived in a personal computer or server-based software database and can be used to provide detailed reports for repair teams or a total historic analysis for future pipeline replacement policies. The leak data can also be integrated with Global Positioning Satellite and geographic information system operating systems.

Initially the loggers were read via a "drive-by" system where the operator gathered information via vehicle-mounted radio. With nearly 100 units in place, the drive-by process became a time-consuming effort. It also meant that leak detection would be delayed by up to a week because the data was only collected once a week. To save staff time and decrease the time to get reports from the loggers, the OMWD installed a pilot fixed-base communications system.

The fixed-base approach requires the installation of small radio receivers in the area being monitored (see Figures 7-17 and 7-18). This allows the operator to collect all data automatically via a fully integrated system that employs the use of permanent field-mounted receivers that communicate with the loggers and relay the leakage information to the operator's desktop at the utility offices (see Figure 7-19). The installation of the system was supervised by the manufacturer to ensure optimal coverage of the targeted pipe network and reliable communication. No further human field intervention is necessary for accurate leak detection, as leak noise will be automatically identified and pinpointed. The leakage manager is notified within one day of its occurrence. Thanks to advanced analysis tools, non-leak noises and other interferences can be excluded to avoid false positives and reduce operating costs.

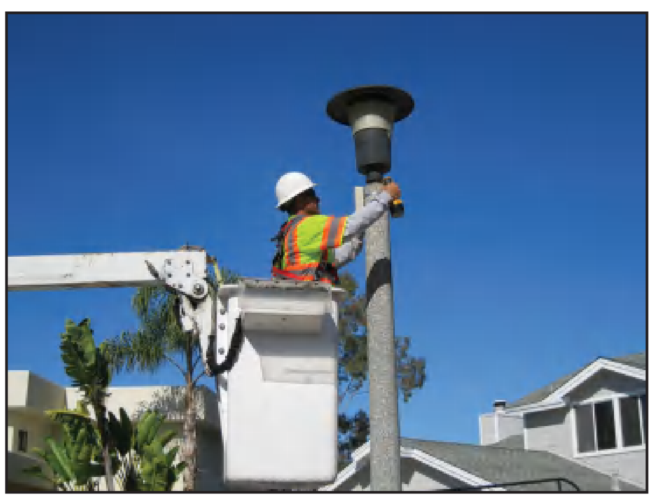


Figure 7-17 Mounting a leak detection fixed-base radio repeater on a lighting pole in the Olivenhain Municipal Water District

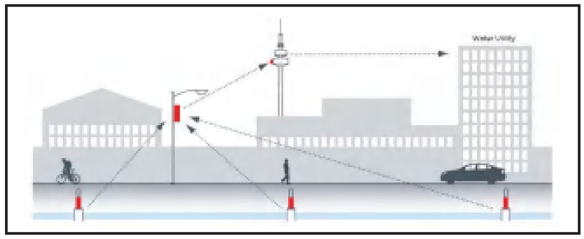


Figure 7-18 Schematic diagram of leak noise transmitter data collection and transmittal to utility offices in the Olivenhain Municipal Water District

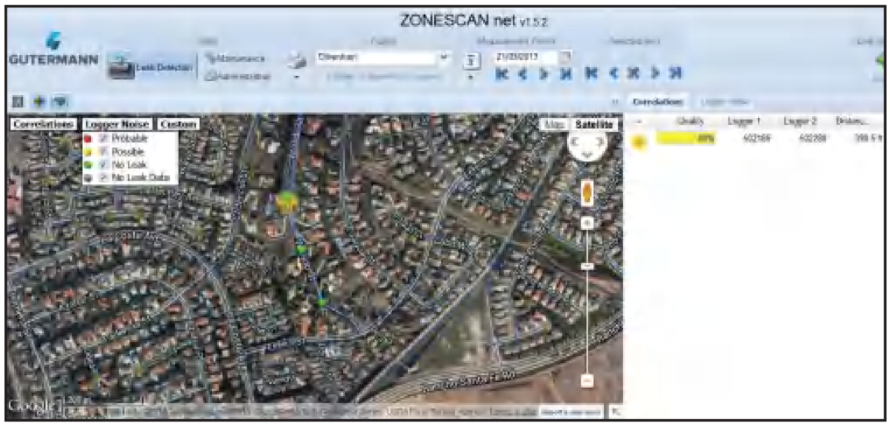


Figure 7-19 Screenshot of the aerial dashboard display of the leak noise transmitter system in use in the Olivenhain Municipal Water District

attributed to finding non-surfacing leaks closer to the low-end detection limit rather than waiting until the leak becomes more substantial. This means that small, unreported leaks are detected quickly, including some leaks that start as unreported leakage or when left undetected become reported leakage.

Inline leak detection sensor. In cases where external acoustic leak detection techniques are not practical, an inline acoustic survey can be conducted. Acoustic sensors have been developed to run through the in-service pipe, bringing the sensor to the leak sound rather than relying on the leak sound to find the sensor. Inline surveys are often appropriate for large-diameter transmission mains, which are often poor at transmitting leak sounds and have limited access points to the pipe. However, some inline technologies have been developed to scan small-diameter piping. Some techniques use sensors tethered to an umbilical cable, and others use sensors that are free-flowing in the pipeline. Both applications have been fully developed commercially and have proven usage histories in many utility situations. Inline methods are able to reliably identify very small leaks on transmission mains with pinpoint precision, without requiring the water main to be taken out of service. This is particularly beneficial in assessing critical pipelines or those that run under rivers, major highways, or other areas where a failure would be particularly damaging.

Inline leak detection uses acoustic sensors that are typically inserted into tapping locations on the pipelines. Some systems allow insertion into 2-in.-diameter valves (such as taps supporting air-release valves), while others require a 4-in.-diameter opening.

In tethered systems, the acoustic sensor is attached via the umbilical cable to an aboveground monitoring station (typically in a vehicle large enough to house the inspection equipment). The cable can typically travel several thousand feet, depending on flow rates and bends in the pipeline, but cannot safely traverse butterfly valves or other inline obstructions. The sensor is propelled by the flow of water, and a trained operator in the aboveground monitoring station controls its movement and simultaneously listens to acoustic data recorded in real time while another operator tracks the sensor's progress aboveground, typically recording and marking any locations of interest such as leak locations and air pockets. Tethered systems provide the operator with good control since the tether can be advanced or retracted as needed to better pinpoint leak noise and navigate the features of the pipeline.

Benefits of tethered leak detection include

- increased sensitivity and proximity to leak noise, which allows for detection of leaks as small as 0.005 gpm, depending on inspection conditions and technology specifications;
- ability to detect multiple leaks during a single deployment;
- ability to move the sensor back and forth along the location of the leak for most precise pinpointing;
- capability for real-time leak locating and marking;
- ability for deployment into complex systems due to operator control over sensor's movements;
- ability to detect leaks in locations with high ambient noise; and
- ability to detect and report the location of pockets of trapped air.

When employing tethered leak detection technology, the following special considerations should be taken:

- The maximum achievable inspection length will be determined by factors such as the length of the umbilical cable (usually around 6,000 feet) and the velocity of the water in the pipeline. In optimum cases, this can reach up to 6,000 ft, although many deployments are limited to a 3,000–5,000 ft range.
- Branching mains along the intended inspection segment must be closed as the sensor passes and can be reopened once it has traversed a certain distance past the branch.
- Inline valves must be noted prior to inspection because certain types, such as butterfly valves, may be impassable.
- Friction forces will develop around the umbilical cable because of the amount and cumulative degrees of bends as well as drag from the tether. Proper planning must be undertaken to ensure that specific pipeline conditions allow for adequate deployment, and pullback tests should be performed at predetermined intervals to ensure that friction forces are within system tolerances.
- Sufficient water pressure must be provided during the inspection to generate audible leak sounds for sensor detection.
- The umbilical cable must remain in tension throughout the inspection to avoid entanglement.

The insertion site for the inline sensor should be able to accommodate setup of all inspection equipment, including vehicles.

Tethered leak detection technology continues to advance and now includes a video sensor to allow for real-time closed circuit television (CCTV) inspection, providing additional functionality to deployments such as the ability to locate pipeline features and

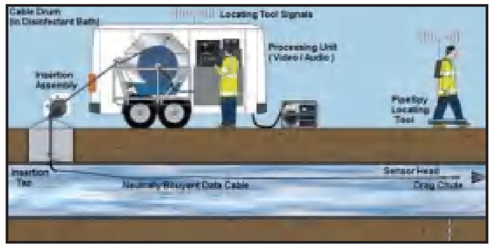


Figure 7-20 The Sahara technology is a tethered inline leak detection system that is effective in pinpointing leaks on large-diameter piping

Courtesy of Pure Technologies

Figure 7-21 Tethered inline leak detection insertion apparatus

Courtesy of Pure Technologies

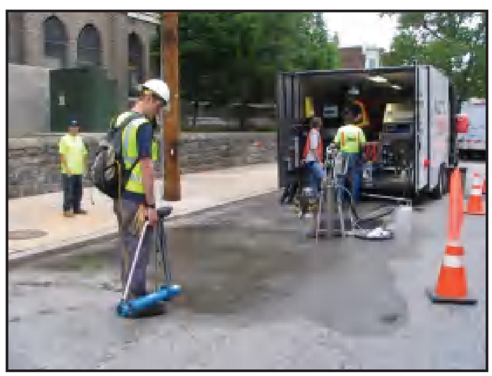


Figure 7-22 Use of inline leak detection technology in a 48-in. water main

Courtesy of Philadelphia Water Department

visual defects. Possible future developments in tethered leak detection technology may include pipe wall assessment capability in conjunction with audio/video recording functionality. This technology is depicted in Figures 7-20 to 7-22.

Free-flowing leak detection is typically employed by insertion of an acoustic sensor into the fully operational pipeline through check valves at pumping stations or tapping locations (such as those used for air valves), usually 4 in. in diameter or larger depending on technology specifications. Prior to inserting the sensor, a suitable, predetermined retrieval location downstream is secured either by use of an inline retrieval tool (see Figure 7-23)

Figure 7-23 Free-flowing leak detection sensor inside the retrieval tool

Courtesy of Pure Technologies

or configuring removal through a fire hydrant or discharge into a reservoir. As the sensor travels through the pipeline, it constantly records acoustic data while intermittently emitting a signal that allows its progress to be monitored at fittings aboveground by operators using tracking devices. The inspection concludes at the retrieval location where the sensor is removed from the pipe and the recorded data is then downloaded for post-processing and analysis. Along with acoustic recording capability, untethered sensors include a battery and onboard memory card, and may typically include an accelerometer among other components depending on the provider's specific technology. The accelerometer records the sensor's movements throughout the inspection, allowing for calculation of its velocity, which is used in conjunction with the known tracking locations to accurately locate leaks.

Free-flowing sensors can navigate tight bends and travel up completely vertical pipes, provided flow velocity is sufficient (usually greater than 1 ft/sec).

Benefits of free-flowing leak detection inspection include

- increased sensitivity and proximity to leak noise, which allows for detection of leaks as small as 0.03 gpm, depending on inspection conditions and technology specifications;
- ability to detect multiple leaks during a deployment;
- ability to detect leaks in locations with high ambient noise;
- ability to detect and report the location of pockets of trapped air;
- ability to pass through inline valves; and
- capability for achieving long inspection distances in a single deployment depending on pipeline operational conditions.

Free-flowing sensors can travel much farther than tethered systems, but these devices cannot be retracted and resent in a single survey as a tethered system; therefore, careful planning and preparation of routes is required, and the free-flowing device must be carefully tracked. Any branching mains from the transmission pipeline must be valved

Tethered Inline Leak Detection Technology for Large-Diameter Piping—Utility Case Study

Dallas Water Utilities (DWU) has completed an annual summer leak detection program since 2004 using inline tethered technology. The program focuses on DWU's large-diameter water transmission (ranging in size from 12 in. to 84 in. in diameter). The inspection program assesses a variety of piping materials including prestressed concrete cylinder pipe, cast-iron pipe, and ductile-iron pipe.

DWU's leak detection program has been successful in locating 120 leaks within 100 inspected miles. The estimated water savings from these leaks is 7.2 mgd. The city has also seen a 17 percent reduction in catastrophic water main failures, possibly as a result of the proactive approach to detecting and repairing leaks. The reduction in failures has reduced property loss claims and service interruptions, as well as reduced treatment and delivery costs.

closed during the leak detection survey. Shorter spacing may be needed in pipelines with many bends. Sensors rely on a minimum water pressure of at least 5 psi so that leaks will generate an audible leak noise.

Because both tethered and free-flowing inline systems depend on the flow of water for propulsion, steps may need to be taken to adjust the flow to achieve the needed minimum velocity to propel the sensor. Opening valves and hydrants downstream of the survey and increasing the flow from pumps upstream can help ensure a smooth survey. For tethered systems, friction builds in the tether as it traverses bends, as does drag from the flow of water along the tether. A brief pullback should be attempted every 300 ft to verify that the friction and drag are within the system tolerances. In addition, care needs to be taken to ensure that slack does not build up in the tether, ensuring that it remains untangled. This can be done using a device for locating the sensor on the surface and comparing the distance actually traveled to the length of tether deployed. Leak audio signals can be clearly identified by a trained operator. When leaks are detected, the location of the leaks should be carefully noted. Likewise, audio signals characteristic of air trapped in the pipe can be clearly identified. Air pockets should be recorded to identify where air can become entrapped.

Inline leak detection is offered as a service by specialized contractors, or equipment sales or leases may be available to utilities needing large volumes of surveys. The service can be expensive; however, it is also highly accurate and able to traverse locations that are inaccessible by traditional leak detection surveys. Although it requires an investment to obtain these services, water utilities have the potential to save money in the long run by identifying small leaks on transmission mains and addressing them before they become large, disruptive failures. Many water utilities have not surveyed their large-diameter transmission mains adequately for leaks, and inline leak detection technology offers an outstanding capability to monitor these important water supply assets. Two brief utility case study examples of the successful use of tethered and free-flowing inline leak detection technology are provided in the "Tethered Inline Leak Detection Technology" and "Free-Flowing Inline Leak Detection Technology" sidebars.

Innovations in electronic leak detection techniques continue to occur. Presently, leak correlators, LNLs, LNTs, and inline systems have all proven to be particularly effective tools in successful programs and should be considered by water utility managers when planning a leak detection program.

Organizing a leak detection program. Leak detection is most often carried out with traditional leak surveys by manually sounding water system appurtenances such as valves, fire hydrants, service connection curb stops, or other accessible points on active piping. Water utility operators conduct a leak detection survey by systematically canvassing the

Free-Flowing Inline Leak Detection Technology for Large-Diameter Piping—Utility Case Study

In early 2012, the Birmingham Water Works Board (BWWB) ran a successful free-flowing inline leak detection program on 7.7 miles of 42-in. reinforced concrete pipe. The inspected pipelines are part of BWWB's system that transports water from the Shades Mountain Filter Plant to different areas of the city and was completed to proactively address water loss on BWWB's large-diameter water transmission mains.

The survey identified 26 leaks of varying size with close location accuracy. Twenty of the leaks have since been verified and repaired by BWWB, while the remaining six leaks have been deferred because of their size or other scheduling reasons.

The free-flowing sensor was able to detect several leaks that were as small as ~1 gpm to as large as ~15 gpm. This information allowed BWWB to make educated repair decisions for each identified leak, allowing for the short-term deferral of repairs for certain small leaks in preference to scheduling repairs of the larger leaks first. Through the location of both small and large leaks in its 2012 survey, BWWB was able to repair high-priority leaks and identify the small leaks that can be repaired to prevent long-term water loss.

water distribution system in such a manner. The development of LNLs allows a significant portion of the labor-intensive leak survey process to be automated. With new leaks constantly forming in water distribution systems, the optimum approach is to focus on areas where leakage is suspected. DMAs detecting high minimum-hour flow provide such a focus.

Analysis of historical leak records can also serve as a guide to predict areas of concern. However, most water utilities that conduct leak surveys schedule the distribution system for leak detection on some regular frequency without necessarily targeting areas currently indicating high leakage volumes. Many small water utilities hire a contractor to survey the entire distribution system once every 3–5 years. Large systems often staff in-house leak detection squads that survey the system on an ongoing basis but, because of the large size of the distribution system, may only cover the system fully once every 1–5 years. The economic intervention frequency (EIF) can be calculated for a water utility using Eq. 7-13. Leak surveys typically require two rounds of sounding to first identify leak noises and then confirm/pinpoint individual leak sources.

If the active leakage control program includes both DMA flow monitoring and leak detection surveys, leakage reduction can be conducted strategically, with leak detection teams deployed only in areas where high minimum-hour flows indicate the presence of newly formed leaks. The major considerations in creating an in-house leak detection program include the following tasks.

1. Develop objectives for leak detection activities by reviewing the findings of the water audit. From the water audit, assess the volume, sources, and cost impact of leakage and estimate how much leakage can be reduced by employing leak detection and repair. Convert the projected leakage reduction to a cost savings of variable costs. Project the needed level of staffing, equipment, training, and crew deployment. Effective leak detection teams can survey roughly 2 miles of pipeline per day at a cost of approximately $200–$400/mi of pipeline. To formulate the work pace, assess the characteristics of the water distribution system, including the following:
    a. Mains and services—types, ages, diameters, joints, installation methods, inspections, leak histories, and operating pressures
    b. Customer water meters and meter-box assemblies—location of the meter (in an outdoor meter pit or indoors); types, brands, and sizes of meters; ages; types of installations; meter shutoffs; coupling; and meter reading frequency

   c. Valves—locations, accessibility (are valve covers buried or stuck?), types, clockwise- or counterclockwise-turning, number of turns to exercise, and how often they are exercised
   d. Fire hydrants—types, sizes, locations, flushing frequencies, and unmetered usage
   e. Pressure-reducing valves, pressure-sustaining valves, and pressure-relief valves—locations and how often they are exercised
   f. Blow-offs and air-release valves—locations and how often they are exercised
   g. Distribution system maps—What is the nature of the mapping (paper or electronic) and what is shown on maps (valves and other appurtenances), how current is the information, and how often is the information updated?
   h. Curb stops on customer service connection piping—typical locations, accessibility, mode of operation (quarter turn), and service pipe material

2. Make a determination as to whether leak detection survey work will be carried out manually or in automated form via the use of LNLs (or a combination of both techniques). This decision will greatly influence the required funding because manual methods require greater labor, while the use of LNLs entails less labor but needs a different form of equipment and training.
3. Assemble the leak detection team by selecting motivated employees with a keen sense of hearing, the ability to discern different sounds, familiarity with the water distribution system and water meters, a sense of responsibility, and the ability to estimate leak flows, complete leak forms, and work independently. One person might conduct the initial listening survey, although additional staff may be required for safety purposes. Ensure that the crew members can work compatibly, have a communication link to others for emergencies, and that work assignments are clearly defined.
4. Provide crew members with good-quality leak detection equipment, including sonic listening equipment with a high-frequency listening probe and a low-frequency ground microphone for pinpointing leaks. When using the ground microphone on turf areas, a "thumb tack" helps provide better-quality sounds. A *thumb tack* is a flat, metal, horizontal plate attached to a strong, metal, vertical spike. Crew members should also have safety equipment, including safety vests, traffic cones, and barricades. Tools to measure flow rates should be provided, including a stopwatch, bucket, measuring cup, pressure gauge, and measuring wheel or tape. Standard water utility working tools, such as meter-box lid lifters, valve-cover lifters, valve keys, curb-stop keys, small bailing cans or small manual pumps, chalk or spray paint to mark street surfaces, pipe locators, and wrenches for tightening meter-spud nuts, should also be supplied. Vehicles should be provided with good lighting characteristics and reflectors.
5. Provide crew members with appropriate training before conducting leak detection work. Instruction on the use of electronic leak detection equipment is available from equipment manufacturers or consultants, or sponsored by AWWA or water operator organizations. Certain state or regional water agencies offer both training and loaner equipment for utilities to undertake periodic leak detection work.
6. Consider the following, when scheduling the leak detection survey:
   a. What types of ambient noise exist in the service area that may conflict with leak detection soundings? Noise interference comes from electric

transformers, building pumps, underground transportation systems (subways), traffic, and other sources. Noise interference can also come from activity associated with the water system, including nearby pumping, throttled or nearly closed valves, air releases, and users who routinely consume water at night. Urban areas have more noise than rural areas.

b. What time of day or night will be most effective to conduct the listening survey? Many large city water utilities schedule crews at night to avoid heavy daytime traffic and noise.

c. What type of protection is required for the leak crew when working in high-traffic or unsafe areas? Crews working at night require additional safety equipment than those working strictly in daylight.

d. What sequence is most effective to pinpoint suspected leaks? Some utilities concentrate on the initial listening phase for several days and pinpoint leaks at the end of the week.

e. What is the most effective route to follow in conducting leak detection? If DMAs are in place, high minimum-hour flows will set leak detection priorities. If leak detection is scheduled on a periodic basis, historically leak-prone areas warrant more frequent leak surveys than less leak-prone areas of the system.

f. What is the key leak survey and repair information to be captured? Forms should be designed and record-keeping procedures established. See the "Sample Leak Management Plan" and sample "Leak Detection Survey Daily Log" sidebars for planning and documenting the leak detection activity. Documentation is critical to identify leak trends in the system, measure program effectiveness, and to counter damage claims arising from leakage impacts on public or private property. Leak detection and repair information should be part of the work order management system.

g. How will leak detection crews communicate and work with repair crews to ensure effectiveness and resolve dry holes that occur when repair crews excavate but find no leaks where the leak detection crew instructed them to dig? Note: Leak detection does not abate leaks; only the repair or rehabilitation action can actually eliminate the leakage. Pressure management can reduce leakage rates and inhibit new leaks from occurring.

Conducting manual leak detection surveys. Water utility personnel often discover leaks fortuitously in the normal course of work, such as in valve exercising, fire hydrant flushing, and meter reading. Conducting a leak detection survey, however, means pursuing a systematic surveillance of the water distribution system to find hidden, unreported leaks. Many utilities survey their distribution systems according to zones or areas outlined on maps. Other utilities prioritize meter reading routes that may minimize distances in covering the system. Many target high-leakage areas more often than low-leakage areas. It is important to recognize that leaks are continuously forming in water distribution systems, and, although leak repairs remove leakages, potential always exists for new leaks to form. A leak could occur the day after leak repairs are conducted, the day before the next survey starts, or at any time in between. Therefore, the average awareness time for leaks occurring between surveys is taken as one half of the time interval between the surveys. If leak detection and repair are conducted annually, the average run time for new leaks occurring is one half of the year, or 182.5 days. Knowing the average run times of leaks based on leak survey frequency is important when performing LCA. Leak surveys are typically conducted in a process that includes four phases:

Sample Leakage Management Plan

Name of Water Utility: *County Water Company* Date: *1/18/2014*

I. Leakage Management Approach

After completing County Water Company's (CWC's) first annual water audit (see Figures 3-5 and 3-6) and leakage component analysis (LCA; see the "County Water Company—Part 6" sidebar), the CWC manager creates an ongoing leakage management program that (1) reduces the potentially recoverable leakage identified from the water audit and LCA, and (2) sustains lower leakage conditions once initial leakage reductions are achieved.

The LCA estimates 396 mil gal of potentially recoverable leakage. The initial economic intervention analysis concludes that, once the target leakage has been achieved, around one third of the system should be checked each year on an ongoing basis.

The CWC manager plans to improve pressure management in a portion of the CWC service area that is providing water pressures much higher than CWC's average level of 65 psi. Optimized pressure levels will be used to cut background leakage and reduce new water main break frequency in this area.

II. Leak Survey and Repair Plan

A. Leak Survey Area and Frequency

A-1. Based on records of previous leaks, type and age of piping, soil conditions, high pressure, and faulty installation practices, list the portion of the distribution system to be surveyed. List the survey frequency.

List the percentage of system to be surveyed each year: *33 percent*. Cover the entire system every three years. List frequency of surveys: *every year during spring to cover 33 percent of the distribution system.*

Describe each area to be surveyed under item B-2 of this plan.

A-2. Total miles of main to be surveyed: **(.33)(250) = 83 mi**

When calculating pipeline mileage, include the total length of pipe and exclude customer service connection piping. If only a portion of the system is surveyed, calculate the benefit-to-cost ratio for only the portion surveyed.

A-3. Average number of miles surveyed per day: **2.0**

Typical survey crews can survey about 2 miles of main per day. Factors include distances between services, traffic/safety conditions, and availability of listening contact points. Explain if more than 3 miles per day are surveyed: *Assume 2.0 mi/d using a comprehensive mix of manual survey and leak noise loggers.*

A-4. Number of working days needed to complete survey (divide line A-2 by line A-3): **41**

A-5. Describe personnel deployment: *Two-person crew performs leak survey in spring each year and assists distribution repair crews during colder season of year when the number of leakage events increases.*

B. Procedures and Equipment

B-1. Describe the procedures and equipment for detecting leaks. The best results are obtained by a comprehensive leak survey technique: listening for leaks at all system contact points (such as pit water meters or curb stops, valves, hydrants, and blow-offs).

Purchase leak detection equipment, including electronic listening devices and eight leak noise loggers. Attend manufacturer training seminars and state training. Listen on all contact points except the Downtown area.

B-2. Describe why the areas noted on the map in Step A-1 have the greatest recoverable leakage potential.

Year 1	*Year 2*	*Year 3*
The Valley District (area of high pressure)	*Remainder of Downtown area*	*Remainder of the system*
One quarter of Downtown (old ductile-iron mains)	*Steel mains more than 40 years old*	

B-3. If listening for leaks will not include all contact points, describe the plan for detecting leaks.

Rotate leak noise loggers in Downtown for nighttime listening; high traffic noise prevents daytime surveys.

Sidebar continues next page

Sample Leakage Management Plan (continued)

B-4. Describe the procedures and equipment to be used to pinpoint the exact location of detected leaks.

Use low-frequency ground microphones to listen over pavement surfaces. Deploy leak noise loggers in Downtown area for night surveys. Use consultant with leak correlator for difficult leak pinpointing.

B-5. Describe how the leak detection team and the repair crew will work together. How will they resolve the problem of excavations of suspected leak locations that prove not to be the leak source (dry holes)?

The leak detection crew and the repair crew will jointly excavate all leaks for the first three weeks and resolve any dry holes thereafter.

B-6. Describe the methods to be used to determine the flow rates for excavated leaks of various sizes.

Use Table 7-3 to estimate leakage rates for all types of leaks. The pressure adjustment equation will be used to calculate leakage rates for the level of water pressure encountered at each leak location.

C. Staffing

C-1. How many utility staff members will be used? **2**

Staffing costs including wages and benefits:
(Note: Night staff may require a higher wage.)

Person 1:	$/hr	*23.20*	$/d	*185.60*
Person 2:	$/hr	*15.75*	$/d	*126.00*
TOTAL			$/d	*311.60*

C-2. How many consultant staff members will be used? **1**

Cost of consultant staff:

Person 1:	$/hr	*60.00*	$/d	*480.00*
Person 2:	$/hr	*0*	$/d	*0*
TOTAL			$/d	*480.00*

D. Annual Leak Detection Survey Costs to Cover One Third of the Distribution System

Leak Detection Surveys	$/d	# of Days	Cost, $
D-1. Utility crew costs:	*311.60*	*41*	*12,776*
D-2. Consultant crew costs:	*480.00*	*16*	*7,680*
D-3. Vehicle costs:	*12.00*	*41*	*492*
D-4. Other:	—	—	*0*
D-5. Total survey costs:	—	—	*20,948*

E. Leak Detection Budget

E-1. Cost of leak detection equipment:*	$12,000 (Initial Cost)
E-2. Leak detection team training:	$3,000 (Initial Cost)
E-3. Leak detection survey costs:	$20,948 (Recurring Cost)
E-4. Total leak detection costs:	$35,948 (First-Year Cost) $20,948 (Year 2 and 3 Costs)

*Eight LNTs and other electronic equipment

Sidebar continues next page

Sample Leakage Management Plan (continued)

F. Leak Survey and Repair Schedule

Indicate realistic, practical dates:

F-1. When will the leak survey begin?	*Mar. 1, 2014*
F-2. When will the leak survey be completed?	*Aug. 6, 2014*
F-3. When will leak repairs begin?	*Mar. 15, 2014*
F-4. When will leak repairs be completed?	*Aug. 27, 2014*

III. Pressure Management/District Metered Area Plan

The average distribution system pressure for CWC is 65 psi; however, a lower elevation area known as the Valley District has an average pressure of 95 psi. The Valley District was developed 30 years ago and comprises 25 miles of pipeline, or 10 percent of CWC's total of 250 miles of pipeline. This area of the distribution system is supplied about 1 mgd on an average daily basis throughout the year, with a peak day of about 1.6 mgd. The Valley District also includes about 5 miles of plastic piping that CWC piloted 25 years ago. As detailed in the "Water Pressure and Leakage" section in chapter 6, failures on plastic pipe follow a variable path failure mode with high N1 exponents, meaning that leakage rates change rapidly with pressure. With high pressure and plastic piping, the Valley District's infrastructure incurs significant background leakage that has recovery potential via optimized pressure management. The LCA shown in the "County Water Company—Part 6" sidebar estimates 210 mil gal of background leakage and 396 mil gal of potentially recoverable leakage in the CWC system, with a proportionally larger volume of this leakage likely to exist in the Valley District.
The CWC manager employs pressure management in this area in addition to ongoing leak detection surveys as the key component of the new CWC leakage management plan. The manager also reviews the break frequencies before and after pressure management to assess to what extent these may have been influenced by the pressure management strategy. The Valley District might ultimately require a different frequency of leak survey intervention than the other areas of the CWC water distribution system.

When considering a new pressure management program for the Valley District, the CWC manager arranges for an engineering assessment to be conducted via the use of a calibrated hydraulic model to evaluate performance implications in advance of conducting actual system changes.

The Valley District is partially isolated from the larger CWC service area by natural boundaries of state park land and a railroad. The Valley District is supplied via four distribution mains size 10 in., 8 in., and 6 in. (2). By closing the two 6-in. supply mains, the Valley District can be configured into a DMA, or more specifically, a pressure management area. Pressure-reducing valves (PRVs) will be installed on the 10-in. and 8-in. mains. With this configuration temporarily established, baseline flow and pressure data are gathered using portable instruments. Typical daily flow ranges suggest that the Valley District DMA can be served by the 8-in. main routinely, with the 10-in. main providing supplemental flows in case of a high fire flow need or other emergency. The PRV on the 10-in. main is set to open at a designated low-trigger pressure level indicative of a high-flow, low-pressure emergency event. A flowmeter will be installed on the 8-in. main downstream of the PRV. An electronic controller will be installed at this primary supply site to allow flow-modulated pressure control to be used for optimal pressure management. To keep startup costs reasonable, CWC determines to keep data collection local, with CWC technicians visiting the primary inflow site every two weeks to download data from the electronic controller, which stores historical data. Minimum-hour flow data will be analyzed to determine leakage trends. Projected costs to establish the DMA with pressure management capabilities include

		Costs
Pressure-reducing valves:	8-in. diameter $2,200 10-in. diameter $4,100	$6,300
Flowmeter (electro-magnetic)	8-in. diameter $7,000	$7,000
Electronic controller	$7,000	$7,000
Precast manholes (2)	$1,200/manhole	$2,400
Misc. piping and hardware	$500	$500
Construction: labor	3 workers, 5 d $24/hr × 3 workers, 8 hr/d × 5 days	$2,880
Equipment: truck	$125/d × 5 days	$625
	Total cost:	$26,705

Sidebar continues next page

Sample Leakage Management Plan (continued)

IV. Leak Management Plan Summary

plan cost = leak survey cost + pressure management cost = $35,948 + $26,705 = $62,653, use $63,000

As discussed in the "County Water Company—Preliminary Leakage Loss Reduction Target-Setting Analysis" sidebar, CWC could strive to reduce up to 402 mil gal to lower its Infrastructure Leakage Index (ILI) from 8.8 to 4.0. The annual savings from this reduction would be $76,400 if this target could be achieved. The LCA in the "County Water Company—Part 6" sidebar notes that 396 mil gal of recoverable leakage exists, so, in theory, CWC could target a reduction close to an ILI value of 4.0. CWC's leakage plan first-year cost of $63,000 is slightly less than this full projected savings level, but after the first year, the leakage survey costs will reduce by $15,000 per year as one third of the system is subsequently checked each year, and the savings from the pressure management scheme will continue year to year without recurring costs, suggesting that the plan is economic to undertake. It has been determined to move forward with this plan and reevaluate it after the first- and third-year intervals.

Prepared by: *C.M. Biggs, Manager* Date: *Jan. 18, 2014*

Leak Detection Survey Daily Log

Name of Water Utility: *County Water Company* Date: *Apr. 17, 2014*
Leak Detection Team Members: *Lloyd Williams and Raymond Smith*
Equipment Used: *Leak noise loggers and ground microphone*
Area Surveyed: *7* Map Reference: *Water Distribution Map*
Street and Block Numbers: *San Antonio, San Gabriel*
Page & Coordinates: *San Juan, San Carlos, San Luis, San Miguel 8600 Block*

Leak Number	Location or Address of Suspected Leak	Utility or Customer (U or C)	Leak Pinpointed? (Y or N)	Leak to Be Rechecked? (Y or N)	Leak Repaired? (Y or N)	Not a Leak? (Date)
51	8959 San Antonio	U	Y	N	Y	
52	NW Corner Firestone & San Gabriel	U	Y	N	Y	
53	SW Corner Firestone & San Gabriel	U	Y	N	Y	
54	SW Corner San Juan & Southern	U	Y	N	Y	
55	8990 San Antonio	U	Y	N	Y	
56	8996 San Carlos	U	Y	N	Y	
57	8921 San Luis	U	Y	N	Y	
58	8659 San Miguel	U	Y	N	Y	

	Meters/ Curb Stops	Hydrants	Valves	Test Rods	Other
Indicate Number of Manual Listening Points Used	483	43	88	0	0
Indicate Number of Leak Noise Logger Listening Points Used	0	0	12	0	0
Miles of Mains Surveyed	3.14	Survey time		16	Hours
Number of Leaks Suspected	8	To be rechecked		8	(Number)
Number of Leaks Pinpointed	0	Pinpointing time		0	Hours

Remarks

Found a 50/50 percentage between valve stem packing leaks and small service meter leaks. Also found two customer sprinkler system leaks; violation notices were delivered to each customer informing them that they are required to arrange for repairs within 10 days.

1. Initial listening survey
2. Re-listening to suspect sounds
3. Leak pinpointing
4. Leak repairs and confirmation of pinpointing

The first three phases are detailed in the following sections with the fourth item discussed in the "Speed and Quality of Repairs: Optimized Leak Repair Functions" section later in this chapter.

Initial listening survey. During this phase, a trained operator conducts an initial listening survey of a large portion of, or the entire, distribution system, recording all suspect sounds. Leak detection is a process of discovery and elimination. The goal is to discover the contact points where leak noises can be heard and eliminate the contact points where leak sounds are not heard. A contact point is any accessible connection to the water main that transmits sound vibrations. This can be a fire hydrant, curb stop, valve, or probe rod touching a section of the water main. The addresses should be noted of all locations where water use, meter sounds, or possible leak sounds exist. This initial search through each area of the system can be conducted quickly. Prior to the start of the listening survey, a leak detection and repair plan should be prepared, like those shown previously in the "Sample Leakage Management Plan" and "Leak Detection Survey Daily Log" sidebars for CWC. Blank forms of the plan and the log are also given in appendix B.

Sound travels a long distance on metallic mains, so listening at contact points allows the listener to hear the sounds of leakage along the length of the main between the points. Sound travels roughly half the distance on nonmetallic mains, such as polyvinyl chloride (PVC), and additional effort is required during listening surveys on nonmetallic pipe. If sound does not carry the entire length of the pipe from one contact point to another, and no other contact points can be found in between, the leak detection staff needs to listen over the main itself with a ground microphone. Figure 7-15 shows the wide variation of sound velocities in pipelines of different materials.

Several factors influence how far sound will travel along nonmetallic lines, including system pressure and pipe diameter. The sensitivity of listening equipment also limits the length of pipe along which sounds can be heard. To determine whether it is necessary to listen directly over mains in addition to contact points, perform the following test:

1. Listen over the main with a ground microphone.
2. Have a co-worker turn on a hose bib at a customer's service.
3. Determine how far along the main the sound of water escaping from the hose bib can be heard.

If the distance between contact points is greater than the distance that the sound travels along the main, the ground microphone should be used to listen over the main at appropriate intervals between 10 ft and 50 ft.

Many sounds can interfere with leak detection equipment. Sounds from customer consumption inside a dwelling include use of showers, toilets, washing machines, pumps, and meters. Even the sound of people talking may be picked up by listening equipment. Sounds from outside a dwelling can be caused by aircraft, wind and rain, street traffic, interference from power lines or transformers, radio broadcasting, or lawn watering. Sounds from water noises usually come from adjacent leaks, valves, or turbulence. All of the sounds may be transmitted through leak detection equipment, making it difficult to isolate and identify leak noises. Faulty equipment, loose electrical connections, improper training, or system pressure less than 15 psi can also obscure or modify leak noises.

Re-listening to suspect sounds. Because of variations in extraneous noise, even at night, it is often beneficial to revisit suspicious noise areas at a later time. The high-frequency contact microphone should be used to listen again for the sounds heard earlier. If the location is quiet, there is no leak. Where practical and where sounds are heard, the meter should be checked to see if it is running; a running meter indicates water consumption. If the meter cannot be accessed, it may be useful to return when the customer is present to view the meter or briefly shut off the service at the curb stop to determine if the source of noise is coming from the customer side of the curb shutoff. If sounds can still be heard when there is no water being consumed, a leak probably exists. That leak must be pinpointed.

Limitations of acoustic leak detection surveys. The use of acoustic listening instruments is a proven procedure for identifying and localizing hidden leakage. However, research organizations and practical experience have demonstrated that acoustic listening only on valves and hydrants or the ground surface leads to many unreported leaks being overlooked. Consequently, for effective leakage-reduction programs using acoustic surveys, soundings should also be performed on all service connections.

The major disadvantages of this approach include the following factors:

- This approach is labor intensive.
- A higher skill level of personnel is required.
- It is difficult to maintain efficient performance.
- There are low daily coverage rates.
- Locating customer service connection piping is often difficult and slow.
- There is limited success on nonmetallic pipes.

Acoustic leak survey results can be optimized by using nighttime operations, uninterrupted listening, and extended listening periods. Nighttime operations add to the safety risk and cost of the work. Automated leak detection methods are an alternative to manual leak detection surveys and may improve the efficiency of the leak detection process.

Automating acoustic leak detection surveys. The "Leak Noise Monitors" subsection earlier in this chapter discusses the technology that provides an automated way to conduct area-wide or localized leak detection surveys. This technology includes leak noise loggers (LNLs) and leak noise transmitters (LNTs). Leak noise monitors technology gives the capability of consistent listening and sound recording, and reduces labor needs. In 2005, American Water began a successful trial using LNT technology in conjunction with an existing AMR system to detect leak sounds and communicate their positions using the same communication network that sends the customer meter reading (Hughes 2005). Small LNTs are attached to customer service connection pipes at specified intervals. These devices monitor sound during the overnight period and select the time of least noise and communicate the data through the AMR system for evaluation at the distribution office. As suspected leaks are identified, staff is dispatched with a leak noise correlator to confirm a leak and pinpoint its location in one trip. An increasing number of leak detection firms are working with AMR/AMI equipment manufacturers to provide advancements to this approach. This is an outstanding example of a water utility employing new technology in an innovative manner to optimize leak detection capability, reduce labor needs, and improve efficiency.

Because the LNT finds leaks when they become audible, a well-spaced deployment of the LNT units can find many leaks at an early stage. For systems with slowly developing leaks (customer service connection piping leaks, pipe joint leaks, and main corrosion leaks), the discovery of leaks and their approximate location at an early stage can significantly reduce unreported leakage loss. Such small leaks can run for an extended period at relatively low flows that may be below discernible capabilities of a DMA. The economics of repairing such low-flow leaks can be based on the benefits from prevention in avoiding eruption into larger leaks or main breaks, rather than the lost water cost alone. However, the LNT can have appreciable lost-water benefit where the cost of water (CV) is high or the area is prone to non-surfacing leakage.

In addition to the approach used by American Water, which mounts small LNTs on customer service connection piping within customer premises, LNTs that are designed for mounting on distribution systems appurtenances, such as valves, are now being manufactured. These devices are designed to communicate within a fixed-network AMI system, just as the LNTs communicate within the AMR configuration. Cellular communications technology can also be employed to transmit the collected data from LNTs to the central data repository, potentially reducing the investment required for fixed network–based data collection.

The most effective leakage management approach uses the appropriate combination of leakage control techniques, as shown in Figure 7-1. Continuous flow monitoring in DMAs provides detection of rising leakage and suggests the opportune time to launch leak detection activities, whether manually or via leak noise loggers. Where applicable, pressure management slows the occurrence of new leaks and can reduce leakage rates from background leakage and unreported leaks. Additionally, water utilities should employ both optimized repair functions and a long-term rehabilitation/renewal program. The proper application and combination of these useful technologies will serve as the best approach to achieve economic leakage management for most water utilities.

Leak pinpointing. The objectives of pinpointing leaks are (1) to determine whether the leak sound is leakage, customer water consumption, or some other noise; and (2) to determine the leak's exact location. Pinpointing the leak can take place with a subsequent field trip after a conventional leak detection survey or it might be conducted during the leak detection listening or re-listening survey. The latter practice is more likely performed when working at night to avoid high noise. Where customer service leaks are suspected as a leak source, a daytime inspection when the customer might allow access to the meter and plumbing may be preferred.

After the initial listening survey, the leak detection team should return to locations of suspected leaks and again listen for the leak sounds. The area should be inspected, paying attention to both sight and sound, using a sonic amplifier and a digital readout, if possible. What might be a leak sound may actually be caused by a PRV, electrical transformer, or other interference.

The survey team should review detailed distribution system maps and locate PRVs, forgotten valves, or other system apparatuses that might make the suspect sound. If, when inspecting the area, another possible cause of the sound is found, the sound should be isolated and identified or quieted temporarily. For example, a customer PRV can be isolated by shutting off the customer service and then bleeding the pressure off the system by opening the customer's hose bib. It should be noted that some large consumers (apartment complexes, hospitals, three-shift industries) can use water on a more or less continuous basis and generate a leak-like sound. The customer should be contacted before shutting off the service. During inspection, the team should be aware of sources of extraneous sound such as nearby electrical facilities or mechanical equipment.

If the leak noise is heard on a customer water meter, the team should listen carefully for leak sounds on both sides of the meter. A determination should be made as to whether the sound is louder on the customer side or the utility side of the meter. Look for obvious signs of customer use, such as sprinklers operating. In this case, the meter may be heard turning, even if the meter hand is not moving. The meter indicator should then be checked for movement; the leak may be in the area of the meter box.

If it is difficult to identify which side of the meter the leak is on, the customer should be notified that the service will be shut off for a few minutes. The angle valve or curb stop should be closed and the system pressure bled from the customer's line by opening the hose bib. If the leak sound stops, the leak is either within the meter box, on the customer's service connection piping, or in the dwelling. If the noise continues, the leak is on the water utility's side of the meter. If the leak is on the customer side of the meter, the customer should be notified that there may be a leak on their service connection piping, interior plumbing, or water-using fixtures. Water utilities typically have policies in place stating how customer service connection piping and plumbing leaks are to be addressed.

If a leak is on the water main or the customer service connection piping, the leak sound may be detectable on adjacent service meters, valves, or hydrants. Listen for sounds of leakage on services adjacent to the suspected meter and determine where the sound is the loudest. Pinpointing the exact location can be accomplished using several methods, as detailed in the following sections.

Ground-microphone method. The objective of this method is to find the location of the loudest leak sound over the main or customer service connection piping. The first step is to determine the exact location of the main or service. An electronic pipe locator can be used to locate the buried main or customer service connection piping. The location of the main or customer service connection piping should be marked precisely on the pavement. Other nearby pipes from which the sound might be coming should be located.

Ground microphones are either monophonic or stereophonic, depending on the manufacture. Stereo models can discern differences in intensity between two microphones, but most models have only one microphone.

When using the ground microphone for pinpointing leaks, the volume should be set relatively low at the beginning, so loud sounds will not be uncomfortable to the staff member listening. The volume adjustment should be kept at the same level throughout each pinpointing sequence. If uncomfortably loud sounds are heard, the volume can be reduced for safety, and the points should be surveyed again to locate the loudest leak sounds. The ground microphone should be used to listen for leak sounds every 5 to 10 ft. Notes should be taken on the sounds intensities. If the equipment has a meter, meter readings should be made. The strongest signal usually indicates the location of the leak. The setting of the volume or other controls should not be changed during this process. Where possible, comparing sounds at points with different surface and compaction characteristics should be avoided. If this is not possible, it should be noted that the same leak sound is quieter at a loosely compacted surface than at a dense one. After pinpointing the leak, its location should be verified by re-listening using the ground microphone. The ground microphone is reliable in pinpointing many leaks but is limited by the existence of interfering noise, thickness of ground cover or pavement, and operator skill level. Ground microphones work best on flat, smooth surfaces; the ground should be prepared as best as practical, or a flat plate (thumb tack) should be used.

Correlator method. See the description given in the "Leak Noise Correlator" subsection earlier in this chapter. Leak correlators are often used directly but may also be used in conjunction with correlating electronic LNLs.

Probe method. This method provides access directly to underground piping for better sounding and is used to double-check the findings when using the ground-microphone or correlator method. A small hole should be drilled through the pavement and down to the pipe over the suspected leak, taking care not to damage the pipe. A metal rod with a handle designed not to slip through the drilled hole (T-handle or equivalent) is inserted into the hole, and a high-frequency sonic microphone is used to listen again for the sound of leakage. Additional holes through the pavement or ground may be drilled as necessary, while trying to keep the rod insertion at a consistent depth. In unpaved areas, the probe can be used as an extension to listen directly on the buried pipe.

Note: For safety and to prevent interruption of service, other utilities should be contacted for clearance before starting to drill. Many areas have a one-call, underground-protection center to clear all utilities from a single communication point of contact. After pinpointing the leak, the pavement should be marked above the exact location of the leak. All information on the leak is recorded in a detection log and turned in for work orders to repair.

Inline leak detection sensor. See the description in the "Inline Leak Detection Sensor" subsection earlier in this chapter for this accurate leak-locating technology, which is used mostly on large-diameter transmission piping.

The accuracy of leak pinpointing cannot be confirmed until the leak has been identified by exposing and/or repairing it, and then perhaps by performing leak detection again to confirm the absence of leak evidence. Repair methods are discussed in detail in the "Speed and Quality of Repairs: Optimized Leak Repair Functions" section later in this chapter. Pinpointing should be closely coordinated with repair activities so that confirmation of the pinpointing success or failure is immediately known. Particularly for customer service connection piping leaks where customers arrange for repairs, leak detection personnel should stay in contact with the customer to determine if the leak detection crew accurately pinpointed the leak. Statistics on pinpointing success should be recorded so that the efficiency of the leak detection program is periodically reevaluated and improved.

There will likely be occasions where the field crew excavates and comes close but not exactly over the leak. The leak pinpointing staff should be available to investigate this condition and determine whether a better location can be found and possible reasons why the leak location was not precise. There will also likely be times when the repair crew excavates and finds no evidence of a leak, a dry hole. If there is no physical evidence of a leak in the area, the leak pinpointing staff must be ready to respond immediately to investigate to prevent lost crew time. The excavated point provides an opportunity to listen directly on the pipe to determine if there is a leak noise in the area. These events, though undesirable, help the leak pinpointing staff to improve their skill level in the future.

Nonacoustic Leak Detection

Although it is the most common technique for leak detection in water distribution systems, acoustic leak detection is just one means of detecting leaks in pressurized water piping systems. Several other techniques have been developed to identify leaks in this piping. While these techniques each have certain advantages, they may also have limitations. These techniques are currently in use commercially to varying degrees. Research continues on some of these and other new methods.

Tracer gas method. Particularly for situations where leaks cannot be detected or pinpointed by traditional acoustic methods, tracer gas leak detection may be effective in identifying leaks. Very small leaks often evidence as hydrostatic test failures on new pipelines awaiting commissioning after construction. They are usually very small and are hard to detect. Tracer gas leak detection initially keyed on these types of leaks but has proven effective for detecting and pinpointing leaks in a wide variety of pipeline situations, both for dewatered pipelines and pressurized pipelines in service. Use of this technology on pressurized pipelines has advanced considerably in recent years.

The tracer gas method uses one of two potential gases: hydrogen and helium. Gas is injected into the pressurized pipeline through standard pipe fittings (standard tap or fire hydrant) and the gas travels with the flow of the water in pressurized pipelines, or toward a vented outlet on dewatered pipelines. As the liquid exits the leak, it returns to a gaseous form. Walking directly over the test section of pipe, the operator uses a specialized instrument that continuously senses the atmosphere at grade. The instrument is highly sensitive and can detect minor seepages of gas to atmosphere. When gas is detected at the surface, the instrument's variable sensitivity setting can quickly verify and pinpoint the leak location. If the surface over the pipe is covered with asphalt or concrete, or soil conditions include frost, it may be necessary to place test holes directly over pipe, normally at 10-ft intervals along the pipe run, to allow the gas to vent to atmosphere.

Tracer gas leak detection technology is suited for any pipe material or any diameter, and can identify leaks that do not generate audible leak noise. It can be used for very long runs of pipeline and is particularly suited for large-diameter mains such as transmission mains where there are very few or distant access points for listening via acoustic leak detection methods.

For detection using hydrogen gas, it is not necessary to dewater the main because the mixture (less than 5 percent) is injected in a liquid form into the water. The gas mixture is a standard mixture of 5 percent hydrogen in nitrogen, purchased already mixed from a gas supplier. **CAUTION: The actual blending of hydrogen and nitrogen is a highly hazardous operation that should only be undertaken by the gas supplier.** Do not handle hydrogen gas in any form other than ready-mixed to 5 percent hydrogen in nitrogen, or less. Any hydrogen–nitrogen mixture containing less than 5.7 percent hydrogen is non-flammable (ISO 10156:2010).

The use of helium gas as a tracer is perhaps more straightforward than the use of hydrogen. The helium gas being used is NSF/ANSI Standard 60 certified for Drinking Water Treatment Chemicals (NSF International 2015). Helium gas was traditionally used to detect very small leaks on dewatered, newly constructed pipeline awaiting commissioning; however, helium gas can now be injected into active, pressurized water mains, with no need to isolate a zone, nor depressurize or shut down the water system. Once the gas is injected into the water main, it mixes with the flowing water and travels throughout the pipe network to the desired area for the leak detection survey. When the helium "marked" water leaves the pipe network—through leaks in the pipe wall, or through loose connections, or at service laterals, meters, or valves—the helium gas separates from the water. Since helium is five times lighter than air, the helium floats to the earth's surface where it can be measured with specialized monitoring equipment. Elevated levels of helium detected above a leaking pipeline indicate a leak is nearby.

Features of helium tracer gas leak detection include

- effective on all pipe sizes and materials, and is particularly suited for nonmetallic and large-diameter pipelines with limited access points;
- not limited by "noise" or electrical interference, system geometry, or length of piping;
- less intrusive than other technologies that insert sensors inside the pipeline;
- uses standard tap or fire hydrant for injection;
- relative ease of implementation; and
- can be used to address challenges of
  - long runs,
  - low/intermittent pressures,
  - high pressures, and
  - changing pipe geometry (connections, angles, joints, butterfly valves).

The helium gas is injected through a standard ¾-in. corporation stop or fire hydrant installed on a water main, pipe, or appurtenance upstream of the area to be surveyed for leaks. Pipeline geometry (connections and turns), pipe diameter changes, or butterfly valves do not interfere with the technology. Helium leak detection is precise; very small leaks can be identified. For example, on a helium gas survey conducted in recent years in Pennsylvania, a 1.8-gpm leak was found on polyethylene plastic pipe (Utility Service Group 2013). This leak was undetectable using acoustic technologies. Tracer gas leak detection has particular advantages in a number of circumstances encountered by water utilities. Since the handling of gases requires specialized skills and equipment, this technology is not typically provided by in-house water utility personnel but instead is provided by specialized service providers who contract with water utilities to conduct the leak detection survey.

Ground-penetrating radar. This method could, in principle, be used to detect leaks in water pipes by detecting underground voids created by leaking water as it circulates near the pipe or by detecting anomalies in the pipe depth as measured by radar. Soil that is saturated by leaking water slows down radar waves and makes the pipe appear deeper than it should be. Ground-penetrating radar (GPR) is similar in principle to seismic and ultrasound techniques. A transmitting antenna sends a short-duration pulse of high-frequency electromagnetic energy into the ground. The pulse is partially reflected back to the ground surface by buried objects or voids in the ground or by boundaries between soil layers that have different dielectric properties. Reflected radar signals are captured by a receiving antenna. The ground's interior is scanned with radar waves in a manner similar to that of ultrasound to obtain cross-sectional images (Hunaidi et al. 2002).

Because the method relies on detecting underground voids around leaks, soil conditions are a factor in the accuracy of the method. Impermeable clay soils may produce different leak-locating characteristics than sandy soils. Other limitations of the method include the requirement for sophisticated equipment and user skill. This technique is not widely used in North American water utilities. However, as research continues, it may find practical application as another effective leak detection tool. GPR may also prove useful in pinpointing the location of the leaking pipe if not the leak itself.

Thermography. This technique detects thermal infrared radiation and displays it as visible images. In an infrared radiation image, the ground surface above a leak may appear cooler or warmer than the surface farther away from it. This temperature difference may reflect variations in the temperature of leaking water and the overlying soil; considerable heat may be transferred between leaking water and surface soil. Also, soil close to the leak becomes saturated by leaking water, which may change its thermal characteristics and make it a more effective heat sink relative to dry soil away from the leak. A thermographic survey of an area uses a high-resolution commercial infrared camera system. The camera should be focused on the ground surface and should capture images over a period of time.

This technique, which also requires sophisticated equipment and user skill, may be affected by many variables, including ambient temperatures of air and soil, relative humidity, seasonal effects, and others (Hunaidi et al. 2002). Thermography is not yet available commercially in an affordable, user-friendly package.

Summarizing Leak Detection Methods and Equipment

The technique and art of leak detection continue to see advances. Leak detection is essential to control leakage to economic levels in water distribution systems. Because new leaks are always occurring in water distribution systems (only the rate of occurrence varies), the water utility should have at hand leak detection and repair capabilities at all times, rather than on a periodic, infrequent basis. Many effective means exist to detect, pinpoint, and abate leaks, but it is up to the management of the water utility to proactively apply these methods.

FURTHER REAL LOSS INTERVENTION METHODS

Active leakage control is a key activity in the four pillars of real loss control, as shown in Figure 7-1. It provides the capability to identify newly forming leaks in a timely fashion. Once an appropriate active leakage control process is in place to quantify leakage volumes and identify individual leaks, appropriate additional intervention procedures must exist to abate leakage via repair or replacement, or otherwise reduce the leakage volumes to economic levels. Each tool has its place in the tool box and should be used as appropriate. The following intervention activities are the remaining three activities of the four pillars of a successful leakage management program, shown in Figure 7-1:

- Speed and quality of repairs: optimized leak repair functions for reported and unreported leaks (short-term actions)
- Pressure management (short-, medium-, and long-term programs)
- Infrastructure renewal and replacement (long-term program)

These activities are discussed in the following sections. When the water utility manager becomes familiar with the advantages and limitations of each of these activities, a strategy can be devised that features the optimum balance of these techniques.

Speed and Quality of Repairs: Optimized Leak Repair Functions

Active leakage control, which includes leak detection surveys and the ability to quantify leakage rates from continuous monitoring of minimum-hour flows in DMAs, alerts the water utility operator to the occurrence of leaks in the water distribution system. Neither of these techniques actually reduces any leakage, however. Once leakage is known to exist at a specific location or across a region of the water distribution system, interventions must be undertaken to abate or reduce the leakage. Leakage interventions should be

- **Timely—**Leak repairs should be implemented soon after the discovery of the leak to minimize leak run time and to contain disruptive effects of the leakage, thereby maintaining good customer relations and avoiding unnecessary liability. Where possible, repairs should be scheduled during favorable working conditions and during the normal working hours of staff.
- **Reliable—**Because of poor workmanship or inferior materials, many leaks recur at the site of previous leak repairs. Repair work should be executed with quality in mind, providing a lasting improvement to the water pipeline.
- **Cost-effective—**Leak abatement programs should be economic, with the annual costs of the program not exceeding the direct savings of the recovered leakage, along with indirect savings of less disruption, deferred infrastructure expansion, and similar savings. Additional factors, such as water quality, enter into a decision to replace or rehabilitate pipelines.
- **Well documented—**The success of the leakage management strategy cannot be weighed until leakage has been corrected and information on the nature of the leak obtained. The repair action is often the critical step in obtaining this information; therefore, a detailed, systematic documentation procedure should be employed to manage the important information to be collected.

Traditional leak repairs have several important steps, including excavation of the pipeline, executing the leak repair, information collection and documentation, and restoration of the street or ground cover above the pipeline. These steps are detailed in the following sections.

Excavating the leak. Water distribution systems are composed of buried pipes and, unless leaks are visible in underground chambers or manholes, leak repairs typically require excavation to expose the leaking section of pipe. The leak detection crew and the repair crew should work together to uncover the leak.

If the excavation is dry—meaning the pipe is not leaking at this location—the leak survey crew should again sound the piping and assist the repair crew in pinpointing the leak. Leaks emanating from the bottom of the pipe can be easily overlooked, and effort should be made to excavate around the full circumference of the pipe to confirm any such leakage. Sometimes a leak source can exist and give no visible sign of dampness or water only several inches away. It should be noted that locations where water is visible or surfacing may not be the location of the leak source. Water from a leak may travel a significant distance from the leak source via underground conduits or undermined soil. Excavating a site based solely on the fact that it is the location of visible water can be a wasteful effort leading only to an intact pipeline. The location of the excavation should be based on the pinpointed leak source from the leak detection activity.

By working together, the leak detection and repair crews can share knowledge and experience that make locating the leak easier. Uncovering leaks requires careful excavation to avoid contacting neighboring underground utilities. Other utilities or the appropriate one-call center should be contacted before digging.

Measuring and estimating losses from discovered leaks. Obtaining a measure of the amount of water lost from leaks is important to gauge the success of the leakage management program and provide data for calculation of real losses in the annual water audit. For larger volume leaks or outright ruptures, distinct changes in metered flow may be registered in DMAs, on SCADA systems, or master meters at water treatment plants, tanks, pumping stations, PRVs, or other existing metering locations. Information from hydraulic models, transmission main flow gauging, and fire flow tests can be assessed to help distinguish routine flows from higher demand flows from main breaks or large ruptures.

To quantify the rate of water loss from a low-volume leak in the field, the type of leak should be noted (main leak, service leak, etc.) so that the awareness, location, and repair times can be determined for the LCA. The configuration (circular hole, split, crack, etc.) of the leak should also be identified if possible. There are several ways to quantify leakage rates:

- Directly by leak type, using Table 7-3.
- By calculating losses using modified-orifice and friction-loss formulas; see Tables 7-4 and 7-5. Table 7-4 applies to circular holes in pipelines. Table 7-5 applies to joint leaks and cracks in pipelines.
- By manual methods, such as using a container of known volume and a stopwatch, or by using a hose and a meter; see Table 7-6. These methods apply to small leaks from valves, meters, pumps, and so forth.

In many cases, it is impractical to obtain a reliable description of the leak opening (circular, crack, etc.) or the size of the opening. In these cases, Table 7-3 can be used directly to quantify a leakage rate, based merely on the leak type.

Reference table. The most accurate way to determine the amount of water lost from a leak or main break event is to obtain a measure of the size of the hole or crack at the leak site and apply one of the following quantification techniques. However, it is often impractical for repair crews to obtain a good assessment of the breech in the piping because of the difficulties in conducting repairs in sloppy trenches, possibly at night, often in subfreezing temperatures, and with emphasis to complete repairs quickly to restore service to customers.

In the event that actual leak measurements cannot be taken, the leak detection supervisor can refer to the values of leakage losses listed in Table 7-3. Leakage rates vary primarily by types of leaks and pressure. A rate of leakage can be easily taken from the various

Table 7-3 Leakage flow rates for metallic piping systems

		Leakage Flow Rate at 70 psi				CWC Leakage Flow Rate at 65 psi*			
		Unreported		Reported		Unreported		Reported	
Type of Leak or Break	Diameter	gpm	mgd	gpm	mgd	gpm	mgd	gpm	mgd
Appurtenances									
Fire hydrant	—	3.5	0.005	3.5	0.005	3.37	0.0048	3.37	0.0048
Valve	—	6.9	0.010	6.9	0.010	6.65	0.0096	6.65	0.0096
Customer service connection piping leaks, all sizes	—	6.9	0.010	6.9	0.010	6.65	0.0096	6.65	0.0096
Water Mains									
Joint leak or repair band leak	6 in.	10.4	0.015	10.4	0.015	10.0	0.014	10.0	0.014
Joint leak or repair band leak	8 in.	17.3	0.025	17.3	0.025	16.7	0.024	16.7	0.024
Joint leak or repair band leak	10–48 in.	27.8	0.040	27.8	0.040	23.7	0.034	23.7	0.034
Circumferential crack	4 in.	34.7	0.050	69.4	0.100	33.4	0.048	66.9	0.096
Circumferential crack	6 in.	55.5	0.080	111.1	0.160	53.5	0.077	107.0	0.154
Circumferential crack	8 in.	76.3	0.110	152.6	0.220	73.5	0.106	147.0	0.212
Circumferential crack	10 in.	93.8	0.135	187.6	0.270	90.4	0.130	180.8	0.260
Circumferential crack	12 in.	111.1	0.160	222.2	0.320	107.0	0.154	214.1	0.308
Longitudinal crack or split bell	6 in.	69.4	0.100	138.9	0.200	66.9	0.096	133.8	0.193
Longitudinal crack or split bell	8 in.	93.8	0.135	187.6	0.270	90.4	0.130	180.8	0.260
Longitudinal crack or split bell	10 in.	111.1	0.160	222.2	0.320	107.0	0.154	214.1	0.308
Longitudinal crack or split bell	12 in.	138.9	0.200	277.8	0.400	133.8	0.193	267.7	0.385

* Leakage rate at 65 psi = (Leakage rate at 70 psi)[$(65/70)^{0.5}$]

Source: *Bristol Water Services 2001*

types listed in Table 7-3 and then corrected for the actual pressure. The leakage rate at the actual pressure P_a can be determined by applying Eq. 7-24:

$$\text{leakage rate at actual pressure } P_a = (\text{leakage rate at 70 psi})[(P_a/70)^{0.5}] \quad (7\text{-}24)$$

Note that the exponent of 0.5 in Eq. 7-24 relates to metallic piping systems. Flexible (plastic) piping systems have a higher exponent value, typically 1.0 or 1.5, but could be as high as 2.5.

Table 7-3 can be applied to the example of CWC, where the average water pressure is 65 psi. The average pressure across the entire distribution system can be applied to the total of leak events during the audit year. Alternatively, if pressures vary across the system, leak events can be grouped and leakage rates determined at the respective pressure levels in each pressure zone or region of the water distribution system.

Calculation method. Of the several means to obtain leakage rates from leak opening measurements in the field, this is the simplest method to perform; however, it requires calculations. The method is helpful for large leaks where the flow is too great to measure and the main must be valved off. It requires measuring the size and shape of the hole and

Table 7-4 Leakage losses for circular holes under different pressures*

Diameter of Hole (in.)	Area of Hole (in.^{2})	Leak Losses (gpm)									
		20	40	60	80	100	120	140	160	180	200
0.1	0.007	1.067	1.510	1.850	2.136	2.388	2.616	2.825	3.021	3.204	3.337
0.2	0.031	4.271	6.041	7.399	8.544	9.522	10.464	11.302	12.083	12.816	13.509
0.3	0.070	9.611	13.59.	16.648	19.224	21.493	23.544	25.430	27.186	28.835	30.395
0.4	0.125	17.081	24.165	29.597	34.175	38.209	41.856	45.209	48.331	51.263	54.036
0.5	0.196	26.699	37.758	46.245	53.399	59.702	65.400	70.640	75.518	80.098	84.431
0.6	0.282	38.477	54.372	66.593	76.894	85.971	94.176	101.721	108.745	115.341	121.581
0.7	0.384	52.331	74.007	90.640	104.662	117.010	128.184	138.454	148.014	156.993	165.485
0.8	0.502	68.350	96.662	118.387	136.701	152.840	167.424	180.839	193.325	205.052	216.144
0.9	0.636	86.506	122.338	149.833	173.012	193.434	211.896	228.874	244.676	259.519	273.557
1.0	0.785	106.798	151.035	184.979	213.596	238.807	261.600	282.561	302.070	320.394	337.725
1.1	0.950	129.225	182.752	223.825	258.451	288.957	316.536	341.898	365.505	387.676	408.647
1.2	1.131	153.789	217.490	266.370	307.578	343.882	376.704	406.887	434.981	461.367	486.323
1.3	1.327	180.48	255.249	312.615	360.977	403.584	442.104	477.527	510.498	541.465	570.755
1.4	1.539	209.324	296.028	362.559	418.648	468.062	512.737	553.819	592.057	627.972	661.941
1.5	1.767	240.295	339.829	416.203	480.590	537.317	588.601	635.762	679.658	720.886	759.880
1.6	2.011	273.402	386.649	473.547	546.805	611.347	669.697	723.355	773.299	820.208	864.575
1.7	2.270	308.646	436.491	534.590	617.292	690.153	756.025	816.600	872.983	925.938	976.024
1.8	2.545	346.025	489.353	599.333	692.050	773.736	847.585	915.496	978.707	1,038.070	1,094.220
1.9	2.836	385.540	545.237	667.776	771.081	862.095	944.378	1,020.040	1,080.470	1,156.620	1,219.180
2.0	3.142	427.191	604.140	739.918	854.283	955.230	1,046.400	1,130.240	1,208.280	1,281.570	1,350.890

*Calculated using Greeley's formula (see Eq. 7-25)

determining the line pressure. A pressure gauge or a handheld Pitot blade could be used to determine the pressure of the water coming from the leak or a nearby fire hydrant. This method also makes assumptions regarding the shape of the hole, which may introduce error.

For losses from such items as pipes or broken taps, an orifice coefficient of 0.80 is assumed and the flow calculated in gallons per minute from Eq. 7-25 (Greeley's formula), which is applied in Table 7-4:

$$Q = \frac{43{,}767}{1{,}440} \times A \times P^{0.5} \tag{7-25}$$

Where:

Q = flow (gpm)
A = the cross-sectional area of the leak (in.^{2})
P = pressure (psi)

If a hole in a pipe were circular, the area would be $A = 3.14\ r^2$. The diameter of the hole should be measured (divide this by one half to give the radius, r), and the pressure in the pipe should be determined.

Table 7-5 Leakage losses for joints and cracks*

Area of Joint or Crack		Leak Losses (gpm)									
		Water Pressure (psi)									
Length (in.)	Width (in.)	20	40	60	80	100	120	140	160	180	200
1.0	1⁄32	3.2	4.5	5.5	6.4	7.1	7.8	8.4	9.0	9.6	10.1
1.0	1⁄16	6.4	9.0	11.0	12.7	14.2	15.6	16.9	18.0	19.1	20.1
1.0	⅛	12.7	18.0	22.1	25.5	28.5	31.2	33.7	36.0	38.2	40.3
1.0	¼	25.5	36.0	44.1	51.0	57.0	62.4	67.4	72.1	76.5	80.6

*For leaks emitted from joints and cracked service pipes (rigid pipe), an orifice coefficient of 0.60 is used in the following equation:

$$Q = (22.796)(A)(P^{0.5})$$

Where: Q = flow (in gpm); A = area (in in.^{2}); P = pressure (in psi).

Table 7-6 Drips per second and cups per minute converted to gallons per minute

Drips per Second	Gallons per Minute	8-oz Cups per Minute	Gallons per Minute
1	0.006	0.25	0.016
2	0.012	0.50	0.031
3	0.018	0.75	0.047
4	0.024	1.00	0.062
5	0.030	1.50	0.094
		2.00	0.125
		2.50	0.156
		3.00	0.188
		3.50	0.219
		4.00	0.250

Note: Five drips per second amounts to a steady stream.

$$Q = (95.436)(r^2)(P^{0.5}) \quad (7\text{-}26)$$

Where:

Q = flow (gpm)
r = radius (in.)
P = pressure (psi)

Bucket-and-stopwatch method. The bucket-and-stopwatch method is as simple as its name. A container is held against the leak for a predetermined time period. The time is measured with a stopwatch. The water captured is measured with a measuring cup or other container of known volume. Then the time and volume are converted to gallons per minute (see Table 7-6). Time intervals that are convenient for the calculation should be used. The leaking water should be caught for 1 minute, and the volume collected is the per-minute flow. For other time periods, see Table 7-7. Table 7-6 provides the conversion from cups per minute to gallons per minute.

To convert gallons per minute to million gallons for a 2-year time period (the average lifetime of a leak if leak surveys are conducted every 4 years), use the following:

Table 7-7 Multipliers for bucket-and-stopwatch method

Time in seconds:	6	10	15	30	
Multiply volume in gallons by:	10	6	4	2	To get gallons per minute

$$\begin{gathered}(1 \text{ gpm})(60 \text{ min/hr})(24 \text{ hr/d})(365 \text{ d/year})(2 \text{ years}) \\ \text{a leak of 1.0 gpm for 2 years} = 1{,}051{,}200 \text{ gal} = 1.051 \text{ mil gal}\end{gathered} \tag{7-27}$$

The bucket-and-stopwatch method is most practical for very small leaks where the drip of water can be reliably captured in a convenient measuring container. It becomes impractical for moderate to large leaks with a strong and/or divergent spray. Measuring large, spraying leaks can be attempted by draping an enveloping device (such as a large canvas, rain jacket, or inverted pail) over the leak and diverting the water into a container.

Hose-and-meter method. This is the most direct method of measuring leaks, but it requires some mechanical effort. A hose is connected to the leak and the flow directed through a meter. Then, the meter can simply be read. Unfortunately, this method is rarely practical for leaks occurring in field conditions.

Leak repair techniques. Leakage occurrences happen in many ways, and the means of repairing leaks are equally numerous. Therefore, this discussion cannot offer an exhaustive account of all of the repair techniques that are available. Instead, only a few of the most common repair techniques are mentioned. The water utility operator or manager is ultimately responsible to ascertain the appropriate repair technique for any given leak condition, based on the nature of the leak, the pipeline materials and construction, how the pipeline is situated (heavily trafficked road, congested underground utilities, excessive depth of cover, etc.), and hydraulic priority. Utility personnel are urged to confer with pipe manufacturers, engineering consultants, AWWA, or other trade organizations to obtain information on the best repair technique and materials for a given repair project.

The level of complexity of leak repair is usually commensurate with the severity of the leak or break. The following are several examples of typical repairs and considerations:

- Small leaks of a few drips per minute can occur from loose packing on a valve or pump. Simply tightening the bolts on a packing gland might quickly resolve this type of leak.
- Customer service connection leaks occur frequently in water utilities. Depending on repair policies, the water utility or the customer may arrange for a repair to a leak (replacing the damaged section of otherwise sound pipe) or outright replacement, if there is evidence that the entire service is deteriorated. A replacement line can be installed in parallel to the leaking line, and then the leaking pipe can be disconnected. This might be required in areas where customer service connection piping made of lead or other outmoded materials exist. There are trenchless alternatives to replace existing pipe including moling and pipe bursting (where the existing pipe is pushed aside and a new pipe pulled into place.)
- One of the most common repair techniques for small-to-medium-sized pipelines is the use of repair clamps to repair ruptures, such as shown in Figure 7-24. These devices can be quickly installed to repair reported ruptures or breaks and are reliable for many years.
- Pipeline joints are often the site of smaller leaks occurring because of worn joint materials, uneven settlement of pipe lengths, traffic loadings, and similar causes. The type of repair depends on the type of existing joint. For larger pipes, clamps specifically designed to encapsulate the bell are available. Some joints can be

Figure 7-24 Repair clamps are commonly used to repair circumferential ruptures on distribution piping since they are quick to install and are highly durable

Courtesy of Halifax Water, Halifax, Nova Scotia, Canada

recaulked, while others, such as split bell-ends of pipe, may need to be cut out and replaced by coupling in lengths of straight pipe.

- For larger ruptures or splits in pipelines, the effective repair may require cutting and extracting the damaged section of piping, and installing one or more lengths of new pipe, coupled or connected to the existing pipeline. This may result in the new length of pipe of one material differing from the surrounding existing pipeline material. For metallic systems, be sure to take into consideration the potential for accelerated external corrosion when coupling components of different metals. Protections, such as bonded joints, may be needed to avoid accelerated corrosion from occurring at such sites.
- Specific pipe materials require specific repair techniques. Many leak repairs on steel pipe, which is highly susceptible to corrosion, can be repaired by welding. Different plastic pipe materials are used in the water industry, and repairs require specific tools and equipment to perform repairs.

A variety of repair techniques are possible, and the potential for water utility personnel to innovate their own repair method is always present. Many unusual pipeline configurations exist, particularly in older systems, so the rule to “expect the unexpected” applies. Weighing the costs associated with making multiple repairs on the same pipe segment against costs to replace that segment can assist the water utility in developing a sound basis for planning its leakage management program. Again, regardless of the repair method, leak repairs should be timely, reliable, and cost-effective to sustain the full benefits of the leakage management program.

An important note regarding sanitary leak repair practices: Leaks and water main breaks present an opportunity for contaminants to enter the water distribution system. The nature of the leak event and the degree of sanitary care exercised by the repair crew will dictate whether additional sanitary methods (flushing, disinfection) are needed for the system to provide continuing service. Most regulatory agencies require that a boil-water order be issued when pressure to the customer drops below an acceptable minimum, typically 20 psi. The water utility should comply with state and local requirements.

Most small leaks occurring under pressure release water from the pipe or appurtenance with little chance of contamination. These leaks can usually be repaired directly without dewatering the pipeline or appurtenance. Under these circumstances, no additional sanitary steps are needed to complete the repair. Conversely, significant ruptures often cause considerable damage and carry a strong likelihood of pipeline contamination.

This can occur during the rupture event as a result of reduced pressures causing backflow conditions, or after the pipeline is shut down and dewatered, drawing contaminated water, soil, and debris into the damaged section of pipeline. In such cases, steps must be taken to ensure that the repaired or replaced section of pipeline is properly disinfected before it is returned to service.

In all cases, crews should use clean work practices in executing repairs, including protecting existing or replacement pipe sections from contamination, using chlorine spray solutions on components that are handled, and similar safeguards. When pipelines have suffered obvious contamination of soil and debris, the utility should disinfect the entire pipeline affected by the rupture. Loss of pressure from large leaks also raises the potential for backsiphonage from customer service connection piping in the area. At a minimum, the affected pipes should be well flushed with a disinfectant residual detected after the repair is made. Detailed guidance exists in several publications (AWWA 2005, Pierson et al. 2001).

Customer service connection piping leak repair policy. In most North American water utilities, responsibility for leakage repairs on customer service connection piping is shared by the utility and the customer. Usually, the water utility has responsibility for the connection piping from the water main to the meter (if outdoors in a meter pit) or at a curb stop or property line (if the meter is located indoors). A small percentage of water utilities assign customers ownership (and leak repair responsibility) of the entire customer service connection piping branching from the water main. As discussed in the "A Further Word on Customer Service Connection Piping Leakage" section in chapter 6, the ability to contain leak run time is critical to an effective leakage management strategy. Policies that rely on customers to arrange for repair or replacement of their own service connection piping inherently require more time to implement than programs where the water utility is responsible for the repair. If the customer owns the entire service connection piping, they are often more reluctant to make arrangements for repair. It is very feasible for water utilities to operate customer service connection piping leak repair programs that efficiently implement repairs in 2–4 days after a leak is discovered. For most customer-arranged repairs, response time typically averages several weeks. The longer leaks run, the greater the leakage losses.

To operate efficient leakage control programs and to save customers the effort and aggravation of arranging leak repairs, many water utilities operate service connection piping insurance or warranty programs. For a small additional fee included in their regular billing, customers can rely on the water utility to make all arrangements for service connection piping repair or replacement when leaks arise, and pay no additional costs. These approaches generally handle service connection piping leaks more efficiently than customer-arranged repairs and help to improve customer relations. Water utilities should track response and repair times, and if they require customers to arrange repairs, the utilities should consider reevaluating this approach as a means to reduce the duration of customer service leaks occurring in their system.

Leak repair information collection and documentation. During and after leak repairs, it is important that information is gathered and documented regarding the nature of the leak or break, the repair method, the underground conditions, street, weather, and costs. Information should be recorded on leak repair reports shown in Figures 7-3 through 7-6. These forms exist in spreadsheet software and can be downloaded from the Water Research Foundation Web site under Project 4372a. This information is needed to conduct a real loss component analysis, to keep appropriate records for legal purposes as well as to identify leakage trends and distribution system condition, and to track the performance of utility staff. It is useful to determine the proportion of failures occurring on main, fittings, and service connections. Additional information might be collected depending on local conditions and priorities. Possible parameters might include the time that a repair crew was called in, the times that water service was disrupted and restored, paving requirements, valves closed to execute shutdowns, fire hydrants operated, chlorine residual, and other useful information. Having data in the electronic format of the spreadsheet software allows for subsequent analysis of the types of pipe that fail, the possible causes, and their locations. Location data is extremely useful in making future decisions about pipe renewal priorities. Data on the annual results of the leakage management activities can also be summarized as shown in the "Leakage Management Program Cost-Effectiveness" sidebar.

Restoring the street surface or ground cover. The final step in the repair process for underground utilities is the restoration of the street surface or ground cover. Excavations of underground utilities are disruptive and unsightly. Traffic is frequently diverted around excavations and delays often occur. Excavations are a safety issue for both the water utility workers and the public. Dust and dirt are common at such sites, and noise from crews and heavy equipment can be a nuisance to the general public and nearby businesses. It is therefore essential that the repair crews give importance to the safe, timely, and efficient restoration of the site after the leakage repair is conducted. The water utility should establish and maintain a good rapport with local and state highway departments to coordinate safe and timely street restorations and paving. This will ensure good public relations and limit unnecessary liability for the water utility.

Pressure Management

Pressure management for leakage control is defined as the practice of managing system pressures to the optimum levels of service, ensuring sufficient and efficient supply to legitimate uses and consumers, while reducing unnecessary or excess pressures, eliminating transients and faulty level controls, all of which cause the distribution system to leak unnecessarily.

Traditionally, the only cost savings used in the calculation of benefit–cost ratio for introducing retrospective pressure management in a particular location was the financial savings in the predicted reduction of leak flow rates (leakage volume saved multiplied by the marginal cost of water). However, since 2006, members of the Pressure Management Team of the IWA Water Loss Specialist Group have developed increasingly reliable methods for quantitative predictions of reductions in break (burst) frequency on mains and services, which result in additional operational cost savings, and also sometimes in extension of residual infrastructure life. These and other additional benefits (Table 7-8) have transformed the economics of pressure management, which is now being implemented in some countries as a means of asset and energy management, rather than simply for leakage control.

Various tools are available for use within the pressure management tool box, which include

- transient control,
- pressure sustaining or relief,
- altitude and level control in tanks and water storage facilities,
- implementation of controlled pressure management areas (often in conjunction with DMAs), and
- pressure stabilization and reduction.

The latter tool is probably the most widely used for leakage control and is often referred to as *proactive pressure management*. However, all of these approaches can provide benefits of leakage control and infrastructure sustainability. It is important to know which tools to apply under specific conditions in the water distribution system.

Leakage Management Program Cost-Effectiveness

Name of Water Utility: *County Water Company*
Name of Report Preparer: *C.M. Biggs*
Date: *9/6/2014*

Leak Detection Survey

Total Number of Days Leak Surveys Were Conducted: 121
First Survey Date: 3/26/2014 Last Survey Date: 5/23/2014

	Meters	Hydrants	Valves	Test Rods	Other
Number of Listening Points:	4,025	862	1,605	0	17

Number of Suspected Leaks: 58
Number of Pinpointed Leaks: 42
Survey Time: 312 hours
Miles of Main Surveyed: 82
Pinpointing Time: 80 hours

$$\text{average survey rate} = \frac{\text{miles of main surveyed} \times 8\ \text{hr/d}}{\text{total survey and pinpointing hours}} = 1.67\ \text{mi/d}$$

Total number of visible leaks reported since survey started, from other sources (not discovered during leak detection surveys): 0

Leak Repair Summary

First Leak Repair Made: 3/29/2014
Last Leak Repair Made: 6/28/2014

Number of Repairs Needing Excavation: 37
Number of Repairs Not Needing Excavation: 21
Total Number of Repaired Leaks: 58

Total Water Losses From Excavated Leaks: 203.5 gpm
Total Water Losses From Non-Excavated Leaks: 78.9 gpm
Total Water Losses: 282.4 gpm

	Excavated Leak Repair Costs	Non-Excavated Leak Repair Costs	Total Repair Costs
Materials:	$699.36	$411.68	$1,111.04
Labor:	$4,377.39	$2,255.72	$6,633.11
Equipment:	$561.40	$248.75	$810.15
Other:	$35.00	$83.50	$118.50
Subtotal:	$5,673.15	$2,999.65	$8,672.80

A. Leak Survey and Repair Program

Step 1. Calculate the value of water recovered, Vwr, from all repaired leaks.

Vwr = (total leakage recovered in gpm)(average leak duration)(water cost, Wc)

Ave leak duration = ½ of CWC's new 3-year leak survey interval = 547 days

Note: The cost-effectiveness for the 3-year interval will be reviewed to see that volumes recovered—once backlogs are removed—still warrant this survey interval.

Wc = short-term variable cost of water = $190/mil gal (See Water Audit, Figure 3-5)

Vwr = 282.4 gpm × 1,440 min/d × 547 d × $190/mil gal × 1 mil gal/1,000,000 = $42,264

Step 2. Assemble Leak Survey Program Costs: from the "Sample Leakage Management Plan" sidebar, Section E. $35,948

Step 3. Divide Vwr (from Step 1) by the total costs (calculated in Step 2).

$$\text{benefit/cost ratio (B:C)} = \frac{\text{value of water recovered}}{\text{total cost of leak detection survey}} = \frac{\$42{,}264}{\$35{,}948} = 1.18$$

For planning continuing leak detection efforts, calculate average survey costs per mile.

Sidebar continues next page

Leakage Management Program Cost-Effectiveness (continued)

Step 4. Determine average survey costs per mile of main surveyed for 3-year cycle (C/mi).

$$C/mi = \frac{\text{3-year leak survey cost}}{\text{total number of miles surveyed}} = \frac{\$35{,}948 + \$20{,}948 + \$20{,}948}{256 \text{ mi}} = \underline{\$304/mi}$$

At $304/mi the projected results are somewhat more expensive than the assumed value of $250/mi (see the "County Water Company—Part 5" sidebar). Still, the program has a strong payback of $35,948/$42,264 = 0.85 year or just over 10 months, so it is cost-effective.

B. Pressure Management Program

Step 1. Calculate the value of background leakage recovered, Vbr, from optimized pressures. Vbr—Assume that ½ of CWC's target background leakage (210 mil gal/year) and potentially recoverable leakage (396 mil gal/year) occurs in the Valley District. One half of (210 + 396) = 303 mil gal/year. Again assume ½ of this volume, or 151.50 mil gal/year, is recovered.

Average leak duration: because the background leakage reduction occurs all year, the average background leak duration is 365 days.

$$Vbr = 151.50 \text{ mil gal} \times \$190/\text{mil gal} = \underline{\$28{,}785}$$

Step 2. Assemble Pressure Management Program Costs: from the Pressure Management/District Metered Area Plan, Part III of the "Sample Leakage Management Plan" sidebar: $26,705

Step 3. Divide Vbr (from Step 1) by the total costs (calculated in Step 2).

$$\text{benefit/cost ratio (B:C)} = \frac{\text{value of water recovered}}{\text{total cost of leak detection survey}} = \frac{\$28{,}785}{\$26{,}705} = 1.08$$

Step 4. Determine payback period for pressure control equipment = $\frac{\$26{,}705}{\$28{,}785} = 0.93$

The pressure control equipment has a life of many years, and payback occurs in just under 1 year, thus the pressure management program is projected to be cost-effective.

Typical pressure variations in North American water distribution systems. Most water distribution systems are designed to provide a minimum working pressure at all points in the system throughout the day. This means that the minimum pressure occurs at some critical point in the system, which is often the highest point in the system, the point furthest from the pressurized source of supply, the point that suffers the greatest head loss, or some combination of these conditions. In striving to attain at least this minimum level of service to the most sensitive location (critical point), the vast majority of the water distribution system may receive pressures that are much higher than this minimal level. While focusing carefully to meet minimal pressure guidelines, many water utilities know little about the maximal pressure occurring in their system day by day. As a consequence of existing pump outputs and tank levels, the pressures within many systems are considered relatively fixed. For many larger water utilities with extended lengths of main over highly variable terrain, there is an inclination to continue extending the water system as a single pressure zone with a resulting increase in *backpressure* at the water delivery source: treatment plant effluent, high service pumps, and so on. This adds to the effect of excessive pressure across a wide portion of the distribution system. As discussed in chapter 6 and displayed in Table 6-1, average pressure data for 233 North American water utilities with validated water audit data found the average of the 233 systems to be 76 psi, but the average for 91 of these systems (40 percent) to be 97.7 psi. Generally, a pressure of 80 psi is

Table 7-8 Multiple benefits of pressure management in water distribution systems

Pressure Management: Reduction of Excess Average and Maximum Pressures								
Conservation Benefits			Water Utility Benefits				Customer Benefits	
Reduced Flow Rates			Reduced Frequency of Breaks (Bursts) and Leaks					
Reduced excess or unwanted consumption	Reduced flow rates of leaks and breaks (bursts)	Reduced and more efficient use of energy	Reduced repair and reinstatement costs, mains and services	Reduced liability costs and reduced bad publicity	Deferred renewals and extended asset life	Reduced cost of active leakage control	Fewer customer complaints	Fewer problems on customer plumbing and appliances

Note: Based on Australian WSAA PPS-3 Project 2008-11 (WSAA 2008), with addition of energy component

taken as an accepted upper limit of a normal operating range for water distribution systems. With many systems averaging almost 98 psi, this indicates that excessive pressure exists in many North American water utilities and strong opportunity exists to explore the benefits for improved pressure management in systems like these across North America.

Figure 7-25 displays a hydrograph of water and pressure supplied to a zone in a typical North American water system. As is typical in most water distribution systems, the graph shows that this DMA experiences significant fluctuations in water demand throughout the day—peak consumption periods at the start of daytime activities and in the evening, coupled with off-peak periods of low demand often, but not always, during overnight periods. At the time of minimal customer consumption (during nighttime hours in many but not all systems), head loss in the system may be near its lowest and pressures might be approaching their maximum. Conversely, peak water demands coincide with periods of minimum pressure in many water distribution systems. This traditional water distribution supply pattern of ensuring guideline minimum pressures during maximum water demand periods results in excessive pressure much of the remaining time in the day.

Some systems may also experience seasonal fluctuations caused by high demands from irrigation during dry growing seasons or by tourist populations flocking to resort areas on a seasonal basis. These conditions can significantly increase water demands on a regular, periodic basis. Again, as a result of traditional design methodology, some water distribution systems may experience excessive pressure during off-season periods—pressure that likely has the potential to be economically reduced. The risks of high pressure at minimum water demands is evident from the fact that major breaks in many water utilities tend to occur during the late evening and early morning hours when system pressures are at their highest or transients occur as a result of reduction (or increase) in pumping or rapid shutoff of system storage reservoirs or tanks that have completed daily filling.

Most of the roughly +50,000 community water utilities in North America perform basic methods of pressure management through the use of booster stations, level controls, and pressure zones. Refining their pressure management may not be a significant additional step for many of these utilities because they already employ basic controls. However, many of the same utilities likely do not have a full understanding of the significant range of financial and operational benefits that may be possible from improved leakage control and water main break prevention when employing optimized pressure management.

Benefits of optimized pressure management. The two primary objectives of pressure management for leakage control and infrastructure sustainability are to

1. reduce the frequency of new leaks and breaks occurring within a water distribution system; and
2. reduce the flow rates of those leaks and breaks and background leakage that cannot be avoided.

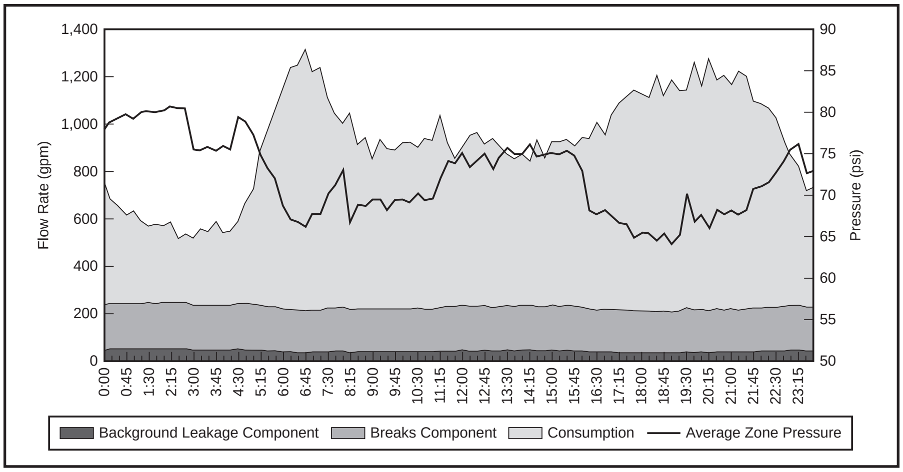


Figure 7-25 Pressure and flow variations in a DMA without specific pressure management controls

Source: *Thornton 2005*

Pressure management and infrastructure replacement/rehabilitation are the only real loss control methods that reduce background leak flow rates. Background leakage is very sensitive to water pressure. Because infrastructure replacement/rehabilitation is the most comprehensive, and most costly, real loss reduction method, pressure management has a major advantage of often being the most cost-effective tool for systems with high background leakage and excessive pressures.

Proactive pressure management cannot be applied universally across all water distribution systems; it is very system specific in the degree to which it can be applied and the benefits derived. Changes in pressure management strategy generally cannot be employed where pressures are consistently at or near the low service-level requirements of the water utility. Such changes may not provide cost-effective improvements where background leakage and break frequencies on both mains and services are low. Therefore, pressure at specific key points and repair frequencies on mains and services (separately) should always be assessed in the development of a pressure management strategy and optimization controls implemented when projected to be successful and cost-effective.

Common questions raised by water utility managers with respect to pressure management techniques include suspicion that customer consumption and revenue will be reduced, fire flow capability will suffer, and other hydraulic limitations will exist. Where such effects exist, they are usually addressed by good engineering at a cost that is more than offset by other benefits. As detailed later in this section, all of these questions can be predicted and addressed through a competent design process and seldom are an impediment to optimized pressure management where this technique is otherwise deemed applicable.

Reducing break frequencies through pressure management. The most reliable results for this type of research are likely to be derived from analysis of "before and after" break frequencies in individual systems in which pressure management has been implemented. Members of the IWA Water Loss Specialist Group Pressure Management Team, and utilities and consultants internationally, have published many case studies where pressure management has produced immediate, significant, and sustained reductions in new break frequencies. Lambert, Fantozzi, and Thornton (2013) provide a number of such references. Also, since 2006, methods have been developed and refined for predicting the relationships between maximum pressure and

- water main break frequency per 100 miles per year (normally excluding fire hydrant and valve leaks), and
- service connection leak frequency per 1,000 service connections/year (excluding small leaks at meters and curb stops).

In many water distribution systems, the presence or absence of pressure surges, or pressure transients, is a major factor in the frequency of occurrence of water main and service pipe breaks and leaks. These brief but dramatic increases in pressure can be caused by pump activation and deactivation, control valves opening or closing too quickly, tank filling operations, or sudden large water demands from industrial consumers, wholesale water utilities, or other large draws. Because they are usually very brief in nature, pressure transients can only be measured over very short time periods, of the order of one second or less, but precise data-logging instruments are now readily available for measuring transients in all types of supply zones, including those supplied by gravity. In developing the pressure and leakage management strategy, consideration should be given to launching an evaluation of the operations and function of pumps, control valves, tanks, and important hydraulic controls to determine if opportunity for harmful transients exists and if cost-effective controls can be incorporated into the strategy.

Most breaks and leaks on water mains and service connections occur because of a combination of water pressure and other contributory environmental and local factors, rather than any single influence. Figure 7-26 shows how reduction of excess pressure in the Durban Central Business District (CBD) in Durban, South Africa, reduced not only the average main break (burst) frequency, but also the seasonal variation. Excess pressure can be considered in simple terms as “the straw that breaks the camel’s back” in exerting the additional stress to trigger many water main breaks.

Similar reductions in service pipe burst frequency were achieved in Durban CBD and there are many such case study examples internationally. Specific predictions for zones with high annual average burst frequencies are given by a prediction method outlined in Figure 7-27, based on research suggesting that good predictions can be obtained by

- assuming annual average burst frequency BF for any zone consists of two components; BFnpd (non-pressure dependent) and BFpd (pressure-dependent);
- each zone has its own current value of BF corresponding to the current maximum pressure at the Average Zone Point, AZPmax;
- pressure-dependent burst frequency BFpd varies with $AZPmax^{N2}$, where N2 ~ 3;
- BFnpd can be assessed from plots of BF and AZPmax for low burst frequency zones; and
- changes in BFpd (and in BF) can then be predicted for any change in AZPmax.

As water pipes deteriorate over time as a result of corrosion, traffic loadings, pressure transients, and other local and seasonal factors, the pressure at which failure occurs gradually reduces until at some point in time, break frequency starts to increase significantly. Pressure management rationale suggests that surges and excess pressures should be removed where possible to prevent the operating pressure from that point where the failure rate increases significantly, thus extending the life of the individual infrastructure components. If a distribution system with low background leakage undergoes leak detection and repairs with a significant reduction of unreported leakage, it might be more vulnerable to surges and excess pressure if the elimination of leaks, in effect, removes an unstructured form of surge relief that each leak (openings in the pipe) offers. Without appropriate pressure control, a system with such a leakage reduction will operate as a “tighter” system and incur higher pressure, making it more vulnerable to surge. Because

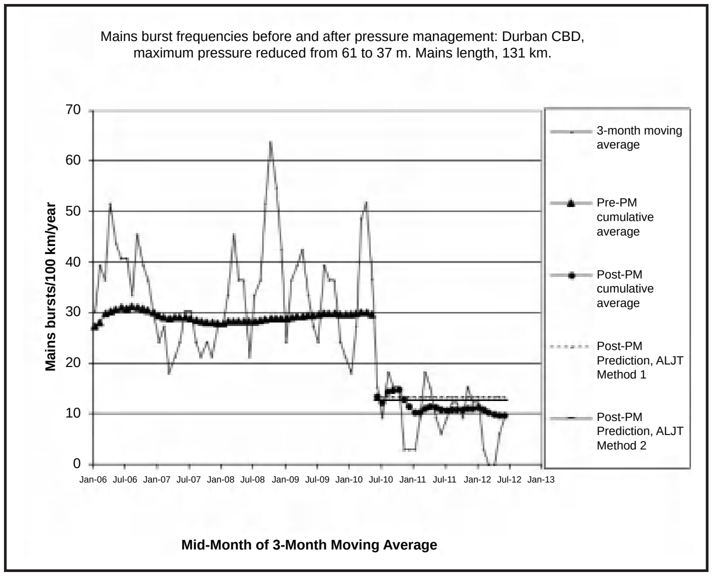


Figure 7-26 Pressure management changes water mains repair frequency in the Durban Central Business District in South Africa

Source: *Data from Ethekwini Water (South Africa)/JOAT/WLR and A Ltd*

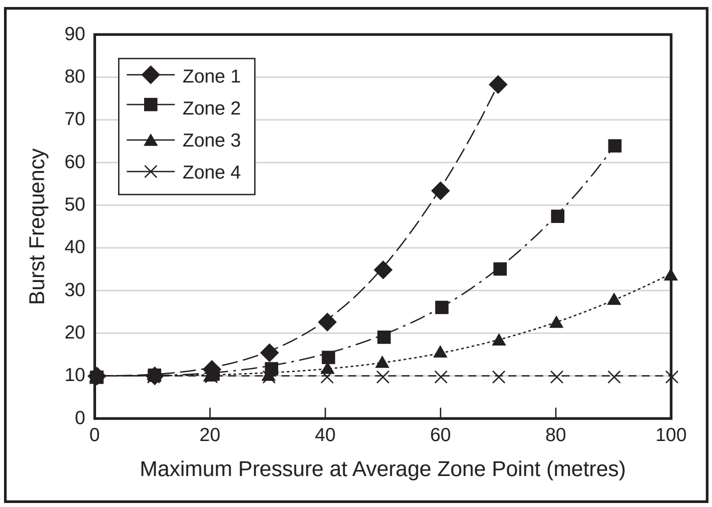


Figure 7-27 General approach to predict changes in annual break (burst) frequency

Source: *Lambert, A.: Leakage Reductions—The Fundamental Role of Pressure Management.* Water World Magazine, *March 2013*

of this, it is important to consider pressure effects throughout the leakage management strategy. In some leakage management projects, pressure controls have been installed prior to the initial leak survey to keep pressures from rising after repairs are conducted.

The US drinking water industry has experienced a growing concern in recent years about deteriorating water infrastructure and the looming high cost of renewing infrastructure to retain reliable water service in the future. In several prominent surveys conducted to gauge the extent of infrastructure needs, many of the water utilities based their condition assessments on the growing frequency of water main breaks as a primary factor in projecting near-term extensive replacement needs. An underlying assumption is that infrastructure replacement is the primary improvement option for long-term infrastructure sustainability. Yet, pressure management can reduce main breaks and extend the life of existing infrastructure while employing methods that are much less costly than complete pipeline renewal. All pipelines eventually require renewal; however, pressure management has the benefit of ensuring that pipelines obtain a full service life, with fewer failures, before outright renewal is required.

Influence of pressure on leakage rates and certain consumption components. The "Water Pressure and Leakage" section in chapter 6 explains the influence of pressure on leakage flow rates, based on the FAVAD (fixed and variable area discharge paths) theory and principles. The N1 exponent for individual small systems, zones, or DMAs can be calculated via a pressure step test in the field. In this test, using a single water supply main, the inlet pressure to the area is reduced in increments or steps, and reductions in inflow rate and the pressure at the AZP are measured. This test provides the data to calculate the N1 value. Care should be taken so as not to lower pressures so severely that customer service is impacted, resulting in low-pressure complaints. Step tests can be performed during the night or minimum-hour conditions to minimize customer impacts.

Some components of customer water consumption also vary with pressure and can be represented using an exponent N3 in the FAVAD equations. N3 exponent values range from 0 (pressure independent, for example, after a storage tank) to 0.5 (open tap) or 0.75 (for sprinkler systems with numerous small orifices). By separating consumption into indoors and outdoors components with N3 values of 0.04 and 0.45, respectively, the FAVAD concept has been successfully applied to predictions of consumption reduction from pressure management in direct pressure systems (Lambert and Fantozzi 2010).

Assessing the potential for leakage reduction through optimized pressure management. The assessment process for proactive pressure management potential is similar to the process used in designing DMAs. In fact, in many cases, the design of DMAs with improved pressure management is conducted in a single comprehensive process. Several tasks should be undertaken to properly assess whether pressure reduction will be suitable for a particular DMA, zone, or distribution grid including the following:

- *Desktop study to identify potential zones, installation points, and issues*—Inspect maps or GIS records to identify areas of potentially high or excessive pressure, and lay out a preliminary configuration of a prospective pressure managed area (PMA). The area must be controllable, or able to be isolated from the general system naturally or by a series of valve closures. One or more pressure-reducing valves (PRVs) may be used if hydraulically necessary. At this stage, it is especially helpful to have input from the water utility field staff who operate the system on a daily basis, because they are often aware of localized problems, such as low carrying capacity or partially closed valves, which need to be resolved prior to field measurements and analysis.
- *Customer consumption analysis to identify consumer types, control limitations, and direct vs. indirect use*—Review customer consumption records to identify the categories of consumption: residential (indoor/outdoor), commercial, industrial, emergency, and so on. A primary focus of this analysis is to identify whether reduced pressures will negatively affect portions of customer consumption so as to negate the potential benefits of the pressure management to the level where it is no longer viable. A full year of consumption records should be reviewed to take into account any significant seasonal variations in customer consumption.
- *Preliminary benefit–cost analysis*—An initial estimated benefit–cost ratio should be calculated at this stage to identify the economic feasibility for real loss recovery in the pressure management scheme. Approximations relying on operator knowledge and preliminary estimations can be used at this stage, because a more detailed benefit–cost analysis can be conducted once field data is collected.

A potential loss in revenue should only be included in the calculation if water conservation is not considered as an objective of the program.

- *Flow and pressure measurements in the field*—If the desktop analysis indicates a good potential for leakage reduction via pressure management, field measurements should be undertaken. Flow should be measured, and the daily, weekly, and, when necessary, seasonal variations in water demand in the prospective PMA should be captured. Pressure should be recorded at the supply point to the potential district, at the AZP, and the point of lowest pressure, the critical point (CP). These measurements provide the data needed to perform the detailed benefit–cost calculation and serve as the design basis for the pressure management scheme. The data can be input into hydraulic models or specialized pressure management models to predict loss control outcomes and benefits.
- *Identification of control methods and devices (PRVs, and related equipment)*—The field data should be analyzed to decide on the type of control, the control limits, and the configuration of the control device. The traditional pressure management installation employs a PRV, in series on a single supply feed to a PMA but with a bypass of larger piping to provide higher flows under an emergency condition. Alternatively, a second PRV can be installed at a location along the PMA boundary at an opposite side of the PMA. The second PRV can be configured as a standby feed, set to open only when the outlet pressure drops to a preset low level indicative of a high emergency flow condition. Once the control devices are identified, modeling can help determine the best pressure control regime to obtain the optimum supply and leakage control conditions.
- *Final benefit–cost analysis*—Once a proposed pressure management design has been assembled, the estimated costs of the project should be weighed against cost savings of the projected benefits. Often the main benefit is a direct cost savings from the reduction of lost water valued at the variable production cost. The *variable production cost* is defined as the variable cost to treat and deliver the next unit of water. Usually power and water treatment chemicals are the main components; however, if a system is approaching maximum capacity, deferred or avoided cost to build a new pumping station or treatment plant should be used. The variable production cost may also be wholesale cost or a user fee, if a utility purchases water from another utility or must pay for its water rights, respectively. In the case of water utilities employing water conservation programs caused by limited water resources and growing populations, the savings might be valued at the customer retail cost of water using the basis that any recovered leakage volumes can be sold to new customers. In addition to variable production cost savings, utilities are finding that new break frequencies are reduced after the implementation of pressure management. This can have a dramatic effect on infrastructure sustainability by extending pipeline life and containing infrastructure replacement costs. This will also provide a distinct direct benefit of avoided damage and repair costs of main breaks that are avoided in the PMA. There may also be indirect benefits to pressure management such as deferment of water main replacement or rehabilitation costs because of the extended life of the infrastructure that may be gained via the pressure management. The utility should study any potential indirect benefits and include them in the economic assessment if they apply.

By following these steps, a rational planning approach to pressure management can be conducted, with anticipated levels of loss control benefits, costs, and impacts projected.

Approaches to optimized pressure management in water distribution systems. Many approaches exist to incorporate optimized pressure management into water distribution operations, some of which are described here.

- *Pump controls.* Pumps are common in most water distribution systems and are typically activated and deactivated depending on system water demand that often includes maintaining appropriate elevated tank levels. Good pump control schemes incorporate a slow starting and slow stopping valve on the discharge side of the pump that inhibits the creation of transients in the distribution system, thereby minimizing risks of resultant leaks and breaks on system piping. Pumping systems employing variable-frequency drives (VFDs) can often meet widely varying water demands with fewer pump changes than systems without VFDs. Improvements in hydraulic efficiency, such as use of VFDs, might also be accompanied by improved energy efficiency. It is likely that many water distribution systems experience surges related to pump activation everyday and an opportunity for cost-effective refinement of pump operations exists in these systems.
- *Pressure zones.* As a result of variations in topography, pumped pressure zones are established to ensure that minimum pressures can be provided to critical areas, particularly to sections of the water distribution grid at higher elevations. Pressure zones represent the broadest level of sectorization, with DMAs the finest level of sectorization, in many water utilities throughout the world. Pressure zones represent the most basic method of configuring the water distribution system for efficient pressure management and are in common use in many North American water utilities. Figure 7-28 shows the pressure zone configuration for the Philadelphia Water Department's service area. Subsectors, such as DMAs, are divided by physical valving with boundaries often dictated by natural or human-made features like water bodies or highways, respectively. Pressure zones are usually quite large in medium- to large-sized water utilities and often have multiple supply feeds; therefore, they do not usually develop localized hydraulic problems because of valve closures. Systems with gravity feeds are usually configured based on ground elevations and systems with pumped feeds configured depending on the level of elevated tanks or storage reservoirs. The boundaries of existing pressure zones, and the typical pressure variations within them, should be well understood in the planning of a pressure management strategy.
- *Pressure-reducing valves.* PRVs are commonly used in water distribution systems and other hydraulic applications. As featured in Figure 7-29, PRVs are designed to automatically reduce an inlet pressure to a designated lower outlet pressure and maintain the constant outlet pressure despite varying flows. This type of control is known as fixed outlet control. Separate electronic controllers, or controls provided by PRV manufacturers, can be connected to PRVs to provide a range of additional control capabilities. Because topography can present significant challenges in providing consistent pressures in many water distribution systems, PRVs are highly effective in reducing excessive pressures in certain sections of a distribution grid subject to widely varying pressure.

Other means also exist to maintain good pressure management in a water distribution system. However, the above list represents the most basic and common means in use, and these approaches should be carefully considered if they are not already in use in the water utility.

A note of caution regarding throttled valves: Many system operators recognize the need for reducing system pressure at certain locations in their distribution systems. It is not uncommon for operators to throttle, or partially close, a gate or butterfly valve to create a head loss and reduce pressure. This method is not recommended, as the head loss created will change as system water demand changes, and excessive wear can occur across the gates or disc of the valve. Cavitation may also occur, risking additional

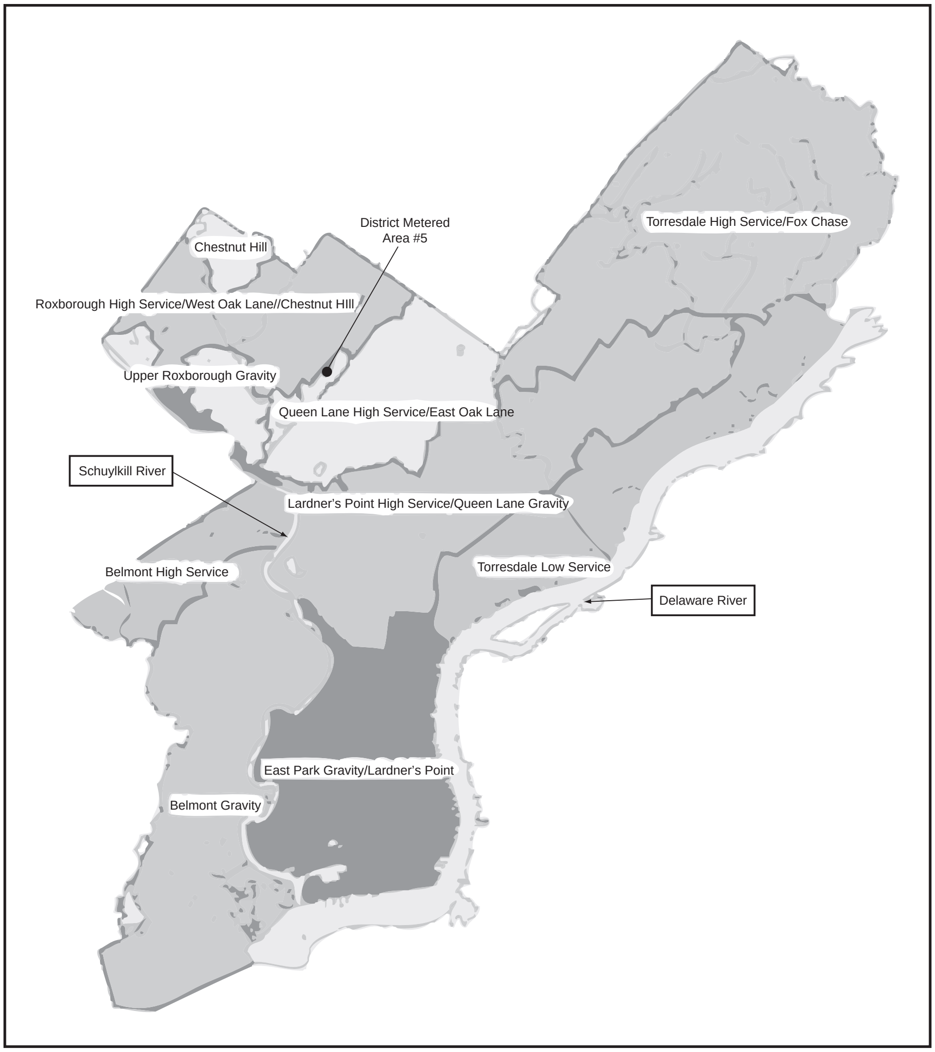


Figure 7-28 Pressure zones and DMA in the Philadelphia Water Department water service area

Courtesy of Philadelphia Water Department

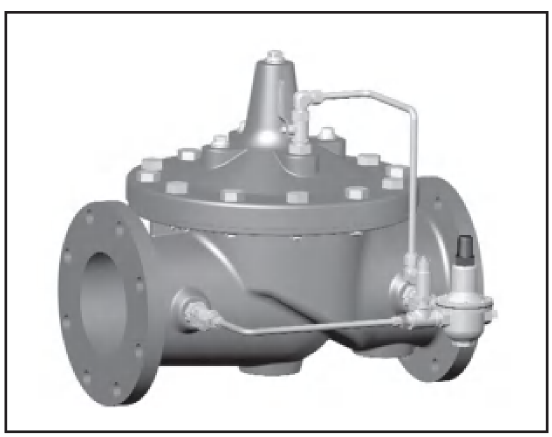


Figure 7-29 Pressure control devices, such as PRVs, provide consistent outlet pressures

Courtesy of Cla-Val Company

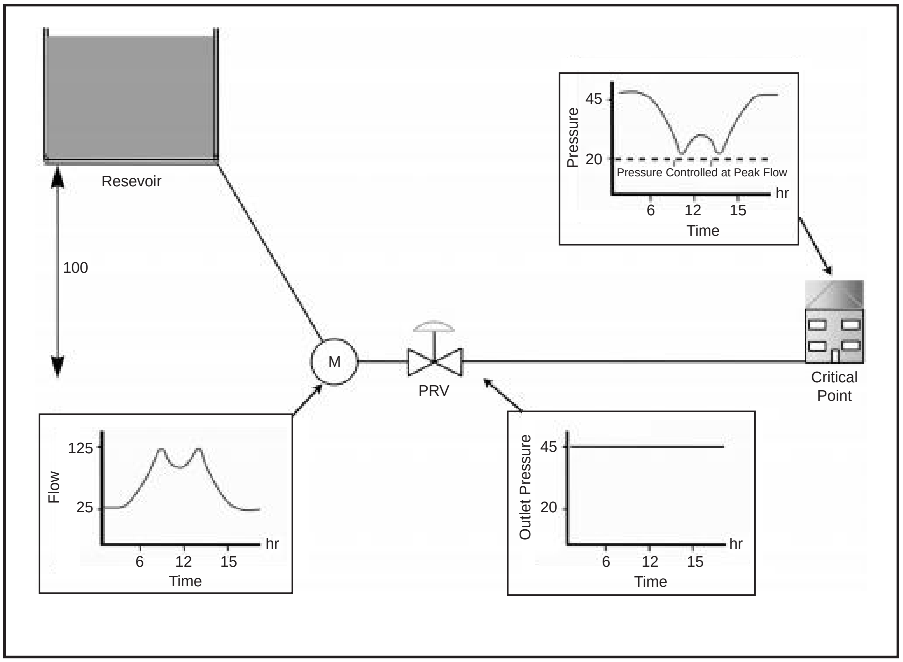


Figure 7-30 Fixed outlet control mode

Source: *Thornton et al.* 2005

damage to the valve. At times of minimal water demand, when a distribution system needs the least pressure, the pressure will be higher. During peak demands, when the distribution system needs the most pressure to supply demand, the pressure will be lower, creating what is often termed as an *upside down zone or district*.

Mechanisms for pressure reduction control using PRVs. Pressure reduction can be employed in various manners, each with advantages for certain applications. Selecting the appropriate level of sophistication usually depends on the distribution system condition, the components of loss, and the ability of the utility to maintain the equipment. Care should be taken when sizing a PRV or other control valve to check the potential head loss through the valve assembly (gate valves, filter, meter, control valve, and pipe fittings), especially when the pressure during the peak hours is already low (as is often the case in systems with weak hydraulic capacity or small or corroded pipes) and modulated control is only desired during off-peak times. If care is not taken, supply may be constrained during peak hours resulting in no-water or low-pressure complaints. Also, cavitation may occur. The following are common pressure reduction control methods:

- *Fixed outlet control.* This is the traditional method of control, typically using a hydraulically operated PRV or similar control valve. This method is effective in areas of uniform supply characteristics, pipelines with good flow-carrying capacity and low head losses, and water demands that do not vary greatly because of seasonal changes. This type of control is common in North American utilities; however, in many of the applications, systems tend to be over-pressurized at off-peak times, as can be seen in Figure 7-30.
- *Time-based modulation.* The pressure-regulating capabilities of a PRV can be modified by using a separate electronic controller with an internal timer connected to the PRV to regulate outlet pressure to preset levels at certain times of day. Control is affected in time bands in accordance with demand profiles. This methodology is very effective for areas with stable demand profiles and moderate pipeline

head losses and is usually used where project cost containment is important but advanced pressure management is desired. Time-based modulation controllers can be supplied with or without data loggers or remote communication links to SCADA or central control centers. Some manufacturers connect the controller to the pilot valve of the PRV and alter the set point of the pilot valve by introducing a force against the existing force of the pilot spring. Other manufacturers use a timer and a solenoid valve to reroute control through preset pilots. This type of control is not recommended for use as a sole means of advanced pressure control in North America because the timer will not respond to increased needs for high flows in an emergency such as a sudden high fire flow demand. The use of a time-based controller to control the second valve in a two-valve supply ensures that pressure can be dropped below that of the fixed outlet pressure. In this case, the main valve, if it is on a flow-based modulation, ensures that additional supply can be made available for emergency demands as required.

- *Flow-based dynamic modulation.* This is a more efficient type of control for areas with changing conditions, pipelines with poor flow-carrying capacity and notable head loss, considerable fire flow requirements, and the need for advanced proactive pressure management to reduce leakage losses. This type of control is implemented by controlling outlet pressure in relation to demand, by connecting a separate electronic controller device to a metered signal output from a flowmeter measuring the water supply input to the PMA. As water demand increases, the controller increases outlet pressure; and as water demand decreases, the controller reduces outlet pressure. Modulation of outlet pressure (within predetermined maximum and minimum settings) is achieved by altering the force against the regular hydraulic pilot spring ensuring that, if the controller fails, the hydraulic pilot on the PRV will return the PRV to its highest hydraulic outlet pressure setting, thus providing a failsafe feature. The controller is normally supplied with a local data logger and optional remote communications. Flow-based pressure modulation combats the effect of head loss in the system, ensuring that critical points where pipe diameters are often smaller, and therefore mechanically weaker, receive a smooth constant lower pressure, as seen in Figure 7-31.
- *Remote node control*. This is implemented by controlling the outlet pressure of the valve in conjunction with the pressure at a remote location or node in the area. The CP is often selected as the node. This method requires the use of a communication link to continuously relay the pressure reading at the node or CP to the PRV site. This can be done via a SCADA system, Global System for Mobile Communications telephone technology, or similar communication mechanism to pass the CP pressure signal to the PRV or electronic controller. This type of control is often affected with nonhydraulic electrically actuated valves of larger diameter such as the one seen in Figure 7-32.

LCA shows that in many cases the smaller-diameter mains and services that are often found at the extremities of the system—which are often also the CPs—have a higher break frequency than the larger-diameter mains found at the entrance to most districts. In cases of very high break frequencies in small extremity mains, both the flow-based pressure modulation mode and remote node-based pressure modulation mode have the effect of reducing volumes of real loss and frequencies of new leaks and water main breaks.

Installation of pressure management systems. PRVs have been used for many years to control the hydraulic condition of water utilities. With significant advances in control technology, PRVs have also become a very efficient means of reducing real losses in water

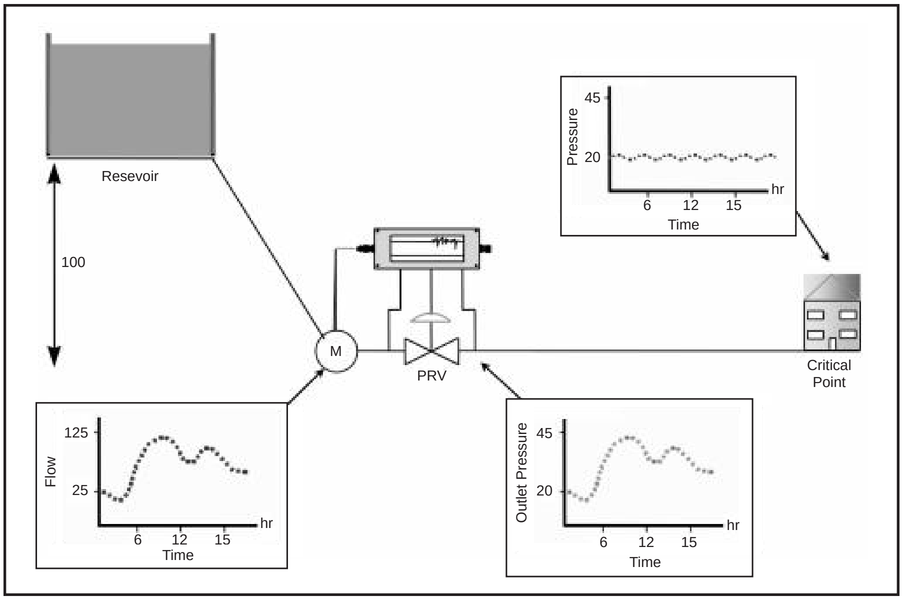


Figure 7-31 Flow-based dynamic modulation mode via a PRV combats high head loss in the distribution system and ensures a smooth pressure profile at the weaker points in the system

Source: *Thornton et al.* 2005

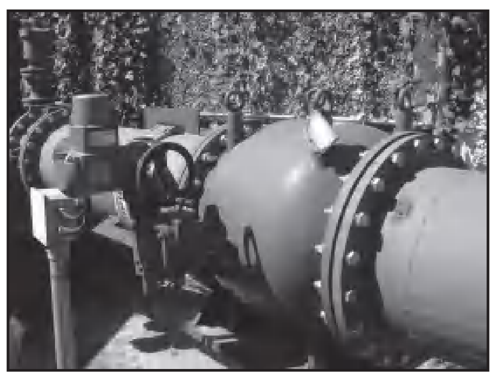


Figure 7-32 Large nonhydraulic valve for remote node-based pressure modulation

distribution systems. As control options become more varied, however, it is important to ensure that proper sizing of PRVs and related equipment is conducted.

Care should be taken when selecting PRV or control valve sizes so that the flows in the PMA do not fall below the minimum acceptable flow for the PRV at its operational settings after leakage has been reduced. It should be noted that diaphragm-type PRVs should normally operate in the 20 percent to 80 percent open range. If flows occur outside of this operating range, the PRV may have erratic control, with greater effects to the flow and pressure than when it is modulating in a nominal manner. This may result in either higher PRV maintenance costs or increased leakage. In situations of wide variation between high and low flow conditions, it is often common to install bypass piping and a second PRV around the main control valve to ensure smooth hydraulic control.

Once the PRV has been properly sized, the installation and type of control should be engineered to allow flexibility and ease of maintenance, ensuring that the investment will

Figure 7-33 Typical pressure management and DMA supply installation

Courtesy of Halifax Water, Halifax, Nova Scotia, Canada

continue to pay off in the medium- to long-term future as well as providing a short-term benefit. Proper installation and startup of the pressure management installation are also critical to the success of the leakage reduction effort and sustainability of the results.

Important features of a good pressure management installation include the following:

- A bypass piping arrangement or secondary supply feed to allow the primary supply feed/PRV to be feasibly taken out of service for maintenance work. If taking the PRV out of service would significantly increase pressure into the outlet zone, using a second PRV to sustain pressures during maintenance of the first should be considered. (See Figures 7-14 and 7-33 for examples.)
- A mainline filter in the PRV to inhibit debris from entering the PRV, and flow meter if one exists
- A secondary filter on the PRV to protect the pilot assembly
- Flowmeter with suitable pulse output signal (if flow-modulated control is desired)
- An air valve to release air from the PRV valve head
- Hand-operated ball valves on the PRV pilot circuit piping for easy isolation
- Gate valves on supply piping for isolation of mainline and bypass PRV feeds
- Inlet and outlet pressure gauges for quick visual monitoring of inlet and outlet pressure

The PRV, piping, and related instrumentation should be housed in a secure, dry chamber protected from the elements, which allows safe access for maintenance and calibration. The PRV may be installed on either the mainline or the bypass. However, designers of pressure management installations worldwide recommend installing the PRV on smaller-diameter bypass piping to supply routine flows, and installing a second PRV on the larger-sized mainline piping to activate when needed to provide higher emergency flow (see Figure 7-33). This configuration often allows chamber access to be located out of street thoroughfares, thereby facilitating easy access and safety for workers. If the installation is part of a DMA with a flowmeter, possibly all of this equipment can be installed on the same bypass piping.

Special design consideration for optimized pressure management. Designing PMAs, within a DMA configuration or otherwise, is relatively new to most North American water utilities. While the impacts of excessive pressures and transients are intuitively clear to utility operators, it is common for the same operators to be apprehensive about reducing pressure, fearing that reduced pressures might generate customer complaints or impair fire-fighting capability. As discussed in the following sections, most of these concerns can be addressed by employing a competent pressure management design process. Such a design might include a gradual reduction in pressure by reducing the PRV setting in increments.

Regarding water distribution system pressure, how low is too low? From a reliability viewpoint, AWWA's Manual M31, *Distribution System Requirements for Fire Protection*, notes, "There is no such thing as a water system that is 100 percent reliable." Ruptures can occur at any time in any part of the system and reduce pressure. "Water utilities should not guarantee that pressure or flow will be provided." However, from a perspective of routine supply, Manual M31 also states that "a water system should be designed to provide some water at 20 psi," and 20 psi has become recognized as a customary, if not legally required, minimum level of pressure needed in water distribution systems in the United States (AWWA 2008).

The primary concerns for water utilities in maintaining minimal water pressures are to satisfactorily meet customers' varying water demands, provide sufficient pressure for fire-fighting flows, and to minimize the possibility of backsiphonage of contaminants. The pressure determined to be the minimally designated service level requirement is ultimately determined in a case-by-case manner in individual distribution systems. By carefully assessing the previous three design factors, it is possible to define the low limits of the pressure reduction, below which system operation may be negatively impacted in some way. Following are some common questions raised by water utility managers when assessing pressure management, and responses for competent design.

- *Will adequate fire flow capability exist in the pressure managed area?* Providing adequate water to fight fires is of utmost importance in North American water utilities. The design process should include a careful review of the types of buildings and potential fire risks existing in the area, as well as a review of prevailing national fire guidelines, such as those from the National Fire Protection Association, and any state, provincial, or local building or fire safety codes that apply. Designing a PMA can provide the opportunity for utility operators to review fire risks in detail for perhaps the first time in many years.

  The hydraulics of the PMA must also be carefully understood, and sufficient pressure and flow data should be gathered to reveal the hydraulic conditions. Because routine water supply in a low-leakage distribution system encounters relatively low flows, and fire flows are generally quite high, the most common and effective design approach is to include multiple feeds controlled by PRVs. A larger feed can be installed to provide high-volume flows. This PRV is normally closed but will open when outlet pressure drops below a set "trigger" level, representative of a large water demand on the system, such as a fire flow. Therefore, if there is a fire, the system has sufficient hydraulic capacity to maintain pressure and flow for fire fighting. The PRVs will automatically regulate pressure as determined by the demand requirement plus the minimum safe operating limit at residual conditions. The design should consider the amount of head loss occurring across the PMA and ensure that the high-volume PRV supply can overcome the expected head loss to provide adequate pressure and flow across the zone. Head loss in pipelines can be significant, and the PRV must be specified and installed so that it will compensate adequately to supply distant locations of the PMA needing an emergency flow. Firefighters can draw pressures down to 20 psi, but fire sprinkler systems resemble nonvolumetric demands. The design may place the emergency PRV in the same chamber as the routine supply PRV, or as a separate supply point distant from the primary supply PRV, if head loss is considerable or demands vary widely across the PMA.

From a design perspective, if adequate fire flow capability existed in the water distribution grid prior to the installation of a PMA, then adequate fire flow capacity can be engineered into the new configuration as well. It is merely a function of applying good research (of fire risks and regulations), gathering sufficient hydraulic data, and good engineering design of the PMA. Sometimes improvements in the conveyance capability of the zone via enlarged or replacement water mains may be necessary to ensure that adequate flow and pressure can be maintained across the PMA under anticipated conditions.

- *Will customers consume less water at reduced pressures, thereby reducing revenue?* First, it is important to understand consumption–pressure relationships. Secondly, if water conservation is an objective of the water utility, pressure management can be tailored to assist this goal. Discussion on these two points follows:
  - Consumption and pressure relationship. In residential buildings, more than one half of consumption typically occurs from uses that are volumetric, which means that water fills a tank or basin of a fixed volume so that the same amount of water is consumed, regardless of the system pressure. Toilets, washing machines, bathtubs, and other basins are common volumetric uses. Hence, reductions in customer consumption from reduced pressures are usually not nearly as significant as perceived. Where outdoor water use for irrigation is a significant part of consumption, pressure reduction may have some impact on revenue. However, utilities with high rates of outdoor consumption are often located in areas where water is not a plentiful resource and reductions in irrigation use might be considered a desired conservation measure that is being matched with an appropriate water rate structure to moderate impacts on the revenue stream.
  - Many North American water utilities are developing water conservation programs and frequently tailor specific water rates as part of the effort. The cost of these programs incorporates the cost of lost revenue, which is usually less than the cost of development of new water resources and supply infrastructure. Pressure management can clearly assist a water conservation program by reducing distribution-side losses and direct pressure water use. Examples of pressure-influenced, nonvolumetric residential use include showers, dishwashers, and sink use that do not involve filling a basin. For water utilities with constrained water resources and water conservation programs, pressure management can serve as an effective tool in assisting the reduction of water demands.

  Systems with high leakage volumes will almost always see a positive benefit from pressure management, even when stacked against a potential loss of revenue, due to reduction of delivery pressure for metered consumption. This is also true for systems with lower losses and high costs to produce or purchase water. The trade-off in leakage reduction benefits gained vs. any reduction of revenue can be estimated and accounted for in the benefit–cost analysis of the leakage management strategy. In situations where a revenue loss is predicted and cannot be tolerated, pressure reduction can be limited to minimum consumption hours, when legitimate consumption is at the lowest level and system pressures are likely to be at their highest of the day.

- *Will hydraulic reliability suffer in pressure managed areas?* If good reliability exists in an "open" area of a water distribution system, adequate reliability can be designed into the PMA configuration. Typically, a primary supply feed providing routine flows coupled with a larger emergency feed should be adequate in most applications. A second emergency feed (three feeds in total) can be added if circumstances dictate. Additional emergency feeds can be added in like manner if needed, but each additional feed brings forth the need for an additional flowmeter, PRV, and increased complexity in the design. If it appears that many feeds are needed to adequately supply a particular area, perhaps the proposed size of the area is too large and the area can be segmented into two or more areas. Pressure management or pressure reduction should be carefully designed when applied to large zones that may include storage tanks or reservoirs, or transmission mains that are responsible for transporting water from one part of the system to another. A calibrated hydraulic model is recommended to model the effects of pressure reduction on the system's ability to transport water from one point to another and to fill storage. Hydraulic models can be used to predict the function of any area before it is put into use.

- *Can good water circulation and quality be maintained in the pressure managed configuration?* Water quality in any distribution system can be affected by a variety of factors including the quality of the water leaving the treatment plant, piping materials, condition of the infrastructure, the status of valves, flow patterns and velocities, water temperature variations, storage tank turnover, the use of flushing programs, and other conditions. A PMA may add concerns because the creation of a zone or DMA requires closing valves, and creating boundaries and reductions in leakage results in smaller velocities. Generally, water quality could suffer because of issues of poor circulation and high water age. Problems that might be encountered include red, rusty water in unlined ferrous pipe (cast iron is common), loss of adequate chlorine residual, increased bacteria counts, and other impacts. Many water quality parameters are temperature dependent; good quality may be maintained during cool months of the year but may suffer during the warm summer months. Water quality data should, therefore, be gathered at different times throughout the year to determine the range of water quality variation in the PMA setting.

  Each DMA/PMA configuration should be assessed on a case-by-case basis. However, several general steps can be taken to ensure that water quality is included as a primary factor in the design and operation of the PMA. First, the utility operator should gather baseline water samples and test for representative water quality parameters during the initial data-gathering phase of the project. Sampling can include gathering measures of chlorine residual along the DMA/PMA boundary, both inside and outside of the zone. Additionally, several key sites should be selected and a variety of water quality parameters gathered, including bacteria, turbidity, metals content, and other parameters typically collected by the water utility in its distribution system. One key site is a location most distant from the primary supply source. Another might be a location with low water velocity or high water age. If problems exist in the distribution system prior to pressure management, opportunity may exist to improve water quality in the design of the pressure management scheme. If good water quality exists in the open system, followup testing should be conducted after pressure management is implemented to determine whether any new water quality impacts emerged after the installation of the PMA.

  Steps to take to minimize water quality problems might include configuring boundaries to minimize the number of dead ends. Try to ensure that larger-diameter piping exists to serve as a supply "spine" through the central part of the area. Watch for pockets of grid with very low velocities. A flushing program may be considered if water quality problems are persistent. Small-diameter bleeder pipes can be installed as a bypass around one or more boundary valves to eliminate dead ends, although this impacts accountability because some unmeasured

> flow leaves the area. As long as water quality is given sufficient attention at all stages of the project—planning, design, and implementation—water quality is capable of being managed just as it is in an open distribution system. The reader is also referred to the discussion in the "DMA Planning Considerations" subsection earlier in this chapter.

DMAs and PMAs can be successfully designed, installed, and operated in North American water utilities. This statement is confirmed by the experience of the Philadelphia Water Department (PWD) in undertaking the implementation of such a system as part of the research project *Leakage Management Technologies* (WRF 2007b). As part of this project, PWD demonstrated the use of DMA and pressure management technologies in the North American setting and carefully completed and documented the necessary steps to achieve this. PWD identified an area of its water distribution system with average pressure over 100 psi, which had a history of high leakage and high water main break rates, the latter of which was driving a high level of water pipeline replacements in the area. After having previously studied four temporary DMAs, PWD established its first permanent DMA, known as DMA5.

The results of the work undertaken to establish DMA5 are shown over the course of time in Figures 7-34 through 7-37. The DMA boundaries were formulated as described in this chapter and resulted in an area of 12 miles of pipeline and approximately 2,250 customer service connections in a Philadelphia neighborhood that is largely residential, but with a number of high-rise residential buildings in one part of the DMA. Figure 7-34 shows a hydrograph of baseline water supply conditions when the DMA was initially configured in 2005 and measurements gathered using portable instruments. The initial findings were startling; leakage within the DMA was approximately 1.3 mgd and was roughly two thirds of the supply into the zone. This translated into a normalized leakage rate of 578 gal/connection/d.

Over the course of the next several months, a concerted leak detection survey was conducted and the permanent DMA was implemented by constructing chambers for a primary supply (with flowmeter and PRV) and an emergency supply main at the opposite end of the DMA and equipped only with a PRV set with a "trigger" pressure level to open only during an emergency condition of low pressure in the DMA. Once configured, an initial fixed-outlet reduction of 30 psi was implemented. A number of customer service connection leaks and two hidden water main breaks were uncovered during the leak survey work. A pronounced improvement in DMA conditions is shown in Figure 7-35 with supply into the zone greatly reduced. Further improvements are shown in Figure 7-36 once the final design employing a flow-modulated pressure management scheme was implemented in 2007. By 2009, after replacement of roughly one-half mile of piping was completed and another round of leak detection was undertaken, the DMA had reached what was judged to be its optimized state, in terms of leakage and pressure management, and is shown graphically in Figure 7-37. At this point in time, the normalized leakage rate had been reduced to 44 gal/connection/d with an Infrastructure Leakage Index (ILI) at a value of 2.5 (PWD's system-wide ILI was 11.6 at the time). This project demonstrated that the use of leakage management technologies as described in this chapter can produce meaningful and sustainable leakage reductions. PWD's experience in this project beyond the research aspects of the project are detailed in the *Journal AWWA* article "Piloting Proactive, Advanced Leakage Management Technologies" (Kunkel and Sturm 2011). In addition to PWD's experience, readers can consult the experience of Halifax Water in Halifax, Nova Scotia, Canada, for their success in water loss control overall, and in establishing DMAs and pressure management extensively across their water distribution system. Halifax Water was also a participant in the research project *Leakage Management Technologies* (WRF 2007b) and several other prominent research and scientific studies on water loss control.

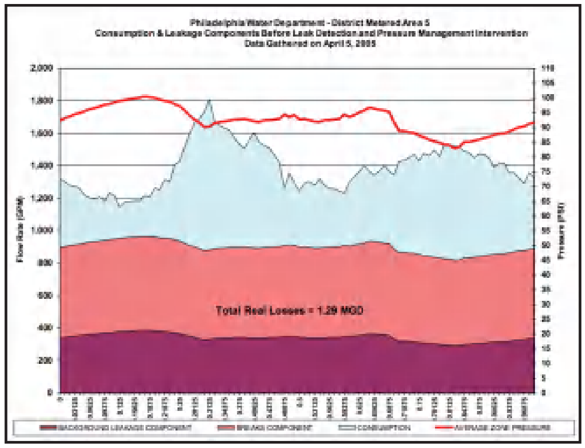


Figure 7-34 District Metered Area 5 in Philadelphia—baseline hydrograph of flow and pressure prior to DMA and pressure management

Courtesy of Philadelphia Water Department

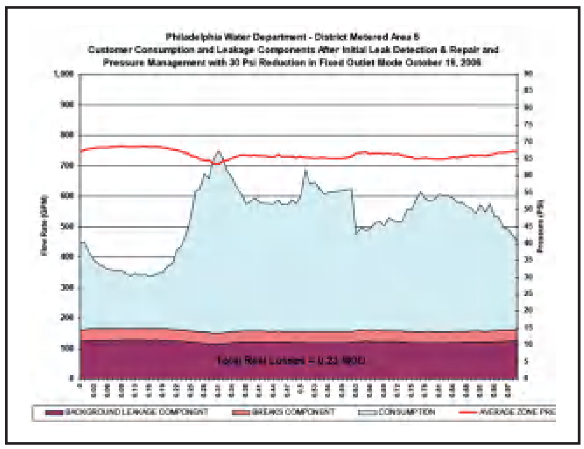


Figure 7-35 District Metered Area 5 in Philadelphia—after configuration into a DMA with basic pressure management and completion of leak detection survey

Courtesy of Philadelphia Water Department

Summarizing pressure management. Pressure management for real loss control and infrastructure sustainability is one of the most effective innovations in water distribution in recent decades. While still largely new to many North American water utilities, it has been used successfully in many areas of the world. Once the pressure–leakage relationship is understood, it becomes clear that leak detection alone does not make for a comprehensive leakage management strategy. Although locating and repairing existing leaks is an essential function in the leakage management strategy, leakage prevention is perhaps the most critical component in sustaining a low-leakage water distribution system. Competently installing high-quality piping materials when installing or replacing a water main or rehabilitating existing pipelines with structural liners or similar technologies are the best long-term means to prevent leaks. However, these are also the most costly and logistically demanding options available to the water utility. Pressure management, however, is a cost-effective way to prevent new leaks on existing, aging piping systems, particularly because it can be applied to sections of the distribution system in the range

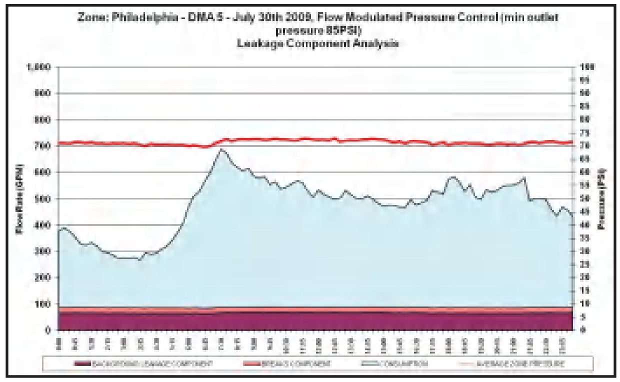


Figure 7-36 District Metered Area 5 in Philadelphia—after refinement of pressure management strategy

Courtesy of Philadelphia Water Department

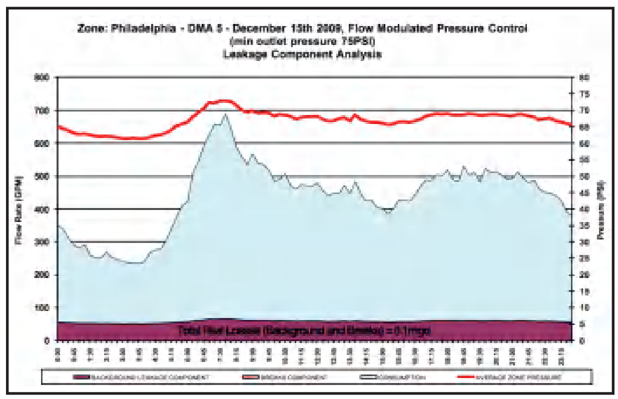


Figure 7-37 District Metered Area 5 in Philadelphia—in an optimized state after final leak detection survey

Courtesy of Philadelphia Water Department

of 10–30 miles of pipeline in a single application, which is a typical size range for most PMAs. Currently, most water utility operators are challenged to maintain aging distribution systems, with the ability to renew only a small portion of their system. Assessing the potential for pressure management can be a highly effective component of the leakage management strategy and long-term infrastructure management, and water utilities should undertake at least a preliminary evaluation of this potential.

Infrastructure Renewal and Replacement

Even the best-maintained water distribution piping and infrastructure eventually serves its useful life and requires rehabilitation or replacement if it is to continue to provide reliable service. In managing water losses and maintaining infrastructure, water utility managers can strive to ensure that infrastructure assets are maintained to attain their maximum life. Only then is the asset lifecycle optimized. Providing the appropriate balance of effective water loss control functions of active leakage control, pressure management, and optimized repairs will extend the life of piping assets to their ultimate range.

Many options exist for rehabilitation and renewal of water distribution system assets, and technology is rapidly advancing in this area. A detailed discussion of these methods is beyond the scope of this publication; however, AWWA offers excellent guidance on long-term infrastructure upkeep through a variety of publications in its Manual of Practice series. The reader is referred to the following AWWA manuals:

- *Concrete Pressure Pipe* (M9)
- *Steel Water Pipe: A Guide for Design and Installation* (M11)
- *PVC Pipe—Design and Installation* (M23)
- *External Corrosion Control for Infrastructure Sustainability* (M27)
- *Rehabilitation of Water Mains* (M28)
- *Ductile-Iron Pipe and Fittings* (M41)
- *Fiberglass Pipe Design* (M45)
- *PE Pipe—Design and Installation* (M55)

Replacement and many structural rehabilitation techniques create renewed pipeline assets. Although this is ultimately necessary for all pipeline assets, it is also the most comprehensive, costly, and involved of all of the pipeline management options. Therefore, every effort should be made to extend the service life of piping to the ultimate level before renewing it. Historically, the only ultimate pipeline option was outright replacement with a new pipeline. This meant full trench excavation for new pipelines, disruption of traffic, noise, dust, and considerable disruption and nuisance to the surrounding area. Rehabilitation lining techniques have also been applied for many years, but these techniques typically only restore flow-carrying capability without providing structural rehabilitation. In recent years, many innovative techniques have evolved to provide structural renewal of existing pipelines in place. The advent of trenchless technologies has given water utility managers many more options in structural pipeline renewal.

Today's trenchless technologies include slip lining with structural and semi-structural liners, pipe bursting, cured-in-place liners, and a variety of similar methods. The primary advantages of the trenchless methods include less excavation and aboveground disruption. Also, because the existing pipeline is rehabilitated in place, less conflict exists with neighboring utilities as opposed to pipeline replacement, which usually requires installation of piping in a new location in the street or right-of-way while the existing piping is abandoned in place. Therefore, twice the lay length is consumed in the right-of-way. Trenchless methods may be the only practical means to rehabilitate pipelines existing in difficult locations such as deep underground crossings of rivers, streambeds, railways, or interstate highways. The direct costs of trenchless methods can be more or less expensive than full pipe replacement, depending on the specific technique, the number of service connections to renew, logistics, and local restoration requirements. However, these techniques give utility operators great versatility in designing the rehabilitation and renewal program, which is a necessary part of water utility management.

Many water utilities view water main replacement as the key to water loss reduction; however, in many cases, larger annual volumes of real loss are often recovered via customer service connection piping replacement programs than outright main replacement. The LCA will indicate where the largest real loss volumes can be recovered.

Rehabilitation and renewal form one of the four pillars to the successful control of real losses in water utilities, and it is essential that water utilities have a program to renew their infrastructure as it reaches the end its service life.

SUMMARY

All water distribution systems encounter leakage, with rates varying according to the conditions of the individual systems. For a water utility to be truly water efficient in its operations, it must proactively manage leakage to contain it to economically low levels. Merely reacting to reported leaks when they become visible and disruptive means that a growing backlog of unreported and background leakage will plague the utility, wasting water resources and inflating production costs.

Many water utilities worldwide have moved beyond basic leak detection and repair to employ comprehensive and holistic leakage management programs. These programs not only seek to quickly identify and pinpoint existing leaks but also better sustain water infrastructure by containing the rate of occurrence of new leaks and breaks. Such approaches are cost-effective for the water utility, fair to the customer rate-payers, and reflect good stewardship of water resources. Many innovative methods and technologies have been developed in recent years, and current water utility managers have a great opportunity to create a new era of water-efficient operations in the North American water supply industry.

REFERENCES

AWWA (American Water Works Association). 2005. ANSI/AWWA C651-05. *Disinfecting Water Mains*. Denver, Colo.: AWWA.

AWWA (American Water Works Association). 2008. Manual M31. *Distribution System Requirements for Fire Protection*. Denver, Colo.: AWWA.

Bristol Water Services. 2001. *Leakage Management Assessment Project*. Final Report to the City of Philadelphia. Bath, UK: Bristol Water Services.

Hughes, D. 2005. A piggyback ride on AMR—Communicating more than just a meter reading. "The Practical Approach to Pressure Control ABC's of Apparent Loss Control and Revenue Protection for Water Utilities" workshop. AWWA Distribution & Plant Operations Conference. Denver, Colo.: American Water Works Association.

Hunaidi, O., W. Chu, A. Wang, W. Guan. 2002. Detecting leaks in plastic pipes. *Journal AWWA*, 92(2):82–94.

ISO 10156:2010. *Gases and Gas Mixtures—Determination of Fire Potential and Oxidizing Ability for the Selection of Cylinder Valve Outlets*. Geneva: International Organization for Standardization.

Kunkel, G., et al. 2003. Water Loss Control Committee report: Applying worldwide BMPs in water loss control. *Journal AWWA*, 95(8):65–79.

Kunkel, G., and R. Sturm. 2011. Piloting proactive, advanced leakage management technologies. *Journal AWWA*, 103(2):62–75.

Lambert, A.O. 2009. Ten years experience in using the UARL formula to calculate infrastructure leakage index. In *Water Loss 2009 Conference Proceedings,* Cape Town, South Africa.

Lambert, A.O., and M. Fantozzi. 2005. Recent advances in calculating economic intervention frequency for active leakage control, and implications for calculation of economic leakage levels. In *IWA International Conference on Economics, Statistics, and Finance*. Rethymno, Greece: IWA Publishing.

Lambert, A., and M. Fantozzi. 2010. Recent developments in pressure management. In *Water Loss 2010 Conference Proceedings*, Sao Paulo, Brazil. Complimentary copies of paper and presentation are available at http://www.leakssuite.com/wp-content/uploads/2012/11/2010_LambertFantozziSaoPaoloIWAI-2010H.pdf.

Lambert, A., M. Fantozzi, and J. Thornton. 2013. Practical approaches to modeling leakage and pressure management in distribution systems—Progress since 2005. Presented at CCWI 12th International Conference "Computing and Control in the Water Industry," Perugia, Italy, Sept. 24, 2013. Complimentary copies of paper and presentation are available at http://www.leakssuite.com/wp-content/uploads/2012/11/CCWI_Sep2013paper_Pressure-burstsALMFJT-1-2003-2013K1.pdf.

Lambert, A.O., J. Koelbl, and D. Fuchs-Hanusch. 2014. Interpreting ILIs in Small Systems. In *Water Loss 2014 Conference Proceedings,* Vienna, Austria. Complimentary copies of paper and presentation are available at http://www.leakssuite.com/wp-content/uploads/2014/11/Pres-on-Low-ILIs-23-Oct.pdf.

Lambert, A.O., and A. Lalonde. 2005. Using practical predictions of economic intervention frequency to calculate short-run economic leakage level, with or without pressure management. In *IWA Leakage Conference*. London: IWA Publishing.

Lambert, A.O., S. Myers, and S. Trow. 1998. *Managing Water Leakage—Economic and Technical Issues*. London: Financial Times Energy.

NSF International. 2015. NSF/ANSI Standard 60. *Drinking Water Treatment Chemicals—Health Effects*. Ann Arbor, Mich.: NSF International.

Pierson, G., K. Martel, A. Hill, G. Burlingame, and A. Godfree. 2001. *Practices to Prevent Microbiological Contamination of Water Mains*. Denver, Colo.: Awwa Research Foundation.

Tardelli Filho, J. 2004. Internal reports. Sao Paulo, Brazil: SABESP.

Thornton, J. 2005. Metro Nashville Water Services Department uses new methods to reduce leakage efficiently. In *AWWA Distribution & Plant Operations Conference*. Denver, Colo.: American Water Works Association.

Thornton, J., M. Shaw, M. Aguiar, and R. Liemberger. 2005. How low can you go? A practical approach to pressure control in low pressure systems. In *IWA Leakage Conference Proceedings*. London: IWA Publishing.

Titus, R., R. Meston, J. Johnson, P. Meschino, and R. Moore. 2013. Leak detection programs identify and control water loss. *AWWA Opflow*, 39(11):8–12.

UKWIR (United Kingdom Water Industry Research). 1999. *A Manual of DMA Practice*. Report Ref. No. 99/WM/08/23. UKWIR.

UKWIR/WRc (United Kingdom Water Industry Research, Water Research Centre). 1994. *Managing Leakage (Report C): Setting Economic Leakage Targets*. UKWIR, WRc, Water Services Association, and Water Companies Association.

Utility Service Group. 2013. *Case Study: Harrisburg, PA Water System—Helium Leak Detection*. Atlanta: Utility Service Group.

WRc (Water Research Centre). 1994. *Managing Leakage. Report J—Techniques, Technology, and Training*. Engineering and Operations Committee. Swindon, UK: WRc.

WRF (Water Research Foundation). 2007a. *Evaluating Water Loss and Planning Loss Reduction Strategies*. Denver, Colo.: WRF.

WRF (Water Research Foundation). 2007b. *Leakage Management Technologies*. Denver, Colo.: WRF.

WRF (Water Research Foundation). 2014a. *Real Loss Component Analysis: A Tool for Economic Water Loss Control*. Denver, Colo.: WRF.

WRF (Water Research Foundation). 2014b. *Real Loss Component Analysis: A Tool for Economic Water Loss Control: Leak Repair Data Collection Guide*. Denver, Colo.: WRF.

WSAA (Water Services Association of Australia). 2008. *Leakage and Pressure Management Stage 1, 2 and 3*. https://www.wsaa.asn.au/WSAAPublications/Documents/PPS3%20Leakage%20and%20Pressure%20Management%20Stage%201%20%202%20and%203.pdf.

This page intentionally blank.

Chapter 8

Planning and Sustaining the Water Loss Control Program

North American drinking water utilities should perform annual water auditing and have specific programs in place to control water and revenue losses. A water loss control program begins with gaining a true sense of the nature and extent of losses and their financial impact on the utility's operations. Water utilities should regularly verify the accuracy of all production flowmeters and maintain the integrity of the Water Supplied volume. They should also employ proactive leakage management activities with appropriate combinations of leak detection and repair, flow monitoring, pressure management, and system renewal. It is important that water utilities gain an awareness of the operational and revenue impacts that occur as a result of water that is improperly metered or billed, wasted, or stolen. Utilities should also put in place mechanisms to ensure that unbilled water—and associated revenue loss—is monitored and contained.

Moving to an informed, proactive culture of routine water audits, active monitoring, and efficient loss control is a rational strategy to preserve water resources, minimize customer service disruption, keep water rates as affordable as possible, improve the financial bottom line of the water utility, and demonstrate accountability to its customers. This chapter discusses the planning considerations in establishing the water loss control program.

The important first step is for the utility to compile the water audit on an annual basis as a standard business practice. The top-down water audit is straightforward to conduct and gives insight to the areas most needing attention as well as initiatives offering a quick payback. The AWWA Free Water Audit Software is an excellent tool to use for a first-time water audit because it can very quickly give a water utility a preliminary sense of their water balance and functional areas where the accuracy of the audit can be improved. Progressively more sophisticated activities should then be conducted over subsequent years as losses are better identified and quantified, and initial success is achieved. All of these activities should be conducted in a manner that can be readily incorporated into the organization's culture and budget, and sustained over the long-term planning horizon of the water utility. The major planning considerations for the water loss control program are detailed in the following sections.

IDENTIFYING DESIRED OUTCOMES AND BENEFITS OF A WATER LOSS CONTROL PROGRAM

Reducing water losses can bring a host of benefits to the utility. Consider how improving the utility's accountability, reducing leakage, and recovering additional revenue can improve the efficiency of the utility's operations. Consider also the current or potential regulatory requirements; economic, environmental, or political considerations; and specific community needs. A variety of potential benefits might be derived by the water utility from a water loss control program. Some of these benefits may impact the utility's performance while others affect the community that is served. A listing of some of these potential benefits is given here:

- Program benefits to the water utility
  - Increased revenue
  - Reduced production costs
  - Reduced source water withdrawals
  - Reduced energy consumption
  - Deferred or reduced capital expenditures
  - Less infiltration into wastewater systems
  - Enhanced knowledge and operation of assets (piping, valves, meters)
  - Reduced liability
- Program benefits to the community served
  - Fewer disruptions in service
  - Equitable water rates
  - Better protection of the environment
  - Enhanced economic development opportunities
  - Less stress on underground utilities
  - Less traffic disruption and damage to streets
  - Effective response to emergencies by the water utility
  - Improved appreciation for the value of efficient water service

The water utility can identify from the above list the specific benefits that are desired outcomes of the program they are structuring. Clearly communicating that these benefits are targeted will help to justify the program to decision makers and other stakeholders.

ESTABLISHING A CROSS-FUNCTIONAL WATER LOSS CONTROL GROUP OR TASK FORCE

Perhaps more than any other aspect of drinking water supply operations, water loss control touches almost every facet or functional area of the water utility and external stakeholders, including the following.

- Source water and production metering: Water utilities should obtain accurate measures of water withdrawn from water resources and determine the volume of treated water supplied to the water distribution system.
- Production cost management: Efficiently maintaining energy, chemical, and residuals management costs can garner significant cost reductions.

- Water distribution system operations: Utility managers should employ flow monitoring, pressure management, and supervisory control and data acquisition systems to assist in system oversight and better control of leakage losses.
- Water distribution system maintenance: Utilities should conduct active leakage control activities, distribution system repair, and employ maintenance management information systems to track these activities.
- Customer metering: The utility should proactively review and update meter sizing, installation, testing, repair, and replacement procedures.
- Customer meter reading: Automatic meter reading (AMR) and advanced metering infrastructure (AMI) systems provide outstanding capabilities to cost-effectively capture customer consumption data, whereas manual meter reading may be the most cost-effective approach for some water utilities.
- Infrastructure management: Rehabilitation and replacement of the water infrastructure is part of a balanced strategy to ensure a low-loss system.
- Water quality: Addressing leakage more efficiently leads to less disruption to the integrity of the water distribution system conveying potable water. Optimized pressure management and effective renewal of distribution assets result in a lower likelihood of intrusion or backflow events resulting from pressure surges and ruptured water mains.
- Sewer collection systems: A portion of leakage often finds its way into the collection system where it adds to the flow burden in the sewer system and at the wastewater treatment plant.
- Water conservation: Utilities with a water conservation program should integrate their efforts with the water loss control program through a joint mission to manage water resources efficiently.
- Customer billing systems: Effectively managing large numbers of customer accounts, consumption data, billing actions, and revenue recovery is critical to program success.
- Water rate setting and finance: Pricing water to ensure full return on investment and efficient use of the resource, and displaying water-efficient operations elevates the stature of the water utility in the eyes of financial institutions.
- Customer service: Rapport with the customer is enhanced when the incidence of disruptive water main breaks and leaks, inaccurate meter readings, billing errors, or excessive water charges are minimized, and an image of efficiency is exhibited by the water utility.
- Public relations: Efficient water management enhances the perception of the water utility in the communities that it serves by better protecting watersheds, keeping water rates affordable, valuing the resource in times of scarcity, and promoting economic development.
- External stakeholders: Interaction with fire departments is necessary to confirm a fire hydrant usage policy and to estimate quantities of water used in fire fighting and training. Most underground water piping lies below streets and highways, and activities must be coordinated with local or state street or highway departments. Coordination with other utilities (electric, gas, communications) is also an essential part of the operation of the water distribution system. Other governmental, community, business, or civic groups might also be important stakeholders to the program.

- Executive leadership of the water utility: Leadership provides the mandate for the listed groups to come together to focus on accountability improvements. Executives also provide guidance and resources to the effort and help communicate its success.

In planning for the new program, utility management should create an organizational structure that allows water loss control to be the central mission of its existence. The occurrence of water and revenue loss is not merely a problem of leakage or inaccurate meters. In truth, real and apparent losses occur in all water utilities to various degrees and for various reasons. As noted in the above list, water and revenue loss impacts the water utility's water distribution, metering, billing, customer service, water quality, renewal programming, and other groups. Therefore, the utility's organizational structure for water loss control activities should include participation by staff serving in these functional areas.

Large water utilities may be able to hire personnel dedicated to form a distinct Water Loss Control or Non-Revenue Water group within the water utility. The head of the group might report directly to the chief executive of the utility, and the various stakeholder units in the utility would be required to report water efficiency data and progress in water loss control activities directly to the non-revenue water (NRW) manager. The advantage of this structure is that it assigns dedicated personnel to water loss control activities in systems with many functions and large amounts of data. The challenge of this approach is that it requires dedicated funding to hire, staff, and maintain the program.

Another possible organizational structure to consider is to form a team, committee, or task force of responsible individuals drawn from 6–10 of the above functional areas within the water utility. While still performing their normal duties, the members of this group can meet periodically to gather and review data, monitor progress, and plan loss control activities. This type of structure provides an opportunity for groups to learn how the various activities are handled by their peers within the water utility. Team dynamics often create the opportunity to quickly uncover water loss that exists merely as a result of misconceptions and gaps in procedure. A team-based approach also allows ideas to be communicated across the spectrum of the organization to obtain the buy-in of many employees. Improved employee cooperation and cohesiveness is therefore a strong side benefit of this approach. Good teamwork procedures need to be put in place to ensure that the team members perform their tasks and are accountable to each other and to the utility management. Systematic reporting procedures within the team and to management are needed. The main advantage of this approach is that no additional personnel need be hired to launch the water loss control program. The primary challenges of the team approach is (1) to ensure that executive leadership provides a clear and concise mandate to all of the involved groups about their role on the team, and (2) for the current staff to squeeze the part-time requirements of new water loss control activities into their existing schedules.

Other possible organizational structures exist for water utilities to employ, and each utility can determine what the best structure is for its needs. The key is to establish water loss control as part of the organization's overall mission and assign and communicate the goals, structure, and responsibilities to all personnel participating in the program. Once the organizational structure is set, the utility is ready to move forward knowing that the activities to control losses are well assigned and responsibilities are clearly defined.

IDENTIFYING RESOURCE NEEDS

The water loss control program can be launched or upgraded with little or no specific funding. The self-assessment nature of the water auditing process can often identify a number of quick, easy refinements, typically in billing system procedure or documentation, which can inexpensively recoup revenue or create cost savings early in the program life. Designing such early funding recovery into the water loss control program provides quick payback that can "seed" further loss recovery activities. Without earmarking specific funding for the program, executive management can launch a program merely by bringing together the appropriate personnel and assigning them meeting time to compile a top-down water audit and explore potential savings. Gaps between resource needs and the utility's organizational capability can be filled by utilizing external resources to implement some aspects of the loss control program.

When available, targeted funding can be effectively employed in the following areas:

- **Training.** In recent years, many advances in leakage management and apparent loss control have occurred. A variety of consultants and other service providers in North America provide training in these successful methods. Many publications, software, videos, and Web resources exist in addition to this manual to provide training resources for operators embarking on a water loss control program.
- **Technology.** With rapid advancements in technology, considerable new equipment exists to assist water utilities in controlling losses and accounting for water. Permanent and portable metering equipment, leak noise loggers and correlators, data loggers, AMR/AMI systems, enhanced billing software, and countless other innovations are available at various cost ranges. The greatest challenge is to determine the most appropriate equipment from an array of many capable models.
- **Specialized services.** A growing number of specialized service providers offer consulting services to the North American drinking water industry. Water utilities can gain guidance on leakage management, billing systems and apparent loss control, new equipment, and other services. These services are typically available to work within the context of geographical information systems, hydraulic models, asset management software, and computerized maintenance management systems that have become prevalent in the drinking water industry. Performance-based contracts, whereby specialized service providers are paid a portion of the value of the losses that they recover, are also available as a means to launch a program in the absence of a dedicated funding source.

In launching or refining the water loss control program, it is quite natural, particularly for water utility board members, accountants, and managers, to become alarmed about "what is this program going to cost us?" While this is a valid question, the utility also should explore the question: "what are our existing losses costing us now?" No system is loss free, and losses impact water utilities with a variety of costs and liabilities. Unfortunately, these costs are often not quantified; instead they are embedded in general operations and maintenance costs and water rates, masking their impact to managers, executives, and customers. The water auditing process sets out to quantify both loss volumes and their cost impact to the utility. Planned expenditures for the water loss control program can only be viewed objectively when compared to the costs of the losses currently affecting the utility and in the context of how the water loss control program meets the long-term goals of the water utility. So, when the question of cost of the program is posed, state objectively that a certain program cost is needed to obtain the targeted benefits as previously noted, along with a financial benefit of a predicted amount of increased revenue and/or reduced production costs.

LAUNCHING THE WATER LOSS CONTROL PROGRAM

Table 8-1 lists the primary activities that should be considered as part of a good water loss control plan. This listing is neither exhaustive nor prescriptive, although it is strongly recommended that production meters be properly installed and managed (see appendix A) as part of the top-down auditing process. Any number of other loss control activities not included on the list—notably those with system-specific characteristics—might be employed to better track water and reduce losses. Similarly, not all of the activities in Table 8-1 are needed by every water utility. The water auditing process will guide utility management in identifying the greatest loss occurrences and economic impacts. Selection of appropriate program activities—particularly those of long-term nature—should be made only when strategically and economically justified and in conjunction with the utility's long-term goals.

As shown in Table 8-1, once launched, several activities of the water loss control program can be conducted concurrently. This allows multiple objectives to be pursued, particularly when these objectives are "owned" by designated "champions" on the aforementioned water loss control team. Also, a number of water auditing and intervention activities provide integrated benefits. For instance, by establishing pilot district metered areas (DMAs), site-specific leakage data can be obtained to better direct leak detection crews, but the data also provide leakage quantities as the basis for the leakage component analysis (LCA) of the water audit. Apparent loss investigations to detect instances of unauthorized consumption may also yield information about cross-connections or metering problems. Once established, many of the activities should be maintained in an ongoing manner. Water auditing should be conducted on a routine annual basis, just as regular financial auditing is conducted.

Table 8-1 also lists approximate time frames to initiate the activities of the water loss control program. These are given as short-term (S), medium-term (M), long-term (L), and ongoing. No attempt is made to attach actual durations to these time horizons because the ability to enact activities varies greatly from one utility to another. For example, the size of the water utility, funding availability, business procedures, and other factors allow some water utilities to implement long-term interventions, such as AMR/AMI systems, in 1 to 2 years while other utilities with more restrictive conditions may require a 5–10-year horizon to affect the same interventions. Also, those activities designated as long-term are more extensive, sophisticated, and costly in terms of scope and may require long time lines for planning, funding, and execution. In most cases, however, utilities could implement the short-term activities in a matter of days, weeks, or months, as long as resources are properly assigned. Ongoing activities can be undertaken at any time once a sound basis for moving forward has been established.

For water utilities that are embarking on their initial effort to control losses, the top-down approach is the recommended starting point. It is described in detail in chapter 3. Descriptions of bottom-up approaches and component analysis for apparent losses are presented in chapter 5. Bottom-up methods and LCA for real losses are presented in chapter 7. While the water auditing process is not specifically a means to reduce losses, it is common for many utilities to realize loss reductions once they have instituted routine water auditing. This process can create an important shift in the organization's culture. Awareness of the water audit can motivate water utility employees to better account for water and minimize waste in their day-to-day activities. The water audit also becomes the primary reporting mechanism to measure the success of the water loss control program from year to year. Once available, the findings of the water audit guide decision making to determine which interventions are most appropriate and economically justified. With commitment, the water utility can build on successes incrementally to establish a culture of accountability and a reputation for water efficiency.

Table 8-1 Water loss control program activity planning matrix

<table>
<tr><th colspan="7">Potential Activities of a Water Loss Control Program
(Not all activities are necessary for every water utility; system-specific needs should be considered.)</th></tr>
<tr><th colspan="3" rowspan="2">Water Auditing</th><th colspan="4">Intervention Activities</th></tr>
<tr><th colspan="2">Apparent Loss Control</th><th colspan="2">Real Loss Control</th></tr>
<tr><th>Time*</th><th colspan="2">Activity</th><th>Time</th><th>Activity</th><th>Time</th><th>Activity</th></tr>
<tr><td>S</td><td colspan="2">Top-down water audit</td><td>S</td><td>Verify accuracy of production flowmeters (this is a very important procedure!)</td><td>S</td><td>Review maintenance records, gather and summarize statistics on water system failures (leaks and breaks). Establish this process as described in chapter 7.</td></tr>
<tr><td>M</td><td colspan="2">Start bottom-up water audit by launching field investigations into specific loss occurrences.</td><td>S</td><td>Flowchart the customer billing process; compile general statistics on the demographics of the customer/meter population.</td><td>S</td><td>Review policies for customer service connection piping ownership and maintenance, an opportunity to reduce customer service connection piping leakage durations.</td></tr>
<tr><td rowspan="8">Ongoing</td><td colspan="2" rowspan="2"></td><td>S</td><td>Perform meter accuracy testing on a small sample of customer meters. Place priority on larger commercial and industrial account meters.†</td><td>S</td><td>Conduct an initial leak detection survey, perhaps via a leak detection contractor; consider use of leak noise monitors.</td></tr>
<tr><td>S</td><td>Audit billing records and visit premises of a representative sample of customer accounts to determine the potential for missed billings or unauthorized consumption.</td><td>S</td><td>Compile data on the variation of water pressure throughout the water distribution system. Identify areas of excessive pressure and evaluate potential for proactive pressure management.</td></tr>
<tr><td rowspan="6">Bottom-up water audit: Conduct detailed investigations of metering, meter reading, and billing operations.</td><td rowspan="6">Bottom-up water audit: Gather field measurement data and minimum-hour leakage analysis; conduct leakage component analysis.</td><td>M</td><td>Install, upgrade, or replace production flowmeters. (See appendix A for guidance.)</td><td>S</td><td>Establish a pilot district metered area (DMA); perform minimum-hour leakage analysis.</td></tr>
<tr><td>M</td><td>Review/implement policies and interventions to detect and thwart unauthorized consumption.</td><td>M</td><td>Create a leak detection squad, or hire a leak detection contractor, to regularly survey the distribution system for unreported leakage.</td></tr>
<tr><td>M</td><td>Investigate the potential costs and savings of instituting an automatic meter reading (AMR) or advanced metering infrastructure (AMI) system to reduce missing or erroneous customer meter readings.†</td><td>M</td><td>Install additional pressure management areas and/or deploy leak noise monitors as deemed feasible and cost-effective.</td></tr>
<tr><td>L</td><td>Install an AMR/AMI system and institute monthly billing based on meter readings.†</td><td>L</td><td>Implement a maintenance management information system.</td></tr>
<tr><td>L</td><td>Install a new computerized customer billing system.†</td><td>L</td><td>Create additional DMAs, if determined to be feasible.</td></tr>
<tr><td>L</td><td>Conduct wholesale customer meter replacement to keep meter population current.†</td><td>L</td><td>Institute or expand capital replacement program for water main infrastructure.</td></tr>
</table>

*Time = time frame: S – short-term; M – medium-term; L – long-term; Ongoing – anytime, assuming a sound basis exists for implementation.

†These initiatives assume that the customer population is metered. If not, the water utility should consider installing customer meters. While not a small undertaking in terms of scope and cost, this effort should be considered as a short- or medium-term initiative of high priority.

Work is underway to assemble information on the costs and benefits of different NRW reduction and control interventions. This information is being assembled to provide utilities with guidance on the cost efficiency and effectiveness of different measures. The guidance will also assist utilities in presenting a “business case” for the financial viability of an NRW program.

REPORTING WATER LOSS CONTROL PROGRESS WITHIN THE WATER UTILITY

The following quote by H. James Harrington is well known to many and has a distinct applicability to water loss control, as well as many other fields of endeavor:

> Measurement is the first step that leads to control and eventually to improvement. If you can’t measure something, you can’t understand it. If you can’t understand it, you can’t control it. If you can’t control it, you can’t improve it.

By assembling the annual water audit, water utility personnel gather data that effectively measures performance, ultimately leading to the ability to better control and improve utility processes and operations. The standard water audit format advocated in this manual classifies and organizes data and calculates objective performance indicators that provide key information on the utility’s water loss standing and the effectiveness of the intervention methods to better control losses.

Water utilities exist in the information age, and the availability and integrity of the information is of critical importance. A wide variety of information is employed in the provision of safe drinking water. This information is needed by those working internally in the drinking water industry, including utility employees, government officials, regulators, service and equipment providers, and external stakeholders such as business and civic groups, customers, and the news media.

In addition to a huge array of water quality information, water utilities frequently maintain data on water flow rates and pressures, infrastructure condition, maintenance activities, customer consumption and billing, leaks and breaks, water main replacement, and a host of other activities. It is important that the water loss control program identifies the key information that is necessary to successfully operate the program and measure performance.

Reliable data collection and sound record-keeping functions should be a prominent feature of the working routine of the water loss control team, who should note the quality and integrity of existing records and documentation during the development of the top-down water audit. It should carefully consider how data is generated, defined and categorized, stored and reported, noting deficiencies and correcting them. The team should also make special note of any data that are not regularly reported but should be. Information mishandling or omission alone can influence the success or failure of the program. Good information management identifies the nature, extent, and locations of losses and ably measures progress in controlling the losses to economic levels. It is likely that refinements to some of the existing record-keeping methods will be needed. At the start of a water loss control program, it is almost certain that gaps in the current data collection will be identified, resulting in the need for new documentation and reports. Persons in the water utility who serve as the “owner” of important data should be identified and be given the responsibility for generating the data in the appropriate format for submittal during the annual water audit data collection period.

A very useful type of report for water utilities is shown in Table 8-2, which displays data from the fictitious County Water Company featured in chapter 3 and throughout this manual. This report is structured to present a high-level, monthly overview of the

Table 8-2 Monthly Non-Revenue Water Report for County Water Company

12-Month Period	Water Supplied Volume (mil gal)	Billed Authorized Consumption (mil gal)	Non-Revenue Water (mil gal)	Number of Commercial, Industrial Customer Accounts	Number of Residential Customer Accounts	Total Customer Accounts
February 2013–January 2014	4,242.83	3,207.70	1,035.13	693	11,391	12,084
March 2013–February 2014	4,241.28	3,215.80	1,025.48	694	11,398	12,092
April 2013–March 2014	4,241.57	3,220.80	1,020.77	694	11,401	12,095
May 2013–April 2014	4,250.46	3,228.70	1,021.76	694	11,422	12,116
June 2013–May 2014	4,256.08	3,229.30	1,026.78	696	11,439	12,135
July 2013–June 2014	4,267.95	3,235.10	1,032.85	696	11,437	12,133
August 2013–July 2014	4,280.82	3,240.70	1,040.12	696	11,439	12,135
September 2013–August 2014	4,293.01	3,246.40	1,046.61	698	11,452	12,150
October 2013–September 2014	4,289.15	3,252.00	1,037.15	701	11,464	12,165
November 2013–October 2014	4,276.26	3,254.70	1,021.56	703	11,461	12,164
December 2013–November 2014	4,268.05	3,256.40	1,011.65	709	11,478	12,187
January 2014–December 2014	4,264.44	3,258.00	1,006.44	706	11,490	12,196

Water Supplied volume, the Billed Authorized Consumption volume, and the difference quoted as NRW. For reference, the number of active customer billed accounts is also listed because this number varies month to month and reflects the size of the customer population. Because of customer meter reading lag time inherent in most customer billing systems and occasional swings in seasonal customer consumption patterns, both the Water Supplied volume and the Billed Authorized Consumption volume are reported on a rolling 12-month basis. This minimizes the "noise" associated with variations in the underlying data associated with short-term reporting intervals that can otherwise skew interpretation of existing conditions. Utilities should avoid reporting direct comparisons of a single month's Water Supplied volume vs. the Billed Authorized Consumption volume because such a comparison is very often misleading. Only 12-month rolling average comparisons should be used for this purpose. Because this report is compiled and circulated every month, all stakeholders are regularly reminded of the general water efficiency standing of the water utility throughout the year.

This is one recommended report that water utilities should compile to keep abreast of their water efficiency status on a regular basis. It is important to remember, however, that this basic report is *not* a water audit. The monthly report in Table 8-2 determines the volume of NRW from a basic difference of supplied and billed volumes. It does not explain how the Non-Revenue Water volume breaks down into volumes of unbilled authorized consumption, apparent losses, and real losses. This breakdown is determined only in the detailed water audit process, which is conducted on an annual—not monthly—basis. Other reports illustrating other performance indicators for distribution system operations and maintenance are also worth considering, such as main breaks per 100 miles of system pipeline per year, meter replacement rates, response time for reported leak repairs, and

Compiling a Monthly Non-Revenue Water Report

It is recommended that water utilities compile the standard water audit on an annual basis as a means to detail the utility's water loss standing and measure its performance. However, water utility personnel need the ability to monitor system performance more often than annually, and the monthly reporting format in Table 8-2 is the recommended approach for providing a general monthly overview of water loss standing. This report provides stakeholders with a high-level glimpse of the water loss standing of the water utility each month. There are two important details to remember in using this report:

1. This type of report is not a "water audit," given that it merely reports the total Non-Revenue Water volume and does not attempt to quantify the individual component volumes of Unbilled Authorized Consumption, Apparent Losses, and Real Losses.
2. This report *must* be conducted using 12-month rolling average values for the Water Supplied volume and the Billed Authorized Consumption volume. Attempting to use individual monthly quantities of these two volumes will invariably lead to a skewed data comparison at some point during the audit year and likely cause great confusion.

By employing a report such as the one shown in Table 8-2, water utilities can stay abreast of their water loss standing continuously throughout the year and use the annual compilation of the water audit to provide the detailed quantities of the Non-Revenue Water components.

so forth. Dashboard formats with features customized for water utility users are increasingly being used to present these types of actionable information. (See also the "Compiling a Monthly Non-Revenue Water Report" sidebar.)

New reports should be created when new technologies, such as DMAs, are implemented. The team should identify information sources and a contact person for each data source and identify internal stakeholders who have the need to know and should receive the report. Reporting is often a very straightforward way to promote success for the water loss control program.

COMMUNICATING WITH COMMUNITY STAKEHOLDERS—PUBLIC RELATIONS

In past generations, the drinking water industry was often referred to as the *silent service* because of its ability to reliably provide safe drinking water without entering into the consciousness of the consumer. At one time, this "no news is good news" image was perhaps an advantage. With the information age of Internet and multimedia, this approach may be a handicap. Stakeholders in any endeavor want and need to be informed. No longer will consumers just trust that the utility knows what's best for them. Effective communication is key to sharing information, educating, and cooperating with consumers and a wide range of stakeholders.

In undertaking a water loss control program, the water utility should implement communications that will announce program successes and educate stakeholders on the value of water efficiency to the community. Potential messages that might be conveyed to stakeholders are

- promoting the value of reliable water supply to the community;
- highlighting the financial benefits of revenue recovery to stabilize water rates and build confidence in the water utility among the lending community;
- emphasizing reduced service disruptions to customers and minimized damage to street or building infrastructure as a result of fewer water leaks and main breaks;

- touting the reduced impact on the environment from reduced withdrawals from rivers, lakes, or wells, as well as less energy consumption from optimized operations;
- delaying or foregoing new infrastructure construction—reservoirs, treatment plants, pumping stations, wells, and so forth—by better long-term management of existing water resources and infrastructure;
- establishing a reputation of strong reliability by sustaining water service during periods of drought;
- enhancing customer perceptions by conveying visible accountability and operational efficiency improvements; and
- integrating the attributes of the program with messages delivered on water conservation and public education campaigns managed by the water utility or by partner organizations such as local watershed associations, conservation districts, and so on.

As part of the development of communication options, a wide variety of stakeholders should be considered. A list of pertinent stakeholders can be identified, with the appropriate messages and timing noted. Stakeholder groups might include

- Customers,
- Community groups,
- Government, at all levels,
- Media,
- Regulatory agencies,
- Educational institutions,
- Public safety (police, fire, emergency management) departments,
- Environmental organizations,
- Financial institutions, and
- Drinking water associations.

Improved communication is also part of the drinking water regulatory structure in the United States. The use of Consumer Confidence Reports is perhaps the most visible example of communication mechanisms that are required by regulatory agencies. Regulatory agencies, particularly in resource-limited areas, may consider increased reporting of water-efficiency practices, and water utilities should be aware of this possibility.

Not all stakeholders need be targeted at all times by all messages. An important approach of the communication plan is to consider

- Who needs to know?
- What do they need to know?
- When should they be informed?

In this manner, the water utility manager or public relations official can build into the program the information or data that need to be gathered, and the program should include a schedule of communications to the appropriate groups. A good communications strategy ultimately benefits the program by garnering support and gaining assistance and recognition.

SUSTAINING THE WATER LOSS CONTROL PROGRAM

With a moderate level of forethought and organization, water utilities can create a water loss control program by forming a team of appropriate individuals from the organization and compiling the annual water audit. The AWWA Free Water Audit Software, described in chapter 3, is a great tool to employ to get started on this endeavor.

The top-down water audit process will likely identify several initial loss reduction priorities to the group and allow them to capture the "low-hanging fruit," or relatively easy recoveries, to launch the program in a successful vein. Because loss control of any nature is an endeavor of diminishing returns, incrementally greater effort is required to recover incrementally smaller returns. It is important that the water loss control program include a realistic long-term vision to ensure that

- loss control efforts continue in a strategic, ongoing manner and a "backslide" does not occur; and
- loss control efforts eventually define the economic breakpoint, beyond which further loss reduction is not economically justified.

Water utilities that exhibit the following qualities are likely to establish water loss control programs that succeed in a sustainable manner:

- Commitment
- Persistence
- Cooperation and collaboration
- Knowledge sharing
- A long-term outlook
- The patience to avoid short-term "quick fixes" that do not provide lasting results
- The ability to implement comprehensive, integrated, and proven approaches that provide lasting benefits

The value of these qualities should be recognized at the beginning of the planning phase. Be mindful of them when selecting the team leader and members. Look for those people who have demonstrated skill, perseverance, and innovation in their work history. Look for a leader who will champion the cause and motivate team members and outside stakeholders during the times when progress appears slow. Avoid adding personnel to the team who fear change, even if they are longstanding in a given position in the utility.

Sustainability also hinges on the ability to implement long-term interventions to control losses. Water distribution system rehabilitation, AMR/AMI systems, customer billing systems, and extensive sectorization via DMAs are all significant undertakings that can require years to plan and implement, yet they hold the potential to generate enormous benefits. The water loss control group needs to show persistence over a long period of time to implement such improvements. Sustainability is a critical planning consideration because it protects against reversal of gains made early in the program and ensures that the ultimate desired outcomes are achieved.

With proper planning, water utilities can launch effective water loss control programs that will ensure efficient water supply operations and protection of natural resources.

Chapter 9

Considerations for Small Systems

While numerous large water utilities serve North America's metropolitan areas with populations in the millions, the vast majority of water utilities are those classified as small systems. Most of these small systems serve only several hundred or several thousand customers in primarily rural areas. In the United States, about 92 percent of the 51,988 community drinking water systems are classified as small systems serving populations less than 10,000. While these systems are great in number, collectively they serve roughly 52 million of the 292 million people (18 percent) that are supplied by community water systems (USEPA 2011). In managing water supplies, some notable differences exist between large and small water systems. Some of the contrasting characteristics of these types of systems in the United States are shown in Table 9-1.

Table 9-1 reflects certain notable differences in the characteristics of large and small water systems in the United States. Small systems often have less capacity in terms of revenue generation and of human and financial resources than larger systems. These distinctions impact the US drinking water industry in all aspects of operation, from source water protection to water treatment and distribution, as well as customer metering and billing. In implementing its water quality regulations, the United States Environmental Protection Agency (USEPA) typically employs a three-tiered approach, requiring the shortest implementation time frames for large systems and longer periods for medium-sized and small systems. This gives the smallest systems the greatest amount of time to prepare for the implementation of new regulations. The Safe Drinking Water Act Amendments of 1996 also include stipulations for capacity development of water utilities to promote the development of appropriate financial, staffing, and managerial capacity of water systems to meet the evolving (water quality) standards being defined for drinking water utilities in the United States.

The pertinent point for water quality in the United States is that USEPA has put into place regulations that apply to all community drinking water systems, while the mode of implementation has been structured to accommodate the notable distinctions between large and small systems. Similarly, sound water accountability and loss control practices are appropriate for all drinking water utilities, although the means of implementation may vary between large and small systems.

Table 9-1 Characteristics of large and small water systems in the United States

Typical Characteristics	Large Systems	Small Systems
Geography		
Typical demeanor	Urban, suburban	Suburban, rural
Service density	Often high-density development	Often scattered, low-density development
Water Resources		
Source water	Often surface water from large reservoir, river, or lake network	Most small systems rely on groundwater or a mix of surface water and groundwater from scattered small lakes, streams, and wells. Some small systems purchase water from a neighboring larger system; occasionally their entire supply is obtained in this manner.
Proximity	A few large sources are usually very proximate to a population center in US eastern states, but often at great distances in US western states.	Many small-volume sources may be needed to serve widespread, scattered, small populations.
Source water quality	Surface impacts, including industrial and development pressures, make water treatment more demanding than groundwater sources. Source water protection is practiced with greater frequency.	Generally, groundwater requires less complex treatment than surface water, but contamination of aquifers occurs to some extent. Less than one half of all small water systems participate in a source water protection program.
Reliability	Large dams and reservoirs exist on many resources supplying large cities, providing storage reservoirs to maintain reliability during short-term droughts.	Many groundwater supplies are shared with the high-water-demand agriculture industry. Certain large aquifers are under stress from unsustainable pumping.
Water Supply Infrastructure		
Ability to meet peak demands	Can rely on water stored in reservoir infrastructure to help supply peak periods.	Must typically increase (groundwater) pumping to meet peak demands.
Water distribution system configuration reliability	Redundancy usually exists to provide enhanced reliability; grid (looping) piping network is typical.	Sole source often exists, offering less reliability; branching pipe networks are common.
System needs	Many systems in urban and older suburban areas are aged and require significant upgrades. Greatest needs are transmission and distribution pipe renewal. Value of needed infrastructure renewal is much greater than for small systems	Small systems are reported to have more than three times the per-household infrastructure needs than large systems (in terms of cost to customer). Greatest need is storage. Cost per customer to fund infrastructure renewal is much greater than for large systems.
Financial/Managerial Capacity		
Ownership	With the exception of several large, private companies (who also may own small systems), most are publicly owned.	The smallest of systems serving fewer than 500 people are typically privately owned.
Customer characteristics	Large number of residential customers but also many commercial, industrial, and agricultural customers that consume a significant portion of the produced water.	Mostly residential and agricultural; ratio of water production to customer connection increases as system size increases.
Revenue potential	Revenue per connection is higher for surface water systems.	Revenue per connection is lower for groundwater systems.
Compliance history for federal drinking water regulations	3.4 water quality violations* per million customers for systems serving more than 10,000 people in 2008.	1,374 water quality violations* per million customers for systems serving less than 500 people in 2008.
Staffing and employee compensation	Greater staffing levels than small systems. Compensation and benefits are greater as system size increases.	Smaller staff than large systems; many staff are part-time employees. Compensation and benefits are lesser with small system size.
Generally accepted accounting principles (GAAP)	Over 90% of systems serving 1,000 people or more use GAAP. Median revenue is 2.5 times greater for systems using GAAP than those that do not.	Only 30% of the smallest systems serving 500 or fewer people use GAAP.
Engineering services	Many large systems conduct engineering programs with in-house staff or mix of staff and engineering consultants.	Small systems often have greatly limited or no in-house engineering staff; work is typically outsourced to engineering consultants.

*Includes maximum contaminant levels, maximum residual disinfection level, and treatment technique violations. Does not include monitoring & reporting violations.

Source: *USEPA 2011*

For example, performance indicators for the normalized measure of real (leakage) losses are different for water systems having a low density of service connections (less than 32 customer service connections per mile of pipeline) and those with a density of connections above this level.

IMPLEMENTING WATER LOSS CONTROL PROGRAMS IN SMALL SYSTEMS

Small water systems may often face more challenges than large water systems in implementing new programs or meeting new regulations. In reviewing the list of water loss control activities in chapter 8 (Table 8-1), it may appear that some of these activities are not practical for the typical small system. However, on closer review, small systems have certain advantages over large systems in some of these areas.

Compiling the Water Audit

Compiling a water audit is the basic step for a water utility to provide accountability to its operations; and the top-down water audit can be compiled with very little effort or cost, making it feasible for utilities of all sizes. For systems that do not currently audit its supplies, this is the recommended first step. By following the AWWA Water Audit Methodology described in chapter 3—using the AWWA Free Water Audit Software—any water utility can conduct a basic top-down audit on its water supply and distribution operations. By compiling a simple monthly report such as shown in Table 8-2 and compiling the water audit annually, any utility—large or small—can establish a routine, top-down auditing process with a very small investment of staff time and virtually no dedicated funding. Water auditing not only identifies the quantities and costs of system losses, it also serves as the tool to measure progress and promotes a change in organizational culture because employees intrinsically sense a greater value for water once they realize it is being closely tracked.

AWWA promotes a common philosophy for water utilities of all sizes: A water audit should be compiled by the water utility on an annual basis as a standard business practice. Once a basic top-down water audit has been established, the water utility should progress to the use of bottom-up measurements and investigations every year to validate the water audit data and better confirm the source and extent of losses. Bottom-up activities do require an investment of staff, equipment, and training to be most effective. Dedicating such resources may be difficult for many small systems. One option to address this issue is to consider the use of a performance-based consulting contract, whereby a consultant performs the investigative work to identify losses and recommends targeted interventions that will recover losses and revenue. The consultant's compensation occurs in the form of a portion of the measurable monetary recoveries recouped from the loss control activities. It is important that the water utility and consultant carefully negotiate the language of the performance contract so that the means to define, measure, and value recoveries are clear and explicit to both parties. Other options to consider for establishing bottom-up auditing activities include traditional leak detection consulting contracts with acquisition of equipment, training, and staff to perform such activities in-house. Federal, state, or regional programs may provide grant funding, training, or even loaner leak detection equipment for these purposes. A successful assistance program was instituted in the state of Georgia and is described later in this chapter. Each utility must evaluate its technical, financial, human resources and capacity to determine the appropriate mechanism for bottom-up validation of its annual water audit.

Addressing Apparent Losses

Apparent losses are the nonphysical losses that occur because of systematic data handling errors in the customer billing system, customer metering inaccuracies, and unauthorized consumption. Apparent losses result in underbilling to customers and cause a loss of revenue capture. Apparent loss recovery is attractive for all water utilities that bill customers based on measured volumes of water consumption. Often, apparent loss recovery results in an immediate payback with the next water bill. Some utilities may also have policies that allow back billing or charging for consumption from previous months if occurrences such as unauthorized consumption have been encountered. This makes apparent loss recovery very attractive from a cost recovery perspective. Some of the considerations for apparent loss control that are practical for small systems to implement are presented below:

- Particularly for systems with several thousand or more service connections, automatic meter reading (AMR) or advanced metering infrastructure (AMI) may be effective, especially for systems with limited personnel. AMR/AMI may or may not be cost-justified for the entire service area, but it might provide considerable benefits for remote sections of the network where it is difficult to obtain regular meter readings. Large customer accounts that consume significant water may be willing to pay an additional fee for the detailed water consumption data from AMI. A small number of large consumers not only provide significant revenue to the water utility, but frequent variations in their consumption patterns can exert challenging operational demands on the supply system.
- Perform a cursory scan of summary customer billing system data, looking for patterns of strange data. Do any negative consumption numbers appear? This could reflect improper billing adjustment routines. Do certain customer accounts record zero or very low water consumption, reading after reading? Periodically inspect unmetered or unbilled addresses: are there signs (lights, people) that the property is occupied? Unless the customer accounts are vacant properties or have stuck (nonfunctioning) meters, these readings could reflect tampering with metering or meter reading equipment. In such instances, these accounts should be investigated to determine if they are sources of apparent loss. Other unusual patterns of consumption data could be identified with relatively little effort. If such anomalies are common, a more detailed investigation of the entire billing system should be considered. Make certain that the process flow of the billing system does not inadvertently underbill customers (see chapter 5 for ways to address systematic data handling errors in the customer billing system). Remember, the billing system tracks consumption that is the basis for revenue generation, so a solid understanding of the workings of the billing system is essential to ensure an optimum revenue flow.
- Verify and balance production flowmeter quantities from primary water sources at wells, lakes, and streams as well as meters measuring flow during and after the water treatment process. These meters provide the measure of source water volumes into the water audit and should be accurately maintained to provide a reliable water audit. Meter accuracy testing services are available from a number of providers at reasonable cost. For many small systems with limited supply, the meters at production facilities may be relatively small and are easier to test and replace than the large flowmeters in larger water utilities. See appendix A for detailed guidance on the management of production flowmeters and water supply data.
- Metering is an essential tool for accountability, and all customers should be metered, including public buildings. Customer meter readers should be alert to detect unauthorized consumption from tampered meters or illegal connections, as well as to detect meter malfunctions identified from suspicious data. For example, it is not unusual to find unauthorized service connections tapped into unmetered

fire lines, and an annual inspection of all fire lines in the system can identify such occurrences. Accounts that consistently register unusually low consumption volumes are worth investigating for unauthorized consumption.

- Establish, communicate, and enforce a clear policy for the use of fire hydrants. A considerable amount of water is taken illegally from fire hydrants in many water utilities. In small systems in particular, customers, firefighters and local public officials can assist by reporting illegal activity with regard to hydrant misuse.
- Test the accuracy of meters on the largest customer accounts. While small systems predominantly serve residential accounts, one or two large commercial or industrial accounts can consume a large portion of the water supplied to the distribution system. Ensuring that the largest consumers are accurately metered and billed can provide a high level of revenue protection with relatively little effort.

Many other approaches to apparent loss control, as described in chapter 5, are viable methods for water utilities of all sizes. Because apparent loss recoveries translate to direct revenue recovery, the apparent loss control program can generate funding to pay for further loss control activities, both apparent and real loss control.

Addressing Real Losses

Real losses include leakage from the water distribution system and customer service connections up to the point of customer metering, as well as overflows from treated water storage tanks or reservoirs. For many water utilities, real losses result in increased production costs to treat and convey water that never reaches a customer. For many smaller utilities, water resources are limited and real losses might be a threat to sustained supply. In such cases, real losses might be valued at the retail cost charged to customers, in following with the thinking that any water saved through leakage reduction can be sold to current or future customers.

Real losses often exert a larger proportional impact on small systems than large systems. A crack in a 6-in.-diameter cast-iron pipe leaking at a moderate rate of 65–100 gpm may result in reduced pressures and compromised water service in a very small system where the pipeline is the primary supply feeding an area of the water distribution system. The same leak may go unnoticed in a larger system where the 6-in. water main is one of many same-sized pipes in a grid of distribution mains. Real loss control can be more important in small systems than for medium- and large-sized systems where resources are limited. Often it is more difficult for small systems to allocate ongoing staff resources to active leakage control as many large systems do. Although aggressive leakage management may seem out of reach for many small systems, there are some advantages that small systems enjoy over their larger counterparts in controlling real losses. Some of these advantages include the following:

- Detecting and repairing one or several notable leaks in a small system could greatly improve its overall accountability, whereas many more leak repairs would be needed to generate the same benefit in a large system.
- The water distribution piping configuration in many small systems is sufficiently small and configured independently to function as one or more individual district metered areas (DMAs). Techniques to measure leakage in DMAs could therefore be implemented with less cost than in many larger systems. In such cases, however, the DMA will likely encompass the system's transmission mains and, possibly, water storage tanks. Design provisions must be undertaken to ensure that water levels in storage tanks can fluctuate within a desired range and still meet pressure management objectives for supply and fire flow in the DMA. The tank

water level should be monitored so that the net change in storage volume over short periods of time (similar calculation as shown in Figure A-15 in appendix A) can be accounted for when quantifying supply flows to the DMA. See chapter 7 for a detailed description of DMAs.

- The limited length of small water distribution system piping means leak surveys can be conducted across the network in a much shorter time frame than large systems. Also, the lack of large urban centers in most small systems means leak survey work does not necessarily have to be conducted at night to avoid noise from daytime activities and traffic common in cities. The unit costs of conducting leak survey work in small systems are often less than in large systems.
- Techniques like step testing are more easily employed in small systems. Step testing requires operation of selected system valves while monitoring for changes in system flows and pressures. Valves operated in the area of a significant leak can exhibit a noticeable change in pressure and flow when closed.

It is also recognized that small systems encounter challenges that aren't always present with large systems. Some of these include the following:

- Small systems often include piping that has been installed in more rural areas of unpaved surfaces such as fields or lawns. Although such leaks may surface more readily, locating underground piping and pinpointing leak detection work are more difficult under these circumstances. Leak detection is also more difficult on nonmetallic (plastic) piping, and plastic piping buried under nonpaved surfaces presents some of the greatest challenges for leak detection.
- Many small systems lack accurate mapping of the underground piping network, and line location tracing is needed to locate the infrastructure.
- Plastic pipe has been installed in many small systems without tracer wire or tape. Therefore, accurate pipe locating is extremely difficult.
- Many small systems conduct leak survey work only periodically and often use contracted leak detection service providers to conduct the work. This makes it difficult to develop and retain in-house leak detection skills of the existing water utility staff.
- The budgets for small water utilities are often very limited, and problems not needing an immediate response are often deferred. Many small leaks are not initially disruptive and are often deferred indefinitely.

There are several steps that small water utilities can take to establish and maintain reasonable leakage management practices in their water distribution systems. The following list states several considerations for real loss control that are practical for any system to implement at a very reasonable cost:

- Maintain a means of water level monitoring or inspection to avoid overflows of tanks or reservoirs. Inexpensive level-monitoring instruments and controls are available to monitor tank levels and avoid such events.
- Encourage customer meter readers and customers themselves to report possible evidence of unreported leakage (leakage sounds, wet spots, damp cellars, flooded meter pits, etc.) on customer service connection piping or water mains.
- Look to reduce areas of normally high water pressure that are common in the valley areas of hilly or mountainous systems. Excessive water pressure aggravates leakage and water main breaks. Do opportunities exist to reduce operating pressures? See chapters 6 and 7 for discussions on pressure management.

- Be mindful of the possibility of hidden leaks that may exist on water mains that cross under major highways, streams, rivers, railroad lines, or other major utilities. These are areas where leaking water can escape without surfacing or notice. Step testing and test shutdowns while checking upstream and downstream pressure measurements may aid in detecting the possibility of leaks at such locations.
- Budget for periodic leak detection surveys of the entire water distribution system or, at least, the most leak-prone areas. Plan on conducting the work periodically (up to every 3–5 years) or when water audits, high system flows, reduced pressure, or other signs suggest increasing leakage. Communicate the need for this process to the board or governing body of the water utility well in advance and remind the leadership each year that this work is upcoming. The return on investment and an estimated payback period can be determined and also communicated to the board and other interested stakeholders so that decision makers are prepped for the work when the time comes to place funds in the budget.

Many of the approaches to real loss control, as described in chapter 7, are viable methods for water utilities of all sizes. The "Managing Water Supply Costs by Focused Leakage Control" sidebar provides a good example of water loss control activities successfully applied in a small water utility—the Water and Wastewater Authority of Wilson County (WWAWC), Tenn. Photos of conditions in Wilson County are shown in Figures 9-1 and 9-2, and an expanded case study account for the WWAWC is given in the USEPA report titled *Control and Mitigation of Drinking Water Losses in Distribution Systems* (USEPA 2010). In addition to cutting production costs, reducing excessive leakage may result in continued economic development in communities that have limited water resources and may avoid or defer the need to develop costly new water resources and treatment infrastructure.

OBTAINING TECHNICAL AND FINANCIAL RESOURCES FOR WATER LOSS CONTROL

The Capacity Development Program of the USEPA is designed to help improve the technical, financial, and managerial capacity of small systems. USEPA developed this program as a result of the Safe Drinking Water Act Amendments, and, while stemming from the need to assist small systems in meeting water quality regulations, the program promotes overall capacity development for efficient overall system operations.

In the United States, several programs exist to offer small systems technical and infrastructure funding, as well as guidance, training, and assistance (USEPA 2002). Some of the larger programs are offered by the USEPA, US Department of Agriculture (through the Rural Utilities Service), and US Department of Housing and Urban Development Community Development Block Grant Program. These programs provide a strong emphasis on guidance, development, and training, although some of the programs also feature loans and grants to install or upgrade water infrastructure. The programs typically include water conservation as one of the criteria for improvement, and small systems can explore the use of such instruments to assist them in compiling a bottom-up water audit, conducting a leak survey, or replacing a deteriorated pipeline.

A groundbreaking example of a small systems technical assistance program was implemented in the state of Georgia by the Georgia Environmental Finance Authority and the Georgia Environmental Protection Division. These two agencies, working with a third-party consultant, developed and implemented a multiyear, multiphase technical assistance and training program (Gallet et al. 2014) on water auditing and loss control for small systems across the state. The program was ultimately driven by the advent of legislation in 2009 (see chapter 2) that mandated water auditing, reporting, and loss control improvements in a broader aim to create a culture of water conservation in the state.

Managing Water Supply Costs by Focused Leakage Control in the Water and Wastewater Authority of Wilson County, Tenn.

The Water and Wastewater Authority of Wilson County (WWAWC), Tenn., is a small water utility located in the central area of Tennessee not far from Nashville. The WWAWC recognizes the value of employing best practices and uses the AWWA Free Water Audit Software to conduct a top-down water audit on an annual basis, and has developed a very effective leakage management program.

The WWAWC operates with a staff of 11 employees (6 in field operations) and services a primarily residential population with 6,926 active water service connections. The WWAWC purchases 100 percent of its potable drinking water supply as treated water from four different supplies through 15 meters that are manually read on a daily basis. The water purchased by the WWAWC is the single largest manageable expense in its annual budget. The WWAWC pays a notably high rate of $2.11 per 1,000 gallons for this imported water supply, which is distributed in the eastern half of Wilson County through 321 miles of distribution piping, which is almost 100 percent polyvinyl chloride (PVC) piping. System pressures vary from 25 to 140 psi, and the average pressure has been estimated at approximately 60 psi. Because of the significant expense of the imported supply, the WWAWC keys heavily on leakage management, as water lost to leaks causes a significant financial impact to the WWAWC. WWAWC has taken on the challenge of aggressive leakage management in a cost-effective manner. Its investment in equipment has been modest and includes three electro-acoustical water leak detectors, pipe locators and valve box locators, as well as one portable ultrasonic liquid flowmeter, which is the costliest device at $8,500.

The WWAWC's primary leakage control strategy is to identify and abate leaks that tend to run for a long duration and to identify water main breaks before they affect the level of service to customers. The run time of a leak consists of awareness, location, and repair times. The WWAWC becomes aware of leakage from customer calls for low or no water pressure, surfacing water, delayed storage tank fill rates, routine sonic leak surveys, water auditing, and minimum night flow measurements in district metered areas (DMAs) that have been established throughout the water distribution system.

Once the WWAWC is aware of the leakage, then locating the individual leaks may consist of physically driving or walking the suspected area looking for surfacing water, partially closing main line valves and listening for water rushing through the valve, conducting a sonic leak survey by listening to the system appurtenances, using the ground-microphone technique with the water leak detector directly over the water main, recording minimum night flow measurements, and step testing by temporarily limiting supply to a portion of the system and monitoring the change in flow.

To optimize repair time, the WWAWC repairs all main breaks/leaks immediately after being located. Service leaks are typically repaired within four working days to allow for the other utilities to respond to a normal Tennessee One Call underground utility locate request. Service leaks that may affect the customer's water quality or quantity or cause property damage are repaired immediately after being located. Large main breaks, where the customer's service is interrupted, tend to surface and are relatively easy to locate. Therefore, these leaks tend to have a high flow rate but run for a relatively short duration. Service line leaks and small main line breaks may leak at a much lower rate, but the duration can be very long and these leaks can be the major contributor to the water loss. Therefore, the present focus of the WWAWC is to establish and implement methodologies to reduce the awareness and location time for these leaks that tend to run for a long duration, and to identify the main breaks before they affect the level of service to the customers. This is not only a water loss issue, but also a water quality issue. By becoming aware and locating main breaks before they blow out allows the main to be repaired under positive pressure with a repair clamp, eliminating the need to cut the pipe and depressurize the distribution system. If the system is depressurized, then a bacteriological sample must be taken and the depressurized section of the system may need to be disinfected. Repairing main breaks under pressure is extremely important in maintaining water quality and service to the customers.

The WWAWC's water distribution system exists in a rural area with a customer density of 22 connections per mile of main. Therefore, the average distance between listening points on services is 240 ft. In the more rural areas of the system, it is not unusual for the distance between listening points to be more

Sidebar continues next page

Managing Water Supply Costs by Focused Leakage Control in the Water and Wastewater Authority of Wilson County, Tenn. (continued)

than 2,000 ft, a distance too great to allow for effective sonic leak detection by direct contact. Listening on the service lines in these areas will tend to only identify service line leaks. In addition, the WWAWC's water mains are nearly 100 percent PVC located out of the road right-of-way under soil and vegetation in fields and often behind fences. Using a ground microphone over the water main to listen for the impact and fountain sounds created by the leak works very well on a water main located under pavement or in the shoulder of the road. But this process is very difficult if the main is under grass or soil in that the leak noise does not attenuate well though soil in comparison to a solid surface (see Figure 9-1).

System pressures at higher elevations are as low as 25 psi. Low pressure produces a weak leak noise, making sonic leak detection much more difficult. In summary, on a rural PVC system like the WWAWC's, a sonic leak survey tends to identify service line leaks but may not detect existing main line leaks. Therefore, the WWAWC implemented 16 DMAs to identify and prioritize the areas where leakage exists or new leaks are emerging.

Each DMA has a means of measuring the input into the DMA either by permanent input supply meters, temporary metering, or via drop testing of a water storage facility. The DMAs range in size from 0.8 miles of water main serving 83 service connections to 99 miles of water main serving 1,912 service connections. The four largest DMAs include a total of 205 miles of the distribution system, which represents 64 percent of the total system. Each storage tank is on telemetry that polls storage tank water levels every 30 minutes. To reduce the run time of the leaks, the WWAWC monitors the minimum night flow (MNF) via the telemetry on the four larger DMAs. Given that the customer base is primarily rural residential, minimal consumption occurs during the MNF period. During the summer months, some nighttime lawn irrigation may occur within housing subdivisions and for select customers. The MNF is that time typically between 1:30 a.m. and 3:30 a.m. when the consumption within the DMA is at its lowest. Each night when pumping is shut down and the DMA is fed via gravity flow from the water storage tank, the tank level changes are converted to a volume over a period of time to calculate the gallons-per-minute flow feeding the DMA. The input meters measuring the water supplied to the 12 gravity-feed DMAs serving the remainder of the distribution system are normally read daily, and these readings are compared to the prior day's readings to determine if a higher rate of flow is occurring, indicating the possibility of emerging leakage. If a daily reading increases and leakage is suspected, then a portable ultrasonic liquid flowmeter is normally installed at the input meter and flow is data-logged at 1-minute intervals (see Figure 9-2). Similarly, if additional leakage is suspected in one of the four larger DMAs based on telemetry data, then a portable ultrasonic liquid flowmeter is normally installed at a flow monitoring site located on the main line at the storage tank prior to entering the distribution system. On smaller DMAs, a sonic leak survey may be conducted to locate and pinpoint the leakage instead of installing the portable ultrasonic liquid flowmeter.

The WWAWC's success in keeping leakage at minimal levels is reflected by its real loss performance indicators calculated by the AWWA Free Water Audit Software. Audit data from 2009 showed the annual leakage volume to be 75.6 mil gal and an Infrastructure Leakage Index (ILI) value of just over 1.0, a very low level of leakage. By 2012, the WWAWC had further reduced its annual leakage volume to 67.05 mil gal. This is allowing the expensive cost of purchased imported water supply to be managed very effectively and to maintain a reliable level of service to the WWAWC's customers. The WWAWC encounters many of the challenges confronting small systems: a low density of connections and wide distances between pipeline sounding locations, considerable piping installed in unpaved areas, hard-to-detect PVC piping, and limited finances and staffing. Yet, by applying proactive leakage management techniques, the WWAWC has established a highly effective leakage management program. The WWAWC's experience proves that the leakage management techniques offered in this manual are effective when they are properly tailored to the specific conditions of the water utility, regardless of its size or general characteristics.

Figure 9-1 Using a ground microphone to listen for leak noise on piping in an unpaved surface in Wilson County, Tenn.

Courtesy of the Water and Wastewater Authority of Wilson County, Tenn.

Figure 9-2 Using a portable ultrasonic flowmeter on a PVC pipeline in Wilson County, Tenn.

Courtesy of the Water and Wastewater Authority of Wilson County, Tenn.

The entire technical assistance and training program was provided to all small systems (those serving 3,300 to 10,000 population) at no cost to the utilities, as it was funded through the 2 percent State Revolving Fund (SRF) set aside for small systems assistance. Phase 1 of the program included a 10-month detailed training initiative, implemented with a series of cumulative regional workshops that promoted peer-to-peer utility interactions and resource sharing, targeted homework periods, and a post-audit validation process modeled from the AWWA Water Loss Control Committee's Water Audit Data

Initiative (see appendix E). Phase 2 of the program provided in-field technical assistance for improvement projects identified from the audits, including finished water flowmeter verification, customer meter testing, and pilot leak detection. The program outcomes for the participating small water systems included demonstrated improvements in technical, financial, and managerial capacity; documented improvements in data validity, including the quantification accuracy of water loss volumes; and follow-through on financing for capital water loss projects such as infrastructure renewal through the SRF loan program.

In addition to the 2 percent SRF set aside for small systems technical assistance and training, technical guidance and promotion of best practices for small systems is also available from the Small Systems Division of AWWA and the National Rural Water Association.

PIPELINE LOCATION AND LEAK DETECTION FOR SMALL WATER UTILITIES

The Water Research Foundation (WRF) sponsored a project titled Pipe Location and Leakage Management for Small Water Utilities (Project 4144), which created technical guidance modules to assist small systems operators in locating their buried infrastructure, identify water loss sources, and locate leaks. The primary output of the project is not a written report but a series of presentation materials suitable for a workshop setting (WRF 2014). (A written report is provided as a supplement to the presentation material that outlines project issues as well as being a reference for other materials to be used by small system operators and trainers.) In preparing the slide presentation modules and a written summary report, the project team reviewed available technologies and provided recommendations for applying them to help small utilities improve the efficiency of distribution system operations. Many recommendations are also applicable to larger systems. Most leak detection devices of use to small systems fall into the following categories: listening rods, ground microphones, correlators, noise loggers, and pipe intrusive acoustics.

The list of leak-locating tools does not include some more sophisticated methods that have been employed in the industry, including fiber-optic cable placed inside the pipe to hear sound or placed outside the pipe (during installation) to detect changes in temperature between the leaking water and the soil temperature. Another nonacoustic method is hydrogen or helium used as a tracer gas to locate leaks in pipelines. The costs of these methods can be more expensive than traditional acoustic leak detection and beyond the practical everyday use by smaller systems. Nonetheless, an awareness of such techniques may be useful, as vendors or consultants may propose such services for emergencies.

The project also highlights pipe-locating methods. To maintain pipe, valves, connections, and service lines, all water system operators need to know their physical location and condition, particularly if they are beginning to fail. The inevitable deterioration of the underground pipe network requires increasing awareness of piping and the controlling valve locations to limit damage in addition to having the ability to identify when and where failures are occurring.

As noted previously, small systems do have unique challenges. Location and leak issues are magnified for small systems where resources may be limited. For example, smaller systems may find that one or two persistent undiscovered leaks can threaten its limited water supply or cause financial hardship. Owing to budget limitations, highly sophisticated locating and monitoring equipment that can help may not be affordable. Labor limitations can be an issue; some operators of small systems also manage other operations including wastewater, parks and recreation, trash collection, highway and other municipal functions. Small systems are more likely to be unmetered at the customer location, though many do see the value of customer metering.

The presentation materials created in Project 4144 are designed to equip operators with knowledge of the basics of line locating and leak locating. It is strongly suggested that workshops using the presentation materials be augmented with firsthand demonstrations of equipment that can usually be made available from vendors and distributors of the equipment. Workshops that were conducted using these tools included such hands-on demonstrations that were well received by attendees of initial workshops conducted for this purpose. These demonstrations are not only informative and complementary, but they break up training fatigue that can occur in an extended classroom setting.

The researchers chose not to provide a program focused on leak-locating techniques without first quantifying the annual volume of leakage in the water system and its cost impact to utility operations. It was decided at the proposal stage to provide small utilities with a means to quantify their leakage to have an improved sense of how much investment should be made in limiting water loss. In addressing the challenge of quantifying system leakage volumes, utilities can rely on the AWWA Water Audit Methodology, as described in chapter 3 of this manual.

A vital issue for the project is effectively communicating the information gathered to the target users: small system operators. Although reports are valuable, most small system operators receive information from their primacy agency and local assistance organizations through training programs, technical assistance, and communication items (newsletters, etc.). Training is often required to maintain operator certification, and organizations that provide training are always looking for good content. Linking the project report or Web content to training and technical assistance efforts is essential for application of the results of this project.

One of the best ways to reach small system operators is through local technical assistance providers. Organizations employed included state rural water associations, the Rural Community Assistance Partnership, and an environmental finance center. These organizations have day-to-day contact with small system operators and are known and trusted sources of information. Also, the only practical way to reach a large number of small systems is through this established network of technical assistance providers. While the training materials created under Project 4144 are fairly complete, it is recommended that a workshop be held to "train the trainer" who can then take the training forward to small water utilities in a given region.

Effective training workshops should have a hands-on component. Therefore, it is essential that presentations be supplemented by vendor or consultant demonstrations of line location and leak detection equipment. As long as the commercial aspects of demonstrations are held in check, this is an effective complement to the material provided from Project 4144.

It is recommended that research work continue to explore methods to better locate buried piping and identify undetected leaks on nonmetallic materials. Although there has been some improvement in locating technologies, there remains considerable difference in detecting leaks on metallic vs. nonmetallic pipe. Acoustic leak detection on nonmetallic pipe is generally more difficult than metallic pipe; however, there are some indications that improvements are being made in acoustic sensing to locate leaks on plastic pipe. Operators from small systems with plastic pipe should consult with several leak detection manufacturer representatives and/or leak detection consultants to identify leak detection devices that are effective in pinpointing leaks on plastic pipe. Alternately, the utility can also employ DMAs to track this leakage.

The material from WRF Project 4144 is free to the public at http://www.waterrf.org/Pages/Projects.aspx?PID=4144. Because of a growing recognition of the importance of water loss control and the need to provide effective tools to water utilities of all sizes, several other research efforts with application to small water utilities have been undertaken in recent years and improved technology continues to develop.

More resources than ever exist for small water utilities to leverage to audit their water supply, metering and billing operations, as well as to better control leakage and revenue losses. As water resource limitations, financial constraints, regulatory requirements, and other pressures continue to mount, the need for improved water accountability and loss control will only continue to grow. Small systems should know that resources are available to them to meet these challenges.

ACCOUNTABILITY IN SMALL WATER UTILITIES

Sound water accountability and a good water loss control program are important for small water systems to operate efficiently. With smaller staffs and budgets, and employees often responsible for a wider array of functions than their larger counterparts, many small systems may find difficulty in launching new efforts to assess their accountability and implement loss control measures. However, promoting accountability is a proactive step that usually offers a financial payback as well as a boost in efficiency as the system ages. The improvement potential is often as strong—or stronger—in small utilities as it is in large systems. The possibility of a relatively quick boost in revenues or reduction in operating costs makes a loss program particularly attractive for many small water systems.

The greatest challenge is often in getting started. Once an initial effort is launched by starting the water auditing process, opportunities for financial and operating improvements quickly emerge. The methods and tools offered in this manual are designed to work for water utilities of all sizes but have been carefully structured with small water systems in mind. The AWWA Free Water Audit Software (chapter 3 and appendix D) was specifically designed to be straightforward and user friendly, and available at no cost, allowing data to be readily input and performance indicators to be calculated. With these tools and methods currently available, water utilities have the potential to quickly assess their water and revenue loss standing and to begin to implement successful measures that will improve their operations, service to their customers, and protection of valuable water resources. Various mechanisms exist to assist small systems with funding, training, or expertise from government-sponsored programs. Included in appendix E are examples of data collected from North American water utilities, including several small water utilities. The data should provide insight to small system managers embarking on their own loss control initiatives. The opportunity to protect water resources has never been better, and small water utilities have as much potential as larger systems in implementing accountable and efficient practices in their operations.

REFERENCES

Gallet, D., et al. 2014. *Stepping Up Water Loss Control—Lessons From the State of Georgia*. Chicago: Center for Neighborhood Technology.

USEPA (US Environmental Protection Agency). 2002. *Sources of Technical and Financial Assistance for Small Water Systems*. Washington D.C.: USEPA. www.epa.gov/ogwdw/smallsys/pdfs/ tfa_sdws.pdf.

USEPA (US Environmental Protection Agency). 2010. *Control and Mitigation of Drinking Water Losses in Distribution Systems*. EPA 816-R-10-09. USEPA, Office of Water.

USEPA (US Environmental Protection Agency). 2011. *National Characteristics of Drinking Water Systems Serving Populations Under 10,000*. EPA 816-R-10-022010. USEPA, Office of Water.

WRF (Water Research Foundation). 2014. *Pipe Location and Leakage Management for Small Water Utilities*. Denver, Colo.: WRF.

This page intentionally blank.

Appendix A

Validating Production Flowmeter Data and the Annual Water Supplied Volume

This appendix provides detailed guidance on the methods for verifying the accuracy of production meters and quantifying error in the data trail leading to the determination of the Water Supplied volume in the annual water audit. This discussion includes detailed instruction on meter accuracy testing for the larger flowmeters that measure production flows. It additionally highlights the need to properly balance supply flows across the water distribution system and make adjustments to correct data errors that inevitably occur from time to time.

IMPORTANCE OF PRODUCTION FLOWMETER MANAGEMENT

The term *production* is used to denote the bulk water volumes that constitute the overall water supply managed by the water utility, including the water audit components: *Volume From Own Sources*, *Water Imported volume*, and *Water Exported volume*. The Water Supplied volume is shown in the Reporting Worksheet of the AWWA Free Water Audit Software (Audit Software) in Figure 3-5 in chapter 3 and is calculated as

$$\begin{aligned}\text{Water Supplied volume} = {} & \text{Volume From Own Sources} \\ & + \text{Imported Water volume} - \text{Exported Water volume}\end{aligned} \quad \text{(A-1)}$$

The Water Imported and Water Exported volumes are considered "custody transfer" volumes, since water is transferred from one water agency to another. The above three volumes typically represent the largest quantities measured by the water utility, usually by the largest flowmeters in the system.

The Production Volumes Are the Most Important Quantities in Ensuring the Accuracy of the Annual Water Audit

The Volume From Own Sources component is the largest quantity that is input into the water audit by most water utilities. For water utilities that import all of their water supply, the Water Imported volume is the largest volume. In each respective case, this volume is the critically important number in the water audit; and the reliability of all water audit calculations greatly depends on the accuracy of this bulk volume. Because this is a large overall volume of water, even small degrees of inaccuracy translate into sizeable volumes of water in error, which can affect the accuracy of the remaining volume components input into the water audit. It is therefore critical that the water auditor give foremost attention to the management of flowmeters measuring this volume, as well as the data trail for these measured values.

In this appendix, the term *verification* applies to the process of confirming the measurement accuracy of a flowmeter. *Calibration* refers to activities to ascertain proper function of instrumentation attached to a flowmeter. Finally, the term *validation* applies to the process of confirming the integrity of all of the variables in the calculation of the Water Supplied volume. These variables occur in a data trail that can be affected by flowmeter inaccuracies, instrumentation error, and adjustments in computer archiving and the final reporting that produces the Water Supplied volume.

The water utility's ability to maintain accurate measurement and reporting of water production volumes requires several important functions that should be conducted in ongoing fashion throughout the year for each flowmeter installation:

- Periodic, reliable verification of the measuring accuracy of the flowmeter that serves as the primary device generating the measured volume
- Periodic calibration and correction of the secondary devices (instrumentation including differential pressure cells or chart recorders) that transfer, and may store, flow data
- Ongoing surveillance of water production and supply data to detect and correct anomalies that can occur in the data. Such data are usually stored in a supervisory control and data acquisition (SCADA) system and/or other computerized archive, historian, or report generator.

Chapter 3 provides instruction on the data collection required to compile the water audit, starting with the production water supply volumes and adjustments that lead to an accurate quantification of the Water Supplied volume for the audit year. Task 1 in chapter 3 requires that the water auditor verify the accuracy of production meters that generate these measured volumes and include necessary adjustments to the annual volume of production flows. The information provided in this appendix gives detailed guidance on the methods available to accomplish this task. The reader is also referred to AWWA Manual M33, *Flowmeters in Water Supply* (AWWA 2006), for additional information on types of flowmeters and applications.

For most water utilities, the Volume From Own Sources component is the largest quantity that is input into the water audit. For water utilities that import all of their water supply, the Water Imported volume is the largest volume. ***In these respective cases, this volume is the most important number in the water audit, and the reliability of all water audit calculations depends greatly on the accuracy of this bulk volume.*** It is therefore critical that the water auditor gives substantial attention to the management of flowmeters measuring this volume, and the subsequent trail that this data follows through final reporting and archiving. Described below are the means to ensure an accurate quantification of the production volume. The methods discussed align with the criteria for high data gradings as defined in the Grading Matrix worksheet of the Audit Software (described in Task 1 of chapter 3). Production water quantity data that is well managed according to these best practices should be assigned a high Data Grading value in the Audit Software.

CONDUCTING FLOWMETER VERIFICATION AND SECONDARY DEVICE CALIBRATION

Flowmeters used to measure bulk supply flows come in a wide variety of sizes, types, and models. For the high flow-rate supplies managed by large water utilities, typical meters include Venturi meters, orifice plates, dall tubes, and magnetic flowmeters. Other meter types in use include turbine, propeller, and ultrasonic meters. Turbine and propeller meters may be more common in small water utilities with lesser production rates than those encountered in large water utilities. Insertion flowmeters may offer greater ease of installation and possibly lower purchase cost (than sizes larger than 12 in.). These devices can be installed in a standard tapping point in a pipeline, thereby occupying a smaller space within the pipeline. However, flowmeter types such as insertion magnetic meters must be custom sized to the installation to ensure correct positions of sensing electrodes to match the equally spaced concentric zones of flow. These meters also require regular maintenance to keep the sensing electrodes clean. Figure A-1 shows a large full-bore magnetic flowmeter being readied for installation. Figure A-2 shows an insertion flowmeter installed in a pipeline. Both meters use the same principle to measure flow, but they are notably different in size, installation requirements, and—for larger sizes—purchase cost.

All meter types have certain advantages in use, accuracy, and cost, but *all* meter types also have limitations. Therefore, water utilities encounter trade-offs of cost, accuracy, ease of installation and testing, and other factors in determining which type of meter to install in a given application. ***In any case, it is inherent that no meter is 100 percent accurate under all conditions, for all flow ranges, or for an infinite life.*** Thus, it is important that the water utility regularly verify the accuracy of the flowmeter on an annual—or more frequent—basis. Leading water utilities verify flowmeter accuracy on a quarterly basis. Others only perform verification based on local or state regulatory requirements, at intervals as infrequent as once every 5 to 10 years. Allowing more than one year to pass without verifying meter accuracy is not good practice because meter performance can degrade over time, flow patterns can change, and water consumption of the customer population can change dramatically, making the range of the flowmeter inappropriate to meet the current conditions.

For example, internal corrosion can slowly build on the throat of Venturi meters. Current Venturi designs include a ceramic coating to protect again this. However, the buildup of corrosion materials on the inside of the older Venturi meters can gradually impair accuracy. Similarly, corrosion buildup or sediment in Venturi meter pressure-sensing lines can also compromise the accuracy of the flowmeter measurements. As another example, accurate measurement of high constant flows that were achieved when a flowmeter was installed may not be produced by the same flowmeter when the water supply patterns shift to varying flows with frequent periods of low flow. Such flow-pattern changes are common when communities transition from large industrial economies to service-based businesses and residential developments.

Typically, water utilities install flowmeters for permanent service in supply pipelines to continuously measure and record water supply flows. The cross-sectional view of a typical orifice plate flowmeter is shown in Figure A-3. The metering element, which provides the capability to measure water flow rate, is known as the *primary device*. In most water utilities, production flowmeters are connected to a telemetry or SCADA system to provide real-time data to the operator of the water supply system. In such installations, the signal or output generated by the flowmeter is connected to a *secondary device* such as a differential pressure transducer, or DP cell (Figure A-4), that converts the flowmeter measurement

Figure A-1 Magnetic flowmeter awaiting installation on a 60-in.-diameter raw water pipeline in Philadelphia, Pa.

Courtesy of the Philadelphia Water Department

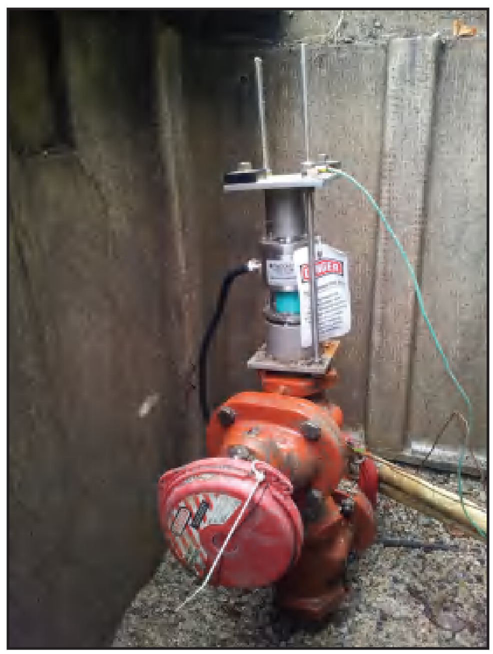


Figure A-2 Insertion magnetic flowmeter in use on a 30-in. pipeline in Birmingham, Ala.

Courtesy of the Birmingham Water Works Board

into a common electronic signal used in the telemetry or SCADA system. An electronic signal with a range of 4–20 mA (milliamperes) DC is standard in the industry. The signal from the primary device must be configured and processed to properly convert the flowmeter measurement units to flow rate volume units for the given application. Data are time-stamped and archived in the SCADA system and typically available to populate user-configured SCADA output reports. In the absence of a SCADA system, flowmeters may be connected to a circular chart recorder (Figure A-5), digital recorder, or other secondary output device where the measured value may be displayed. The data will also generally be stored on electronic data loggers for data archiving and analysis purposes.

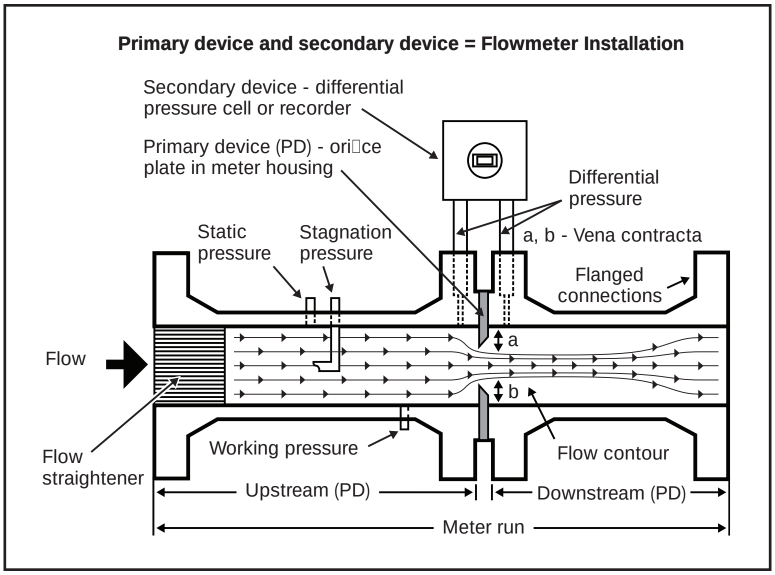


Figure A-3 Cross-sectional view of an orifice plate flowmeter installation

Figure A-4 Bank of differential pressure transmitters (DP cells) at the effluent pumping facility of the Crescent Hill Water Treatment Plant, Louisville, Ky.

Courtesy of the Louisville Water Company

To validate the annual volume generated by the flowmeter system, it is important to undertake each of the following validation steps:

- **Step 1.** Verify the flow-measuring accuracy of the primary device at least annually.
- **Step 2.** Calibrate the secondary electronic device on a routine basis; once every six months is recommended.
- **Step 3.** Confirm that the output reports of the telemetry or SCADA system match the secondary device output and are accurately configured to balance flows across the supply system. The utility should also ensure that data errors and data gaps that occasionally occur in all systems are systematically identified and corrected on a frequent, routine basis.

Figure A-5 Chart recorder and bank of chart recorders at the Queen Lane Pumping Station in Philadelphia, Pa.

Courtesy of the Philadelphia Water Department

Primary and Secondary Device Accuracy and Calibration

Be sure to verify the accuracy of the primary device—the metering element—as well as calibrating the secondary device—the electronic instrumentation transferring the flowmeter signal. Many water utilities are diligent in routinely calibrating secondary (electronic) devices such as differential pressure transmitters (DP cells) or other instrumentation. However, many of the same utilities fail to independently test the accuracy of the primary metering element of the flowmeter. Many flowmeters across the water industry have not been tested for years—or sometimes decades. If technicians "calibrate" the transmitters to produce a reading identical to the measurement from the flowmeter, then any existing error in the flowmeter measurement is carried through the transmitter to the SCADA system. It is essential that the flow-measuring capability of the flowmeter be confirmed with independent measurement on a periodic basis—at least annually—to properly manage these devices and to determine the quantity of Master Meter Error Adjustment to include in the annual water audit. Technicians should inspect DP cells carefully before calibrating them to make certain that all connections are water-tight and leak-free. Water leaking from a Venturi or orifice meter pressure-sensing line to a DP cell can cause distorted readings.

It is important that the water utility manager undertake all of the above activities to ensure that supply volumes are accurately measured, collected, and stored for retrieval to enter into the annual water audit. It is very common for water utilities to conduct Step 2—calibrate the secondary device—as the sole meter verification activity and then assume that they have sufficiently validated the production flow data (see the "Primary and Secondary Device Accuracy and Calibration" sidebar discussion). This electronic calibration action alone does not confirm the flow-measuring capability of the primary device. Calibration also does not account for data configuration errors or data gaps that occasionally occur in the SCADA system data or archived data. It is essential to quantify any measureable inaccuracy in the flowmeter as the first and most important step, and include this as a representative annual volume in the Master Meter Error Adjustment components that exist in the annual water audit.

In addition to verification of the primary device and calibration of the secondary device, it is essential that all telemetry or SCADA system output reports are accurately configured to present a realistic listing of production data. The data should be properly balanced across the water distribution system to account for changing water levels in storage tanks, flows transferring across pressure district boundaries, and other unique configuration features of the water distribution system. The data shown in these reports should be frequently monitored and corrected for data gaps or errors that periodically occur. Errors in

Figure A-6 Flowmeter located with insufficient spacing to allow for a streamlined flow profile and meter accuracy testing

the tabulation of flows across the distribution system should be taken into account to obtain an accurate quantification of the annual Water Supplied volume. Detailed information is provided below, particularly on data gaps and other sources of error in reported data.

SPECIFYING AND INSTALLING FLOWMETERS

In the design and construction of water treatment plants, pumping stations, and reservoirs, the specification and installation of flowmeters can often be viewed as minor details in the myriad of design features of the project. Quite often the task of specifying the flowmeter—a relatively small activity in an otherwise large project—becomes an afterthought, or entirely forgotten, until late in the design process. In such cases, the specification of the flowmeters is often rushed and the flowmeter type, location, and installation logistics may be less than ideal, resulting in a poorly functioning metering system. Many flowmeters in use today suffer compromised performance because the wrong meter for the application was installed in too cramped a space with no means to verify the accuracy of the meter. Many engineers tend to specify oversized flowmeters based on perceived high, but rarely occurring, peak flows, resulting in a meter installation with built-in inaccuracy and limited means to verify its accuracy or improve its performance. Figure A-6 shows a meter installed in a very poor configuration; "The Problems With Poor Meter Installation Configurations" sidebar explains why this configuration is problematic in terms of compromised accuracy and the inability to test the meter.

Many of the flowmeters in use today are not properly sized, typed, or situated for the application in which they are intended to serve. A guidance document produced by the Department of Ecology of the State of Washington claims that up to 75 percent of installed flowmeters are not performing satisfactorily, and improper selection accounts for 90 percent of the problems users have with meters (Department of Ecology, State of Washington 2015). When embarking on a water infrastructure project, the water utility manager should check to ensure that sufficient priority and attention are given to the design of the flowmeter—early in the design process. The design engineer must have a good understanding of the pipeline flow characteristics and issues that can cause distorted flow profiles that can eventually lead to inaccurate flow measurement by the flowmeter. Not all design engineers are well versed in flowmeter technology, and it is important that the designer obtain sufficient knowledge (through research or outsourcing the design) to assemble a competent flowmeter design.

Accuracy and repeatability are desired traits of a well-designed, specified, and constructed flowmeter installation. The engineer must specify the proper type of meter in the correct configuration to attain high accuracy and good repeatability. Ideally, flowmeters should be sited where the flow is relatively undisturbed, or approaching laminar conditions. Flowmeters sited near bends in pipelines, butterfly valves, or similar devices can suffer compromised performance due to the skewed velocity profiles of the turbulent flows created by these pipeline features. Good practice requires that flowmeters be sited at an acceptable distance from pipeline features that skew the velocity profile. To achieve a streamlined velocity profile, a flowmeter can be installed at a location with reasonable lengths of straight, unobstructed pipe adjacent to the meter. Table A-1 includes guidelines for upstream clear distances for various types of flowmeters. If it is not possible to allow for desired pipe spacing adjacent to the flowmeter, straightening vanes or strainers may be installed upstream of the flowmeter to condition the flow across the flowmeter. Some meter manufacturers advertise that they manufacture meters that require little or no adjacent spacing. While technology continues to improve and reduced spacing requirements may be possible, caution should be exercised by the engineer to confirm the reliable performance of the particular meter type before making a purchase. The engineer should check with water utilities that employ the particular type of flowmeter to confirm its function.

Early in the design phase, the engineer should give attention to the flowmeter function, including the expected range and variation of flows, and site and space availability, allowing sufficient space for in-place accuracy testing, instrumentation, and the maintenance needs of the flowmeter system. For a flowmeter to function correctly, it must be properly sized, the right type of meter for the application, and well-sited for performance, maintenance, and testing. Manufacturer product specifications and recommendations should be followed. Once constructed, the flowmeter should be tested for function and accuracy as part of the system commissioning, and startup problems should be immediately rectified. The water utility manager should require that all documentation, including product literature, specifications, and procedures, be submitted to the water utility by the manufacturer or installer. The water utility should keep these documents safely stored and refer to them regularly to help guide its maintenance and testing functions. All meter verification test records should be stored with this literature.

The Problems With Poor Meter Installation Configurations

The metering installation shown in Figure A-6 is a prime example of a water meter installation that suffers from poor design and installation, creating problems that serve to compromise the accuracy of the meter and inhibit the ability to reliably test the meter. The 8-in. turbine meter installation shown in Figure A-6 actually serves a large apartment building and is not a production meter. However, turbine meters are often used in production meter settings, and the issues that exist with this meter are illustrative of problems often encountered with production meter configurations.

As installed, the flow profile across the meter is disturbed by the adjacent 90° pipe bend upstream of the meter. To ensure a smooth flow profile across a turbine meter, straight unobstructed pipe should exist for a minimum distance of 10 pipe diameters, or 80 in., upstream of the meter. If a strainer is installed upstream of the meter, this requirement can be reduced to 5 pipe diameters, or 40 in., of straight pipe. Additionally, there should also be a minimum of 5 pipe diameters, or 40 in., of straight pipe downstream of the meter. In this cramped configuration, there is no space available to test the accuracy of the meter via an independent meter such as a portable insertion meter or strap-on ultrasonic meter placed downstream of the meter. An improved design of this installation would likely call for the meter installation to exist in a belowground vault. This would eliminate the need for 90° bends and allow for straight pipe to exist adjacent to the meter.

Table A-1 Recommendations for desired upstream, unobstructed straight pipe length for common water utility flowmeters

Flowmeter Type	Length of Recommended Straight Pipe (stated in terms of number of pipe diameters for the given application)
Venturi	4–10 diameters—depending on the type of any flow-disturbing obstruction in the pipeline
Orifice	5 diameters
Flow tube	4–10 diameters—depending on the type of any flow-disturbing obstruction in the pipeline
Pitot tube	10 diameters
Propeller	5 diameters
Turbine	10 diameters—assuming a flow-straightening element is used (otherwise 25 to 30 pipe diameters)
Magnetic	5 diameters
Ultrasonic (Doppler shift)	7–10 diameters
Ultrasonic (pulse transmission†)	7–10 diameters (and 5 diameters downstream)

*Information is based on engineering judgment and conservative best practice observed in the water industry by AWWA Water Loss Control Committee members

†Includes transit time flowmeters

VERIFYING FLOWMETER ACCURACY

Several methods exist for verifying the accuracy of the primary measuring device used in generating a volume of water supplied through a production pipeline. The methods are somewhat varied, but they ultimately provide an assessment of the entire flowmeter system, including the primary metering device, secondary instrumentation, and SCADA system data handling.

The general methods available to quantify the accuracy of production flowmeters are more or less feasible depending on the size, type, and configuration of the flowmeter installation. These methods include the following options:

1. Use a meter testing facility. Remove the meter and test it at a meter testing facility. This is generally practical only for meters up to 20-in. Some utilities keep two meters in stock, rotating one out-of-service for testing while the second meter is installed in the production pipeline to keep the water supply continuously metered.
2. Test the meter in-place by comparing the meter-generated volume to the volume generated by a second, portable calibrated metering device. This can be accomplished by using a trailer-mounted meter test apparatus for production meters in the size ranges of 3 in. to 8 in.; or for larger meters, use of an inline meter (insertion or strap-on) installed temporarily on the same pipeline as the primary flowmeter.
3. Compare volume measurements from the primary meter to other permanently installed flowmeters existing in series within the same supply pipeline or system. By employing a *mass balance technique* to compare this data, unusual variations in flow patterns can be discerned. This technique may not serve as a direct indicator of the level of accuracy of a particular flowmeter, but instead serves to denote if the flow trend recorded by two or more flowmeters in series is in, or out, of control. It therefore can be helpful in indicating when a given flowmeter begins to lose accuracy.
4. Conduct a water storage clearwell or tank drop test. This method makes use of the availability of water stored in a clearwell, tank, or reservoir to serve as a comparative measure of flow through a flowmeter.

The goal of the above methods is to obtain an assessment of the accuracy of the flowmeter at flow ranges that are representative of actual operating conditions. Accuracy is stated as a percentage representing disagreement of data within a range (AWWA 2006). To obtain a numerical determination of the accuracy of a flowmeter, an appropriate meter testing procedure should be followed. Each of the above methods has certain advantages and limitations in assessing flowmeter accuracy. The basis for selection of the most appropriate of these methods is usually dictated by the attributes of the flowmeter installation and scheduling logistics. A detailed description of each of the above approaches is given below.

Use a Meter Testing Facility

This approach may be the most precise means to determine the accuracy of a meter at various flow ranges. A number of private companies provide reliable meter testing services. These companies have precise test equipment and can conduct meter testing under carefully controlled conditions. Many water utilities also maintain meter test facilities. These facilities, however, are often limited to the smaller-sized meters (less than 12-in.) used for customer accounts and may not accommodate larger-sized production flowmeters. Although this approach can provide highly accurate test results, it has the disadvantage of requiring the effort to remove the meter from service, transport it to the meter testing facility, conduct testing, and return the meter to its location within the water supply system. Additionally, while testing is likely to be highly accurate, the meter will be tested under laboratory conditions, rather than field conditions. *If factors exist in the field that adversely impact the accuracy of the meter, then this condition will not be present when testing under laboratory conditions at the meter testing facility.* If unusual in-situ conditions are known to exist at the flowmeter installation, this method may not be the most appropriate approach, and one of the other methods described below should be considered instead.

Use of a meter testing facility may be feasible only for production meters up to size 20 in., so this approach will not likely be possible for many medium- and large-sized water utilities with larger production meters. Where feasible, this method of meter testing may be accomplished by rotating a small complement of meters out-of-service periodically for testing on a regular basis. Refer to AWWA Manual M6, *Water Meters—Selection, Installation, Testing, and Maintenance*, for further guidance on meter testing options and procedures (AWWA 2012).

Test the Flowmeter In-Place: Compare Volume to Portable Meter Installation

This is perhaps the most common approach for testing large flowmeters that are not practical to test at a meter testing facility. The approach relies on the use of a portable calibrated metering device that generates a flow measurement over a defined test period. The volume measurements of the subject flowmeter and the test meter are then compared, with any difference expressed as a percentage. The type of portable meter varies with the size and flow range of the production meter. Two approaches exist: one for low-flow applications found in small water utilities, and one for larger-flow applications typically found in medium- and large-sized water utilities.

Portable meter test apparatus. This approach can usually be feasibly used to test turbine or propeller meters of sizes 3-in. to 8-in. in-place, as long as the flow does not exceed the practical limits of the meter test apparatus. In this way, the production meter test is executed in the same manner as testing of customer meters for commercial or industrial buildings. Many water utilities have an existing program for testing of these types of meters for customer accounts, and the same method can be applied for smaller production meters. A meter test apparatus is often mounted inside a van or truck and water is passed through the subject meter and the test meter in series and the volumes compared. (See Figures 5-10 to 5-13.) Meter testing services also exist to conduct this type of testing on a periodic basis. Details on this type of testing can be found in *Water Loss Control* (Thornton et al. 2008). Because this method is feasible only for relatively small meters, the approach may be applicable for only smaller water utilities that have relatively low production flows and smaller flowmeters, typically of size 8 in. or smaller. Note: To employ this method, test ports must exist on the flowmeter, and normal operational service on the subject water pipeline will be interrupted.

Inline flow comparison using portable test meters. This technique is typically used to determine the accuracy of large flowmeters. Many water utilities in high-density urban and suburban areas supply relatively large volumes of water through metered production pipelines at the effluent of water treatment plants, pumping stations, or reservoirs. The larger size of the flowmeters on these pipelines and the high volumes of flow passing through them make these installations impractical for testing using a portable test apparatus, where water flowed through the test apparatus must be deposed of as waste. Thus, these meters must be tested in-place with water supplied through the meter and host pipeline within the routine expected range of flows.

Inline flow measurement uses a portable calibrated meter inserted into, or strapped onto, the host pipeline downstream of the subject flowmeter to provide a volume measurement in series with the subject flowmeter. The test meter is usually attached to a data recording device so flows can be measured and logged for a period of hours or days. This has the advantage of allowing volume measurements to be gathered for sufficient time to observe the normal variation from high to low flows occurring in the production pipeline. It is recommended that inline flow measurements be conducted for a minimum of 24 hours for each flowmeter that is tested for accuracy. If possible, flows should be measured for multiple days if the flow varies widely between weekday and weekend periods. If flows vary widely across the seasons, consideration should be given to conduct distinct inline measurement in each season. If production flows are relatively constant at a given water utility, shorter durations for the inline flow measurements may be considered. However, caution is urged to maximize the test duration for the purposes of test integrity and repeatability. Measuring flow for only 1–3 hours does not necessarily provide reliable results.

One of the earliest portable flow measuring devices invented for commercial use is the insertion Pitot rod invented in 1896 by Edward Shaw Cole, who later founded a company that provided flow measurement and meter testing services for many years. The Pitot rod is based on the hydraulic principle discovered in 1730 by Henri Pitot who found that the differential pressure in two tubes inserted into the flow in upstream and downstream positions is proportional to the square of the velocity of the flow. Thus, by obtaining a differential pressure measurement, the velocity of flow can be determined. By measuring the cross-sectional area of the pipeline, the flow rate in the pipeline can be determined by the use of the Continuity Equation given here:

$$Q = V * A \tag{A-2}$$

Where:

Q = flow rate (length^3/time)

V = velocity (length/time)

A = cross-sectional area of the pipeline (length^2)

Figure A-7 Insertion Pitot rods in-place to measure flows for comparison of water flow in large flowmeters

The commercially designed Pitot rod is a portable metering device that can be inserted into an active pipeline via a standard tapped ferrule (corporation stop) connection in the pipeline (see Figure A-7). The accuracy of these devices is generally ±2 percent across a wide range of velocities and flows, and they are very useful for testing large flowmeter installations that have no other practical means for verifying flow.

Insertion flowmeters are also advantageous because they can be moved to various depths inside the pipeline and are able to measure velocity across the profile of the pipe. A separate insertion pipe caliper is used to obtain an exact measurement of the internal diameter of the pipe at the point of the measurement. The diameter can then be used to obtain an accurate measure of the pipeline cross-sectional area at the point of flow measurement. Because many pipelines suffer a buildup of corrosion products on the internal walls of the pipe, the actual internal diameter is often less than the internal diameter at the time of manufacture. It is important to obtain an exact measurement of the internal pipe diameter to quantify an accurate measure of the flow in the pipeline.

Once velocity measurements are taken across the pipe, a velocity profile can be plotted. The velocity profile is created by graphically plotting the velocity values measured across the diameter of the pipe. The shape of the velocity profile is dependent on several factors. In the ideal conditions of flow in a very smooth-walled pipe, flow is uniform and approaches laminar (smooth) conditions, and the velocity profile takes the shape of a semicircle (Figure A-8). For many water pipelines that have been in use for long periods of time, internal corrosion products built up on the pipe wall produce the commonly found bullet-shaped velocity profile shown in Figure A-9, with the greatest water velocity occurring at the center of the pipeline and lower velocities nearer to the pipe wall due to the friction effects of the pipe wall surface. The velocity profile can exhibit a nonuniform profile due to a pipeline feature (which may or may not be known to the water utility) that is disrupting the streamlined flow in the pipe. This can be due to devices such as a butterfly valve downstream of the measuring point (Figure A-10) or a partially closed gate valve downstream of the measuring point (Figure A-11). The velocity profile taken at measuring points that are near pipe bends may also produce a nonuniform, or skewed, shape such as that shown in Figure A-12. Flowmeters sited at locations of a skewed velocity profile may suffer compromised accuracy, thus knowing the velocity profile is essential to understanding the level of accuracy of the flowmeter.

The *pipe factor* is determined as the ratio of the average of the velocity values across the pipe to the value of the velocity at the centerline. The pipe factor is constant over all rates of flow for a uniform flow profile (Walski 1984). The pipe factor is used in the calculations to determine the flow measured during the designated test period. Once all of

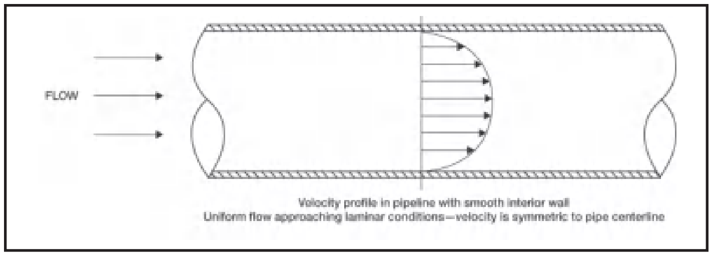


Figure A-8 Velocity profile in a smooth pipeline with unobstructed, uniform flow approaching laminar conditions

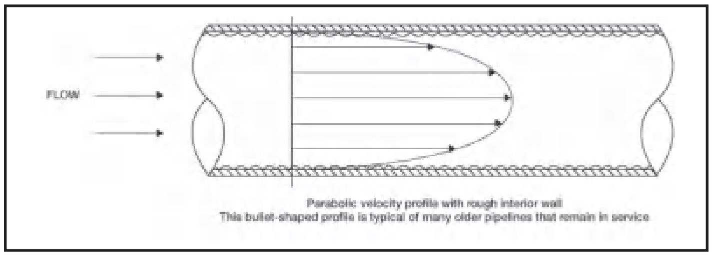


Figure A-9 Velocity profile in pipeline with moderate internal corrosion

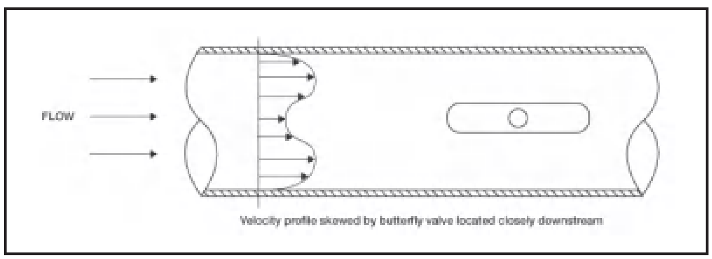


Figure A-10 Velocity profile upstream of a butterfly valve in a pipeline

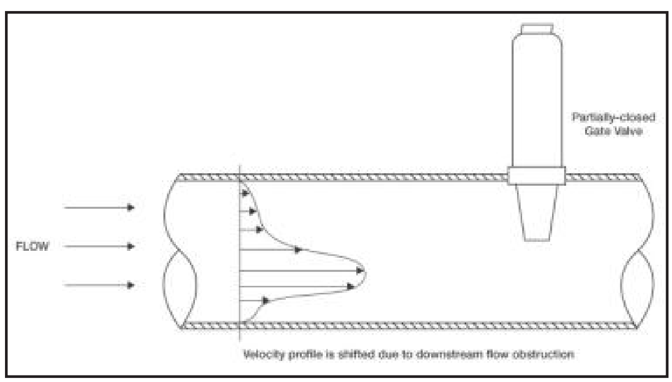


Figure A-11 Velocity profile upstream of a partially closed gate valve in a pipeline

this baseline data is gathered, the test period can be started by inserting the meter probes into the pipeline at the centerline velocity and recording the pressure difference occurring during the test period. At the end of the test period, the differential pressure values can be converted to velocity values and the flow rate calculated for time increments during the test period. The total flow recorded during the test period by the insertion meter can be

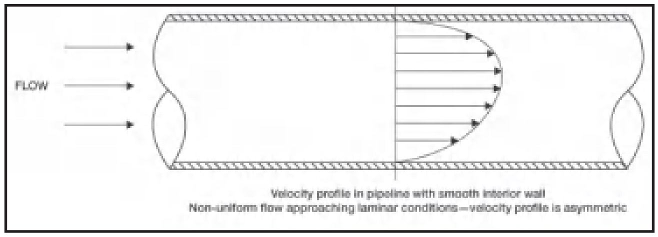


Figure A-12 Velocity profile skewed by close proximity to a bend in the pipeline

compared to the volume measured by the subject flowmeter and the difference expressed as a percentage of inaccuracy of the flowmeter. Flow rates at the peak and minimum periods can also be compared.

Because Pitot-rod-type insertion meters are used at standard ferrule (corporation stop) connections on the water pipeline, some water utilities have constructed permanent meter test locations with a ferrule tapped into the pipeline, and a manhole or chamber constructed around the ferrule. In this way, the insertion site is protected and available for periodic use. Similar to proper location selection for a permanent flowmeter, care and consideration for adequate upstream clearance should be given when selecting a location for the test site ferrule(s). Ideally, one test location is installed on each production pipeline downstream of the production meter. Space limitations may not allow a test location on individual production pipelines, but it may be possible to create a test location on a common pipeline, or header, downstream from a bank or manifold of metered pipelines. This is common for production pipelines at water treatment plants and pumping stations. Depending on the configuration of pipelines and meters, it may be necessary to halt flow in individual pipelines by closing line valves or halting individual pumps to force flow through a single pipeline. In such cases, it is important to make certain that closed valves tightly seal water and do not allow any water passage across the valve. Every pipeline configuration has unique features, so the piping and flow patterns should be carefully evaluated in advance of testing to identify the most representative and effective test location and test duration to achieve a meaningful assessment of production meter accuracy.

When conducting inline flow accuracy testing, it is important to assess not only the measure produced by the flowmeter, but also the entire data trail from the flowmeter installation to the SCADA system, data historian, and final reporting. The signal produced by the flowmeter is typically routed through a secondary device such as a differential pressure cell or other electronic interface, and then to the SCADA system, which archives the data or transfers it to a separate data historian. Water utility staff typically rely on SCADA system reports that present daily flows in an hour-by-hour (or other time increment) listing. The archived data is ultimately the finished data that is used as the basis to produce the Water Supplied volume in the annual water audit. Water utilities should establish a procedure that confirms the flow quantities created by the flowmeter, as well as the quantity value at the secondary device and the final quantity archived in the SCADA system or historian. It is not unusual to find differences in the value of the same parameter at each of these points in the data trail. A good metering management procedure is given in Table A-2.

While insertion meters are a practical means of obtaining flow measurement in series with an existing flowmeter, "strap-on" ultrasonic meters also offer portability and ease of use in generating flow measurements. The most common type of ultrasonic meter used for drinking water applications is the transit time meter, which uses pulse transmission to detect the velocity of flow. Transit time meters use a pair of transceivers to send and receive an ultrasonic pulse in the direction of the flow of water, followed by a return pulse against the direction of the flow. In a flowing liquid, the speed of the pulse directed

Table A-2 Production flowmeter system procedure for inline meter accuracy verification

1. Inspect the metering installation. Confirm that the location and piping configuration of the flowmeter and related instrumentation matches as-built drawings. Make note of any differences found at the site.
2. Record information about the flowmeter and installation (model, type, serial number, date installed). It is important to keep detailed records of all equipment, and maintenance and testing activities.
3. Confirm the meter range. This is the maximum output value of the meter and the minimum output value. Are these values properly configured in the supervisory control and data acquisition (SCADA) system?
4. Inspect the differential pressure (DP) transmitters or cells. These devices should be mounted at the same elevation as the meter and near the meter. Check the connections of water pressure sensing lines from the flowmeter to the transmitter. Connections should be secure and not leaking any water.
5. Calibrate the DP transmitters and related instrumentation to the SCADA system. Ensure that a signal can be read at the transmitter and the value reliably reported in the SCADA system.
6. Assess the piping configuration. Does a flowmeter exist on each pipeline that extends from the water source (often downstream from a pump or stored water clearwell)? Identify a location to install a ferrule on the pipeline (for insertion meter use) or a location to install a strap-on ultrasonic meter. If a location downstream from the flowmeter is not available, an alternative location further downstream on a "header" pipeline may be the next best location.
7. Be mindful to monitor any "controls" that are employed to conduct the testing. For instance, it may be necessary to close valves on connecting piping to isolate flow into a single pipeline or header pipe during a flowmeter accuracy verification test. It is important that such valves close fully and do not seep or "pass" flow across the valve. This stray flow might not be measured and would therefore corrupt the integrity of the accuracy test process.
8. By using a Pitot-rod-type insertion meter as the test meter, the internal pipe diameter can be callipered and velocity measurements gathered across the diameter of the pipe to construct a velocity profile. Confirm that the velocity profile appears similar to a "bullet" shape. If an unusual shape is obtained for the velocity profile, investigate to confirm whether an obstruction such as a partially closed valve exists downstream of the flowmeter. The function of flowmeters in congested piping locations with turbulent flow may be improved by installing straightening vanes upstream of the meter to smooth the velocity profile of the flow.
9. Conduct the inline flow measurement using the test meter (Pitot rod or ultrasonic). The duration of this measurement should be at least 24 hours, and should strive to capture the full range of flows normally encountered in the pipeline.
10. When the test meter is installed, compare its readings with the signal at the DP cell and the SCADA system to ensure that the portable meter is properly installed and producing a reasonable reading.
11. At the end of the measurement period, collect the data logged by the test meter and compare it to the SCADA system readings (and DP cell reading logged during the process). Note the variance of these values over the test period. Aggregate the data over the test period and obtain the average variance, measured in percentage over-registration or under-registration.
12. Define actionable levels for further action by the utility. For example, findings of ±3 percent (97–103 percent) may warrant no action. Findings of ±6 percent may warrant further inspection of all equipment, recalibration of DP transmitters, and possibly a retest. Findings of more than ±10 percent may warrant the above rechecks, retesting, and consideration of meter replacement, depending on the age of the meter and other factors.

downstream is increased by the speed of the stream. When directed upstream, the speed of the pulse is slowed by the flow. The time difference between the two pulse transmissions through the stream is a function of fluid velocity, which can be calculated (AWWA 2006). Transit time meters require 7–10 pipe diameters of straight pipe upstream and 5 pipe diameters downstream for proper performance. It is imperative to locate this device where these straight upstream/downstream piping requirements can be met. Ultrasonic meters can be designed for permanently installed use or for portable use as a strap-on device. Users should be cautious about the location of the pipeline to install a strap-on ultrasonic meter since scale or corrosion product buildup inside the pipeline may compromise the accuracy of the meter. The user should have knowledge that the strap-on location is relatively unaffected by internal corrosion or scale buildup. This type of meter is also sensitive to noise and vibration, so care must be taken to locate the meter in a stable, quiet location.

Compare Volume Measurements From the Primary Meter to Other Permanently Installed Flowmeters Existing in Series

Similar to the use of inline flow measurement that obtains flow values on the host pipeline in series with the subject flowmeter, this method relies on meters in series. However, this approach is only available to water utilities that have *permanently installed* meters in series. This method is not applicable to water utilities that have only a single flowmeter for the water that they supply to the distribution system. With two or more production flowmeters installed in series, the water utility can compare the values on an ongoing basis in a structured format known as the *mass balance technique*. It should be emphasized that this approach is *not* strictly a meter accuracy verification tool, but instead is an indicator of the level of control in the flow management process. It serves as a good surveillance tool to help detect when data from one or more flowmeters begins to "stray," thereby indicating the beginnings of meter accuracy degradation or other metering system upset. While use of the mass balance technique can assist utility operations, it is nonetheless recommended that the water utility attempt to verify flowmeter accuracy independently via one of the above methods and employ the mass balance technique as an additional monitoring check. Still, the mass balance technique alone offers distinct advantages of production flow validation if it is available to a water utility. It is a very useful approach if accuracy verification of individual meters is difficult. Granted, it is more expensive to install additional permanent meters in series than to use portable meters. Therefore, the water utility manager must decide whether the cost to implement such an approach is worthwhile. In some cases, production flowmeters have been installed in series because source water pumping is located a considerable distance from water treatment works and metering was desired at each step of the process. If metering exists in series—even if the meters are located several miles apart—the engineer or operator can employ the mass balance technique.

Example of the mass balance technique. In addition to verifying most of its production flowmeters individually, the Philadelphia Water Department (PWD) employs the mass balance technique to serve as a monitoring and alert system and as a basis for flow adjustments from data produced by certain flowmeters that have a known level of inaccuracy. PWD supplies water from three water treatment plants across a water distribution system that includes more than 3,000 miles of piping. PWD's largest water treatment plant draws water from the Delaware River, while two smaller plants take water from the Schuylkill River. A schematic of the supply configuration for PWD's Queen Lane Water Treatment Plant, which draws water from the Schuylkill River, is shown in Figure A-13. The Queen Lane system includes three banks of flowmeters in series: (A) at the raw water pumping station at the Schuylkill River, (B) between the raw water sedimentation basin and the pretreatment building of the plant, and (C) at the plant effluent, where the finished drinking water is sent to the water distribution system. Note that the A meters at the Schuylkill River are located approximately one mile from the B and C meters, which are on the grounds of the Queen Lane plant.

PWD employs the mass balance technique in a structured manner by compiling production flow data from its SCADA system, which generates a routine mass balance report that is reviewed each business day. A copy of the report for the month of June 2012 is shown in Table A-3. As shown in the report, a daily volume of water measured by the A, B, and C banks of production flowmeters are listed (in million gallons, or MG). The differences in the values from the A to B meters, B to C meters, and A to C meters are calculated and displayed, both by difference in volume and by percentage. The average volumes for the month were reported as 62.03 mgd at the A meters (raw water), 60.97 mgd at the B meters (pretreatment), and 56.42 at the C meters (plant effluent). It is important to recognize that differences in these values are normal and indicative of the process features of the water treatment system. Since the A meters register water "from the source" and

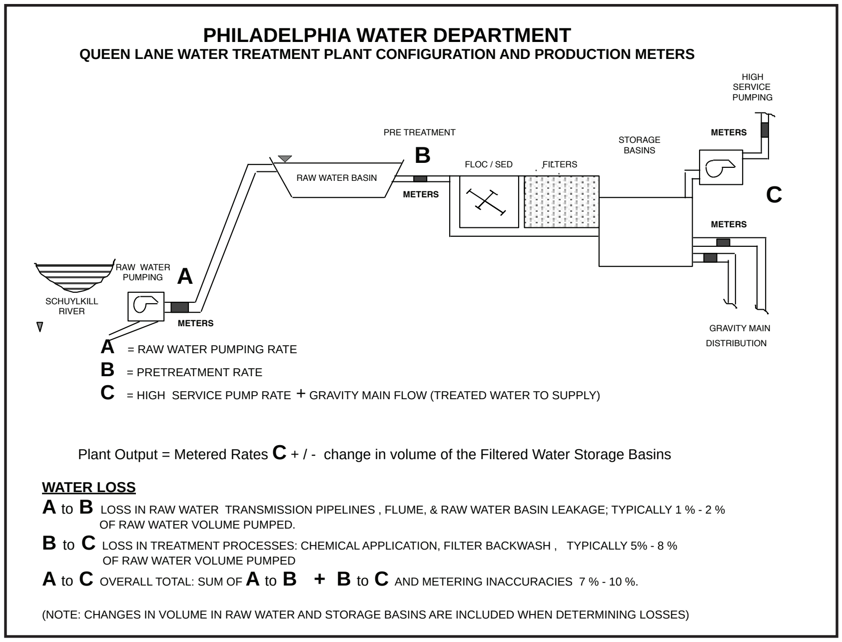


Figure A-13 Schematic of the water supply configuration of the Queen Lane Water Treatment Plant in Philadelphia, Pa.

are located a considerable distance from the B meters, there is an expected "loss" of water attributed to leakage in several large raw water transmission mains, seepage into a large raw water sedimentation basin, and an inherent level of inaccuracy of the two banks of meters. This difference is typically about 1 mgd or approximately 1.5–2.0 percent of the raw water volume.

The trend of higher volumes from the upstream flowmeters to lower volumes for downstream flowmeters is normal for meters in series, particularly when they are located some distance apart. This is common since pipeline leakage loss or treatment process loss will occur on the piping between the flowmeters. Water volumes passing downstream meters cannot be greater than their upstream counterparts since water cannot be "created" in transit through the production pipeline. If volumes registered by downstream flowmeters are greater than upstream flowmeters, then it is a given that downstream and/or upstream flowmeters have appreciable inaccuracies.

The difference between the B and C meters represents water volumes drawn from the process to assist in water treatment operations. Some of the water used for filter backwashing and other plant processes is routinely flushed to waste and appears as a "loss" or difference in the B and C volumes. Under normal operating conditions, the difference between the B and C columns is approximately 4.55 mgd, or approximately 7.5 percent at the Queen Lane plant. On a day-to-day basis, the relative differences of the volumes in the A, B, and C columns are generally constant or experience only a small degree of variation. If a more pronounced variation occurs—either suddenly or incrementally over a period of days or weeks—PWD is effectively alerted to either an upset of the treatment plant process, an increased pipeline leakage loss, or a loss of accuracy in the metering of water volumes in the A, B, or C columns. Note that the differences displayed here are valid for Philadelphia's Queen Lane Water Treatment Plant, but the flow patterns and metering locations at a given water supply system are unique. Therefore, the volume difference data is also unique to that system's configuration and operation.

Table A-4 shows hypothetical data for July 2012 for PWD's Queen Lane plant. Similar to the data displayed in Table A-3, relatively consistent differences in the A, B, and C

Table A-3 Mass balance report for the Queen Lane Water Treatment Plant in Philadelphia, Pa., showing consistent production metering data reflecting stable operations and good meter accuracy

PHILADELPHIA WATER DEPARTMENT
QUEEN LANE WATER TREATMENT PLANT—MASS BALANCE REPORT
Volumes shown in million gallons, MG

	A	B	C	A-B		B-C		A-C	
Date	Raw Water Pumping Volume ± Storage Elevation Change	Plant Pretreatment Volume	Plant Effluent Volume	MG	%	MG	%	MG	%
06/01/12	56.82	55.90	51.55	0.92	1.62	4.35	7.78	5.27	9.27
06/02/12	57.69	56.60	52.17	1.09	1.89	4.43	7.83	5.52	9.57
06/03/12	58.16	57.10	52.75	1.06	1.82	4.35	7.62	5.41	9.30
06/04/12	56.77	55.90	51.56	0.87	1.53	4.34	7.76	5.21	9.18
06/05/12	58.50	57.50	53.02	1.00	1.71	4.48	7.79	5.48	9.37
06/06/12	57.82	56.80	52.33	1.02	1.76	4.47	7.87	5.49	9.49
06/07/12	57.03	56.00	52.03	1.03	1.81	3.97	7.09	5.00	8.77
06/08/12	57.19	56.30	51.99	0.89	1.56	4.31	7.66	5.20	9.09
06/09/12	57.92	56.90	52.81	1.02	1.76	4.09	7.19	5.11	8.82
06/10/12	58.01	57.00	52.57	1.01	1.74	4.43	7.77	5.44	9.38
06/11/12	58.39	57.40	53.18	0.99	1.70	4.22	7.35	5.21	8.92
06/12/12	55.89	55.00	50.72	0.89	1.59	4.28	7.78	5.17	9.25
06/13/12	57.46	56.50	52.17	0.96	1.67	4.33	7.66	5.29	9.21
06/14/12	58.11	57.10	52.66	1.01	1.74	4.44	7.78	5.45	9.38
06/15/12	57.96	56.80	52.96	1.16	2.00	3.84	6.76	5.00	8.63
06/16/12	58.03	56.90	52.89	1.13	1.95	4.01	7.05	5.14	8.86
06/17/12	58.10	57.10	52.85	1.00	1.72	4.25	7.44	5.25	9.04
06/18/12	57.90	56.90	52.67	1.00	1.73	4.23	7.43	5.23	9.03
06/19/12	58.71	57.70	53.48	1.01	1.72	4.22	7.31	5.23	8.91
06/20/12	70.99	69.80	64.71	1.19	1.68	5.09	7.29	6.28	8.85
06/21/12	77.24	76.00	70.39	1.24	1.61	5.61	7.38	6.85	8.87
06/22/12	76.30	75.00	69.59	1.30	1.70	5.41	7.21	6.71	8.79
06/23/12	68.68	67.50	62.52	1.18	1.72	4.98	7.38	6.16	8.97
06/24/12	68.94	67.80	62.83	1.14	1.65	4.97	7.33	6.11	8.86
06/25/12	65.07	64.00	59.30	1.07	1.64	4.70	7.34	5.77	8.87
06/26/12	63.07	62.00	57.38	1.07	1.70	4.62	7.45	5.69	9.02
06/27/12	63.80	62.70	58.29	1.10	1.72	4.41	7.03	5.51	8.64
06/28/12	66.82	65.70	60.54	1.12	1.68	5.16	7.85	6.28	9.40
06/29/12	70.85	69.70	64.26	1.15	1.62	5.44	7.80	6.59	9.30
06/30/12	72.75	71.50	66.40	1.25	1.72	5.10	7.13	6.35	8.73
Total	1,860.97	1,829.10	1,692.57	31.87		136.53		168.40	
Average	62.03	60.97	56.42	1.06	1.72	4.55	7.47	5.61	9.06
Maximum	77.24	76.00	70.39	1.30	2.00	5.61	7.87	6.85	9.57
Minimum	55.89	55.00	50.72	0.87	1.53	3.84	6.76	5.00	8.63

Table A-4 Mass balance report for the Queen Lane Water Treatment Plant in Philadelphia, Pa., showing unusual data variation suggesting unstable operations or compromised meter accuracy for the period July 25–31, 2012

PHILADELPHIA WATER DEPARTMENT
QUEEN LANE WATER TREATMENT PLANT—MASS BALANCE REPORT
Volumes shown in million gallons, MG

	A	B	C	A-B		B-C		A-C	
Date	Raw Water Pumping Volume ± Storage Elevation Change	Plant Pretreatment Volume	Plant Effluent Volume	MG	%	MG	%	MG	%
07/01/12	72.05	70.95	65.38	1.10	1.53	5.57	7.85	6.67	9.26
07/02/12	72.28	71.17	65.85	1.11	1.54	5.32	7.48	6.43	8.90
07/03/12	72.35	71.23	66.05	1.12	1.55	5.18	7.27	6.30	8.71
07/04/12	69.86	68.48	63.16	1.38	1.98	5.32	7.77	6.70	9.59
07/05/12	71.85	70.64	65.50	1.21	1.68	5.14	7.28	6.35	8.84
07/06/12	72.05	70.95	65.65	1.10	1.53	5.30	7.47	6.40	8.88
07/07/12	74.80	73.45	68.02	1.35	1.80	5.43	7.39	6.78	9.06
07/08/12	75.28	74.14	69.07	1.14	1.51	5.07	6.84	6.21	8.25
07/09/12	76.44	75.25	70.12	1.19	1.56	5.13	6.82	6.32	8.27
07/10/12	77.02	75.69	70.22	1.33	1.73	5.47	7.23	6.80	8.83
07/11/12	76.24	75.22	69.77	1.02	1.34	5.45	7.25	6.47	8.49
07/12/12	73.82	72.43	67.29	1.39	1.88	5.14	7.10	6.53	8.85
07/13/12	71.62	70.23	65.37	1.39	1.94	4.86	6.92	6.25	8.73
07/14/12	71.28	70.06	65.02	1.22	1.71	5.04	7.19	6.26	8.78
07/15/12	70.33	69.09	64.23	1.24	1.76	4.86	7.03	6.10	8.67
07/16/12	70.11	68.85	63.87	1.26	1.80	4.98	7.23	6.24	8.90
07/17/12	70.08	68.91	63.82	1.17	1.67	5.09	7.39	6.26	8.93
07/18/12	69.88	68.47	63.34	1.41	2.02	5.13	7.49	6.54	9.36
07/19/12	69.43	68.22	62.98	1.21	1.74	5.24	7.68	6.45	9.29
07/20/12	68.95	67.77	62.45	1.18	1.71	5.32	7.85	6.50	9.43
07/21/12	68.04	66.92	61.90	1.12	1.65	5.02	7.50	6.14	9.02
07/22/12	67.96	66.63	61.67	1.33	1.96	4.96	7.44	6.29	9.26
07/23/12	69.23	68.11	63.23	1.12	1.62	4.88	7.16	6.00	8.67
07/24/12	69.98	68.44	63.56	1.54	2.20	4.88	7.13	6.42	9.17
07/25/12	70.88	69.56	**64.22**	1.32	1.86	5.34	7.68	**6.66**	**9.40**
07/26/12	72.05	70.88	**65.23**	1.17	1.62	5.65	7.97	**6.82**	**9.47**
07/27/12	73.17	71.77	**65.94**	1.40	1.91	5.83	8.12	**7.23**	**9.88**
07/28/12	74.56	73.23	**67.04**	1.33	1.78	6.19	8.45	**7.52**	**10.09**
07/29/12	76.77	75.22	**68.67**	1.55	2.02	6.55	8.71	**8.10**	**10.55**
07/30/12	75.88	74.48	**68.05**	1.40	1.85	6.43	8.63	**7.83**	**10.32**
07/31/12	74.43	73.13	**66.11**	1.30	1.75	7.02	9.60	**8.32**	**11.18**
Total	2,238.67	2,199.57	2,032.78	39.10		166.79		205.89	
Average	72.22	70.95	65.57	1.26	1.75	5.38	7.58	6.64	9.19
Maximum	77.02	75.69	70.22	1.55	2.20	7.02	9.60	8.32	11.18
Minimum	67.96	66.63	61.67	1.02	1.34	4.86	6.82	6.00	8.25

volumes are listed for the period July 1–July 24, 2012. However, as highlighted in bold on the report, a small but noticeable increase in the difference between the B and C values is apparent for the period July 25–July 31. This difference is evidenced by an increase in the percentage difference from the A to C volumes. Typically, the difference in the A and C volumes, by percentage, is approximately 9 percent. However, the percentage difference for the period July 25–31 averages 10.3 percent and shows a steady increase across all of these days, reaching more than 11 percent on July 31. This trend suggests that the C volume—the treated water effluent—appears to be under-registering a portion of flow. PWD operates six effluent water production meters in the C bank. The data from the six meters are added to give the C total. It is likely that one of these meters encountered a problem around July 24 or July 25 and ultimately is causing the C total to be lower than expected. Note that the problem was identified by observing the unusual pattern in the percentage difference, not the volume difference. While the suspected problem is likely an under-registering production meter, the total flow for the C meters gradually increased during the late part of July since all water production was increasing, likely due to increasing water demand during hot July weather. If one looked only at the C volume, it would not be evident that the C volume was lower than might be expected. Thus, although monitoring water volumes is important, looking at volumes alone may not be sufficient to detect anomalies. By monitoring the percentage difference of the mass balance technique in addition to the volumes, the water utility can identify subtle changes in production meter data.

PWD's daily review of mass balance data from across its system provides the capability to flag the data anomaly occurring in the C volume at the Queen Lane plant. More detailed data from the six individual C meters can then be reviewed to see if one or two meters' data were producing inordinately low readings. Often, in such cases, this is the finding. Technicians can then be dispatched to inspect the metering installation to correct any problems that they find in the field. Once corrected, it is expected that the difference in the A, B, and C values will once again conform to the normal variation pattern.

The mass balance technique can be used if two or more permanently installed and well-functioning production meters exist in series. It can be a very effective means to detect often subtle changes in metered data that reflect an emerging problem with a flowmeter or the subsequent flow data trail. Since relatively few water utilities have multiple meters installed in series, this technique is not available to all water utility managers. However, for those systems that have meters in series—or those that choose to install them—the mass balance technique offers a reliable capability for improved production meter management.

Conduct a Clearwell or Water Storage Tank Drop Test

This approach compares a measure of the volume of water leaving a water storage facility (clearwell or tank) over a fixed period of time to the volume of water measured by a production flowmeter for the same period of time. The term *clearwell* is used to denote a treated water storage structure that exists immediately effluent, or downstream, to the treatment works, and upstream of the production flowmeter on the pipeline supplying water to the distribution system. This is a very typical configuration found in many water utilities; however, many varied configurations also occur in the water industry and may or may not lend themselves to conducting a drop test. Similar to the mass balance technique, this method can only be applied in water systems with a supply configuration that allows all of the water being supplied to emanate from the storage facility and pass through the flowmeter.

Example of a drop test for County Water Company. An acceptable configuration for a drop test is shown in Figure A-14 with a clearwell at the effluent of a water treatment plant for County Water Company (CWC), the fictitious water system described in chapter 3. Treated water enters the clearwell where it is briefly stored before flowing out of the

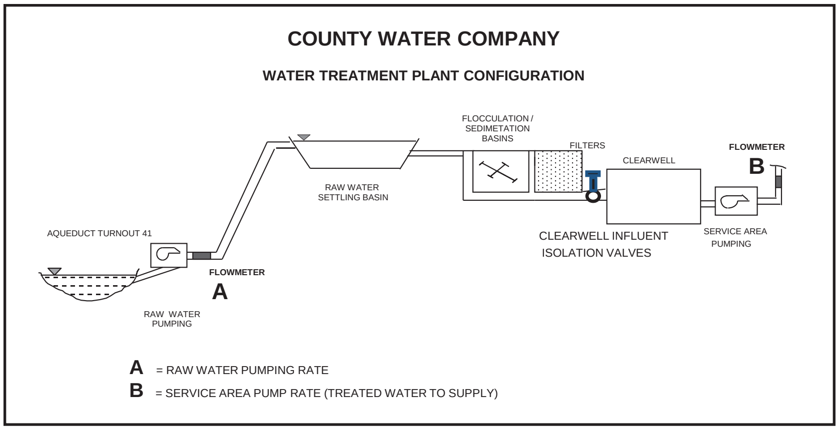


Figure A-14 Schematic of the treated water clearwell and water supply piping configuration for County Water Company's treatment works from Aqueduct Turnout 41

clearwell, into the service area pumping station, and into the supply transmission pipeline, which is equipped with a flowmeter (flowmeter B). In this case, a single flowmeter exists on the supply pipeline; however, it is not uncommon to have two or more supply pipelines—each with a flowmeter, or a single flowmeter on a common header for all of the pipelines—emanating from a clearwell.

A clearwell drop test can be conducted on CWC's system shown in Figure A-14 by halting the flow of water into the clearwell for a limited period of time, generally 2–4 hours. Drop tests are often conducted during night hours when water demand is low and water treatment rates can be halted temporarily, or the supply redirected to other service areas that the water treatment plant might supply. In this way, halting flow for several hours has minimal impact on normal operations. Executing the drop test during the low-demand night hours is also a good way to determine the accuracy of the flowmeter at the low flows that occur during nighttime. This is important since large flowmeters tend to be less accurate at low flows than medium or high rates of flow. As stated previously, however, it is essential that the assessment of flowmeter accuracy include flow ranges that are representative of actual operating conditions. As such, a group of drop tests at various flow ranges should be considered.

Prior to the drop test, valves on the influent piping supplying water to the clearwell are fully closed. Thus, during the drop test, water only flows out of the clearwell; there is no incoming flow to the clearwell from the treatment works. Hence, the storage level in the clearwell "drops" as water is sent into the water distribution system. Knowing the change in water level and the geometry of the clearwell, the water utility manager can calculate the volume of water that exited the clearwell during the test period. This calculated volume is divided by the total time of the test to obtain an average test flow rate. The test flow rate is then compared to the average flow rate generated by the production meter over the same period of time.

The results of the drop test for the primary source of CWC (treatment plant at Aqueduct Turnout 41) are shown in Table A-5. In this case, the volume of water supplied to the distribution system was determined to be 315,970 gallons over the 3-hour test period. Dividing this volume by 180 minutes of the test period gives an average test flow rate of 1,755.4 gpm. While the test was being conducted, the instantaneous flow rate from the production meter was recorded at each 15-minute interval. The resulting average value of the production meter flow rates was determined to be 1,694.8 gpm. Because the test flow rate is higher than the rate produced by the production flowmeter, it is assumed that the production flowmeter is under-registering flow—in this case, by approximately 3.48 percent.

Table A-5 Example tabulations of a drop test conducted at County Water Company's water treatment plant at Aqueduct Turnout 41

COUNTY WATER COMPANY
CLEARWELL DROP TEST ANALYSIS FOR PRODUCTION METER ACCURACY TESTING

Date of test: Mar. 31, 2014	Tank height: 18 ft
Source 1: Turnout 41	Tank volume: 511,000 gal
Cylindrical concrete tank diameter: 70 ft	Tank geometry: 28,389 gal/ft

Time	Clearwell Elevation (ft)	Volume in Clearwell at Given Water Level (gal)	Clearwell Volume Reduction in 15-Minute Period	Production Flowmeter Reading at Each 15-Minute Increment (gpm)
2:00:00 a.m.	17.82	505,892		
2:15:00 a.m.	16.55	469,838	36,054	2,325
2:30:00 a.m.	15.44	438,326	31,512	2,042
2:45:00 a.m.	14.48	411,073	27,253	1,771
3:00:00 a.m.	13.58	385,523	25,550	1,655
3:15:00 a.m.	12.73	361,392	24,131	1,548
3:30:00 a.m.	11.94	338,965	22,427	1,432
3:45:00 a.m.	11.18	317,389	21,576	1,391
4:00:00 a.m.	10.46	296,946	20,443	1,302
4:15:00 a.m.	9.68	274,806	22,140	1,417
4:30:00 a.m.	8.82	250,391	24,415	1,561
4:45:00 a.m.	7.83	222,286	28,105	1,802
5:00:00 a.m.	6.69	189,922	32,364	2,091
Change over 3-hour period	17.82 – 6.69 = 11.13 ft	505,892 – 189,922 = 315,970 gal		
Average flow rate from tank drop		315,970 gal/(3 hr × 60 min/hr) = 1,755.4 gpm		
Average flow rate measured by flowmeter				1,694.8 gpm

Note: Production meter error from the drop test = [(drop test flow rate – meter flow rate) / drop test flow rate] × 100% = [(1,755.9 – 1,694.8)/1,755.9] × 100% = 3.48%, under-registration

To achieve accurate results from a drop test, several controls must be in place. Because all incoming water into the clearwell must be halted, it is important that influent valves tightly seal water when they are closed. Water "passing" by the valves will compromise the test. All of the water in the clearwell must exit the storage facility via the effluent pipeline housing the production flowmeter being tested. This may require temporarily closing valves on any additional pipelines that also emanate from the clearwell or storage facility. If leaks are known to exist in the clearwell walls, then a portion of the water will leak out of the basin and not pass through the flowmeter. This will compromise the accuracy of the drop test by making it appear that the flowmeter is under-registering the flow. To confirm the existence of leakage from the clearwell, close both influent and effluent valves surrounding the clearwell for a brief period of time (assuming that it is feasible to temporarily resupply the service district from another source). If the clearwell level drops appreciably when all flow is halted, then leakage exists and a leakage rate can be measured over this brief period of time, and the leakage rate can be factored into the drop test results. Ultimately, leaks in the clearwell should be located and repaired.

Lastly, it is critical that the water level measurement is accurate because the calculation of the test volume and flow rate depends on knowing the level change. It is recommended that, prior to conducting a drop test, the level instrumentation be carefully checked and the level sensor calibrated to ensure that it is providing an accurate measure of the clearwell water level. If necessary, physical measurements of the clearwell level could be taken by using a calibrated “dipstick” inserted into the clearwell and read every 15 minutes. Also, a temporary calibrated pressure gauge, with an attached data logger, can provide accurate data to obtain clearwell level measurements based on pressure head readings. The temporary pressure gauge should be installed inline (with a corporation stop or similar tapping device), upstream from the permanent meter being tested. Physical measures of the clearwell geometry are also advised rather than reliance on construction drawing dimensions. Care must be given to minimize measurement error for both clearwell geometry and level.

For water utilities that have an acceptable configuration, drop tests can be conducted periodically to serve as a reliable accuracy check for production flowmeters. Unfortunately, drop tests are not possible for all water utilities because their systems are not easily isolated between a single storage facility and a single production flowmeter. In other cases, influent supply cannot be feasibly halted or influent valving does not exist to halt the supply flow. However, the clearwell drop test is another valid means of production meter accuracy testing available to water utilities.

Notes on compound error rates. When testing flowmeter accuracy, it is important to consider the impact of compound error rates when using a portable calibrated flowmeter to compare to a permanently installed flowmeter. For instance, a properly factory-calibrated, portable ultrasonic flowmeter could have an accuracy specification of ±2 percent. When comparing flow data from this meter to that of another meter with similar accuracy specification, the overall error rate could rise to as high as 4 percent. For instance, if precisely 100 gallons of water were passed through two such flowmeters in series, the test ultrasonic meter could display a value between 98 and 102 gallons and still remain within its acceptable range of error based on factory calibration. The permanent flowmeter being tested could report a similar range.

When testing using two meters in series, the person conducting the test generally does not know the exact volume of water passing through the meters and uses the difference between the meters to establish accuracy. In these cases, the person conducting the test may assume that the test meter (portable ultrasonic meter, Pitot rod, or similar device) is the baseline and that any difference between this meter and the permanent meter being tested represents the absolute error. If exactly 100 gallons were to pass through this installation, it is possible that one meter would display 98 gallons and the other would display 102 gallons, and the test would register a difference of 4 percent, when the actual difference is 2 percent.

Perhaps the ideal testing condition is to pass a known volume of water through the flowmeter and compare the known volume with the quantity registered by the flowmeter. Thus, the clearwell drop test and testing of meters in a laboratory using a test tank are two ways of reducing error due to test meter compounding.

BALANCING FLOWS ACROSS WATER SUPPLY SYSTEM TO OBTAIN FINAL WATER SUPPLIED VOLUME

Production flows include the water supplied from treated water sources such as water treatment plants, well fields, and import/export flows. These flows are considered inputs to the water distribution system (except for exports, which leave the system). To determine how much water actually enters the distribution system on a given day (the Water Supplied volume), the net volume of water going into and out of storage tanks, as well as across multiple zones or districts, must be accurately derived and used to “balance” flows across the entire water supply system.

If a system is small and simply configured with one source of supply and no storage tanks, then the Water Supplied volume is derived merely from the data registered by the flowmeter on the single source of supply. However, if a system is supplied by multiple sources, includes one or more water storage tanks, and/or is segmented into pressure zones or district metered areas (DMAs) that provide some of the metered data, then the net impact of the shifting of flows must be “balanced” across the system to determine how much water entered into the water distribution system. Ideally, balancing tabulations should be reviewed every business day. Many water utilities operate supply and distribution systems that include multiple pressure zones, DMAs, and water storage tanks or reservoirs while importing and exporting flows. It is not uncommon for even small water utilities to include dozens of inflows and outflows that require accurate tracking to determine the Water Supplied volume for a given day. Because of this complexity, it is good practice for utility personnel to monitor and balance supply flows on each business day. Reviewing such data less frequently—on a monthly or annual basis—results in a strong likelihood that data disruptions will be missed, inducing error into the annual Water Supplied volume. It is also important to conduct regular meter accuracy tests on the flowmeters that measure import and export supplies and flow in/out of water storage tanks and across pressure districts and DMAs. Depending on the system configuration and the location of flowmeters, flow measurement error from any of these flowmeters can upset the flow balancing process across the entire system. Similarly, instrumentation that measures the water level in storage tanks should be regularly calibrated to ensure accuracy in the tracking of water storage levels.

Chapter 3 provides an example of flow balancing from the four water storage tanks for CWC (see Table 3-5). In this example, the water volumes in the four tanks were observed at the beginning of the first day of the audit year and the end of the last day of the audit year (start and end volumes). For utility water storage facilities that “float” on the water distribution system pressure, water levels should be fluctuated on a daily basis to prevent stagnation of the water. Over the course of long periods of time, their net elevation change is very little if they are operated in a consistent manner. As an example, many utilities strive to achieve set water storage levels at midnight of each day, and perhaps also at a set morning hour such as 4:00 a.m., prior to the onset of the heavy morning water demand. If operators achieve the same midnight tank level day to day, then there is no net impact to the supply of water to the distribution system. The amount of water that flows into the tank on a given day is offset by the same amount of water that flows out of the tank during the day. Thus, if consistent, repeatable operations are in place throughout the year, the approach used for CWC in chapter 3 is adequate. However, tank operations are not always routine and repeatable for each of the utility’s tanks for each of the 365 days in a year. Thus, it is advisable to use a more detailed tracking, as discussed below.

For most water utilities, variations and/or disruptions in tank operating conditions are a periodic occurrence throughout the year. For example, many storage tanks are taken out of service for inspection and cleaning for several days each year, and the volume of water flushed and filled in the operation should be distinctly tabulated. Occasionally—usually due to the failure of a level sensor or operator error—tanks may be overfilled with water wasted to an overflow pipe until the problem is reported and corrected. Tank level data transmitted to the SCADA system may occasionally be disrupted because of malfunction of the water level sensor or communication link to the SCADA system. In all of these instances, the storage facility water level data will not be accurate and should be corrected to obtain the true volume of water flowing into or out of the tank on the day(s) of the unusual operations. Therefore, it is good practice to monitor storage tank data every business day. In this way, the circumstances of individual disruptions can be identified and corrections to the data can be made close to the time of the event, with corrected data included in weekly and monthly reports. If data are reviewed on an infrequent basis—or not at all—then inaccuracies caused by storage level data disruption will be missed and the annual Water Supplied volume will be in error.

In addition to water flows into and out of water storage facilities, flows are often routed into and out of pressure zones and DMAs. These flows should also be tracked every business day and problems corrected to achieve the greatest degree of accuracy in the Water Supplied volume. Distribution systems that are highly sectorized with many zones and DMAs often rely on flowmeters tracking flows into and out of these discrete areas. It is common in many utilities to sum the daily flow from all pressure zones and DMAs and compare ("balance") them with the volume total from production flowmeters, along with an adjustment for changes in water storage tank volumes. Since all flowmeters are subject to some degree of inaccuracy, and flowmeter data is subject to occasional disruption, the data from the meters into these sectors should be reviewed on a business-day basis and corrected when such problems are identified. In a general sense, the sum of the flows tabulated from all zones and DMAs should equal the total of the flow supplied to the distribution system from the finished water production flowmeters, including the net change in water storage tank levels. If the total of the individual zones does not equal the total of flow into supply, then metering or data issues likely exist in sector meters and/or production flowmeters, and these should be investigated and corrected.

Table A-6 shows an example water supply balancing report for CWC. For illustrative purposes, data for a 10-day period in the month of September 2014 is listed, although such a report is usually configured to report data from the entire month. The report lists the flows from the two supply sources, volume into or out of the system's four water storage tanks, and the water imported from a neighboring water utility via the City Intertie interconnection piping. As seen by reading from left to right for each day, the water from the two primary sources are added, the storage tanks volume changes are tabulated (flow out of storage is added to the volume of water supplied; flow into storage is subtracted from the volume of water supplied), and the imported water from City Intertie is added to obtain the aggregate volume of water supplied for the CWC system each day.

The example from Table A-6 illustrates one of any number of minor upsets that can occur in a water distribution system over the course of a year. Utilities should employ a process of routine water supply data review and correction to ensure that the annual Water Supplied volume is as accurate as possible. While Tables A-6 and A-7 are representative of the fictitious County Water Company, Figure A-15 is a screenshot of an actual SCADA system report for the City of Ames, Iowa. As previously described, the key elements of balanced supplies are included in Figure A-15, with pumped flows and changes in reservoirs and storage tanks shown in tabular form with data listed on a daily basis. The general configuration of the report shown in Figure A-15 serves as a good example for water utilities to follow in balancing their supply flows. Such reports, however, must include all of the system components unique to the water utility and should be configured to reliably balance the flows across the water distribution system.

CWC personnel can reliably determine the Water Supplied volume to the system on a daily basis by using the report shown in Table A-6. Anomalies in the data are detected quickly and corrected on a regular basis. Such a problem was encountered on Sept. 3, 2014, when Storage Tank 3 overflowed for 5 hours. Table A-7 is a daily report of the water levels of all four of CWC's water storage tanks, with hourly readings recorded. At 10:00 hours, the level reading for Storage Tank 3 became locked at 19.60 ft due to a disruption in the reading coming from the water level sensor. Unfortunately, the operator on duty did not initially

Table A-6 Water supply balancing report for County Water Company

COUNTY WATER COMPANY—WATER SUPPLY REPORT
Quantities in million gallons, MG

Date	Source 1 Aqueduct Turnout 41	Source 2 Well Field	Volume From Own Sources	Storage 1 Apple Hill Vol Chg*	Storage 2 Cedar Ridge Vol Chg	Storage 3 Monument Road Vol Chg	Storage 4 Davis Vol Chg	Volume to Supply ± Storage	Source 3 City Intertie Imported Supply	Data Correction	Water Supplied
9/1/2014	12.00	1.10	13.10	+0.04	–0.08	+0.28	-0.02	12.88	1.10	0.00	13.98
9/2/2014	12.18	1.09	13.27	–0.03	–0.03	–0.04	-0.07	13.44	1.04	0.00	14.48
9/3/2014	11.78	1.02	12.80	+0.02	+0.06	+0.05	+0.06	12.61	0.89	–0.30	13.80
9/4/2014	11.68	0.77	12.45	+0.02	+0.11	+0.06	+0.03	12.23	0.86	0.00	13.09
9/5/2014	11.21	0.79	12.00	–0.03	–0.05	–0.23	-0.02	12.33	0.83	0.00	13.16
9/6/2014	11.66	0.81	12.47	+0.04	+0.08	–0.03	+0.13	12.25	0.88	0.00	13.13
9/7/2014	11.58	0.84	12.42	+0.02	+0.04	+0.06	0.00	12.30	0.84	0.00	13.14
9/8/2014	11.62	0.75	12.37	–0.04	–0.06	–0.03	–0.10	12.60	0.94	0.00	13.54
9/9/2014	11.48	0.78	12.26	–0.02	+0.03	+0.05	+0.04	12.16	0.91	0.00	13.07
9/10/2014	11.71	0.88	12.59	+0.03	–0.09	–0.05	–0.03	12.73	0.87	0.00	13.60
Total	116.90	8.83	125.66	+0.05	+0.01	+0.12	+0.02	125.53	9.16	–0.30	134.99
Average	11.69	0.88	12.57	+0.01	0.0	+0.01	0.00	12.55	0.92	–0.03	13.50
Maximum	12.18	1.10	13.27	+0.04	+0.11	+0.28	+0.13	13.44	1.10	–0.30	14.54
Minimum	11.21	0.77	12.00	–0.04	–0.09	–0.23	–0.10	12.16	0.83	0.00	13.07

Note: An increase in tank storage over 24 hours means volume is subtracted from supply; decrease in tank storage results in volume added to supply. The data correction of 9/3/2014 was due to an overflow event at Storage 3 (Monument Road), which caused water to be wasted to the tank overflow for 5 hours (see Table A-7).

*Vol Chg = Volume Change

recognize this situation and continued to operate the system in a manner that filled water into Storage Tank 3. After 5 hours, the tank—which was already at a high level—reached capacity and began to overflow. This condition lasted for several hours until the event was detected and operations undertaken to halt flow into Storage Tank 3 at 20:00 hours.

Because of the failure of the level sensor and operator error, the recorded tank level for the day was inaccurate, and a certain volume of water was overflowed to waste. Water lost to an overflow is a real loss. Since the event was detected within several hours, the water utility manager reviewed the data and made a correction to account for the volume of water lost in the overflow. This was done by estimating the flow rate into Storage Tank 3 after 10:00 hours. It was assumed that the average flow rate in the tank from 7:00–10:00 hours was maintained throughout the day. Thus the tank was estimated to be full by 15:00 hours (3:00 p.m.) with an equivalent volume of water continuing to flow until 20:00 hours. The estimated volume of water lost to the overflow was 296,425 gallons, or approximately 0.3 mil gal. This volume was added to the volume of water supplied for Sept. 3, 2014, and recorded as part of the real losses for the audit year.

Because the event was contained to several hours and data on the tank level and overflow volume was carefully tabulated, a correction was added to the volume of water supplied shortly after the incident on Sept. 3, 2014. By providing close monitoring of water supply data, timely corrections to data anomalies can be implemented and a high degree of accuracy of production data can be maintained throughout the audit year. If the water utility merely used the tank levels from the first day of the audit year and last day of the audit year (as shown in Table 3-5), the adjustment needed from the above event would be omitted, causing a degree of error in the annual Water Supplied volume. Although the data anomaly from this single event is small, water utilities may have such upsets

Table A-7 Water storage tank report for County Water Company showing corrections for storage tank overflow event

COUNTY WATER COMPANY—WATER STORAGE TANK REPORT Hourly Water Storage Tank Levels and Volumes for: Sept. 3, 2014										
Time (hours)	Storage Tank 1 Apple Hill 50,000-gal capacity 12-ft depth		Storage Tank 2 Cedar Ridge 300,000-gal capacity 15-ft depth		Storage Tank 3 Monument Road 1,000,000-gal capacity 20-ft depth		Storage Tank 4 Davis 250,000-gal capacity 18-ft depth		Corrected Data (gal)	Comments
0:00	2.13	8,884	6.56	131,228	18.82	941,000	9.21	127,942		
1:00	2.33	9,713	6.73	134,623	18.89	944,382	9.39	130,345		
2:00	2.62	10,927	6.86	137,238	18.95	947,602	9.62	133,561		
3:00	2.96	12,321	7.01	140,178	19.00	950,201	9.81	136,289		
4:00	3.40	14,167	7.19	143,876	19.06	952,945	10.09	140,087		
5:00	3.70	15,423	7.36	147,254	19.12	956,231	10.39	144,321		
6:00	3.90	16,231	7.38	147,567	19.24	961,764	10.41	144,567		
7:00	3.75	15,641	7.34	146,856	19.37	968,295	10.33	143,478		
8:00	3.58	14,923	7.31	146,112	19.47	973,719	10.44	144,987		
9:00	3.54	14,754	7.34	146,897	19.57	978,345	10.54	146,327		
10:00	3.56	14,827	7.41	148,223	19.60	980,112	10.78	149,725		
11:00	3.65	15,221	7.52	150,342	19.60	980,112	11.07	153,765		Tank 3 level disrupted
12:00	3.64	15,153	7.66	153,123	19.60	980,112	11.44	158,927		
13:00	3.76	15,674	7.81	156,234	19.60	980,112	11.77	163,495		
14:00	3.90	16,239	7.96	159,278	19.60	980,112	12.02	166,873		
15:00	4.18	17,428	8.11	162,187	19.60	980,112	12.22	169,652	1,000,000	Tank 3 overflowing
16:00	4.49	18,693	8.24	164,734	19.60	980,112	12.45	172,845	1,055,285	Tank 3 level
17:00	4.62	19,231	8.38	167,549	19.60	980,112	12.67	175,927	1,110,570	Tank 3 level
18:00	4.43	18,457	8.52	170,381	19.60	980,112	12.78	177,478	1,165,855	Tank 3 level
19:00	4.62	19,234	8.65	172,987	19.60	980,112	12.91	179,234	1,228,140	Tank 3 level
20:00	4.96	20,672	8.78	175,623	20.00	1,000,000	13.07	181,567	1,296,425	Tank 3 overflow halted
21:00	5.37	22,389	8.95	179,034	19.97	998,256	13.25	183,954		
22:00	5.90	24,567	9.21	184,112	19.89	994,538	13.37	185,678		
23:00	6.36	26,489	9.39	187,896	19.79	989,745	13.45	186,822		
0:00	6.91	28,792	9.58	191,548	19.75	987,634	13.57	188,453		
Tank elevation difference	4.78		3.02		0.93		4.36			
Tank volume difference		19,908		60,320		46,634		60,511	296,425	Tank 3 overflow volume (real loss)

occurring periodically at many water storage tanks throughout the year, and the data difference can become appreciable.

VALIDATING SCADA SYSTEM OUTPUT DATA (CORRECTIVE DATA ADJUSTMENTS)

Most water utilities use SCADA systems—or similar data collection and archival systems—to collect and store data from production flowmeters and other distribution system instrumentation on a continuous, real-time basis. SCADA systems allow operators to

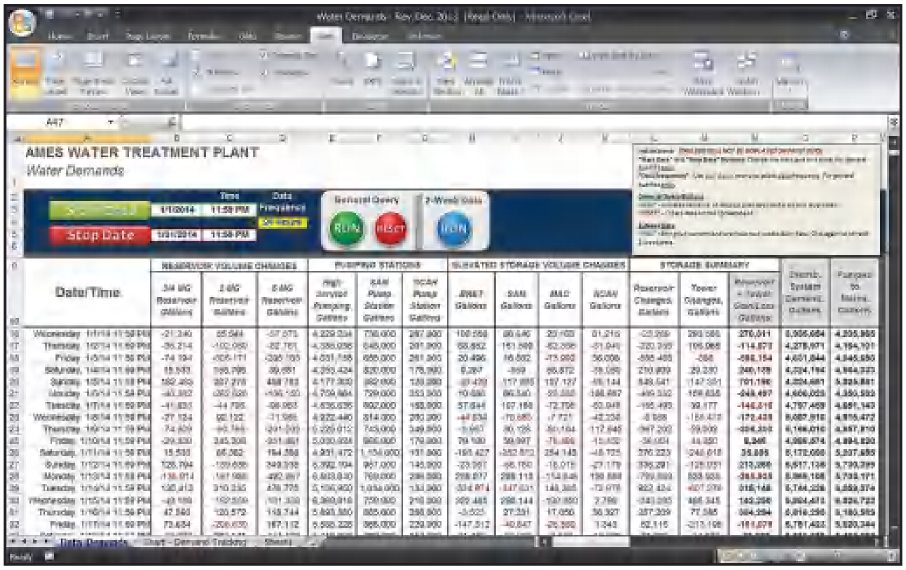


Figure A-15 Ames, Iowa, SCADA system water supply tracking report

Courtesy of the City of Ames, Iowa

closely monitor the performance of the water distribution system and provide the ability to detect system variations and upsets such as fluctuations or loss of pressure, pump failure, power outages, or other common disruptions. SCADA systems also serve as repositories of large amounts of water distribution data that are continuously collected and archived in a historian or other data repository. Sensors are typically installed at key locations in the water distribution system to collect data on water pressure, rates of flow, water storage tank levels, and elevations of rivers, lakes, streams or wells that provide source water. They also monitor system status such as the pump status (on/off), position of large flow-regulating valves, electric power supplies, and many other system parameters. The sensors and related instrumentation are vulnerable to failure, vandalism, harsh weather, and other factors that can disrupt their performance.

By leveraging the extensive capabilities that are available from most SCADA systems to send alerts and display data in output reports, system operators can learn a great deal about the function of the water distribution system. Ideally, to assess supply operations across the system, output reports should be created to display balanced water flows throughout the entire water distribution system, including production pipeline flows, import/export flows, flow into and out of individual water pressure zones, DMAs, and water storage tanks. A variety of utility reports, such as the mass balance report (see Table A-3), should also be configured and generated on a routine basis.

Depending on the nature of an upset or malfunction that can befall any such device, the data generated by the equipment can become skewed or completely corrupted. Hence, despite the fact that the hydraulics of the system (flow and pressure) may be functioning normally on a given day, the data delivered to the SCADA system can be in error if a sensor fails or the data collection device malfunctions. One type of disruption is the "data gap" that occurs when a field device malfunctions and temporarily produces no data. Such disruptions happen periodically in all water utilities. Usually these events are quickly detected by operators, and technicians are efficient in restoring the function of the device and resuming the data stream. But for periods of several hours or perhaps several days, there may be a lack of data reported to the SCADA system. Unfortunately, if the system operator or engineer does not routinely scrutinize and correct SCADA output reports, the reporting will misstate the Water Supplied volume to a particular part of the system. To maintain accurate reporting of water supply data, the water utility should

- give supply data accuracy a high priority in its operations—the data displayed in output reports should accurately reflect the hydraulic conditions in the water supply systems;
- establish written procedures for routine, systematic review of all data, with clear guidelines for making corrective adjustments to all data that are found to be in error;
- configure SCADA system data archival and reporting functions to allow corrective adjustments to data to be incorporated as needed; and
- fully document the nature of data gaps that occur, as well as the adjustments and description of corrective actions taken to restore the integrity of the reported data.

If the water utility implements a structured process as described above, it will better ensure that the data displayed in the final output reports accurately reflect the water supply conditions occurring in the utility for the reported period of time.

Data Gaps in Pumped Supply Reporting and Corrective Adjustments

Table A-8 shows a SCADA system output report that logs pumped flow into a water pressure district on a given day. The data presented in the two left columns (time, flow rate) is typical of a water pressure zone report. However, as part of the example, this table has been expanded to allow corrective adjustments to be displayed by adding two columns that show how data adjustments are used to correct for a data gap that occurred.

In this scenario, pumped flow supplies one of the water pressure zones in a large water utility. The supply typically averages about 8.9 mgd, but varies from approximately 7.9 mgd during the minimum nighttime hours to more than 9.3 mgd during daytime peak hours. As shown in Column A, the pumped flow reading into the zone became zero at 4:00 a.m. SCADA systems will typically send an alert to the system operator when such a condition occurs. The operator must check other SCADA data and indicators to gain insight to the cause of the zero reading, first by checking other hydraulic indicators for the supply to the zone. In this case, the operator observed the SCADA system indication that the pump remains in the "ON" status, and the water pressure sensors at the pump discharge and key points in the zone are within a normal range. Thus, indicators show that normal hydraulic operating conditions exist; therefore, the system is most likely still pumping water and all demands are being met. However, the reading from the flowmeter has been disrupted and displays zero. The most likely reason for the zero reading is a failure of the flowmeter or disruption in the communication of the data to the SCADA system. This might occur due to an external problem such as a lightning strike or severe weather impacts, or merely a malfunction of the flowmeter or communication equipment.

If the operator had found that other hydraulic indicators were also disrupted—such as the pump in the "OFF" status and/or reduced pressure throughout the zone, then the problem would have most likely been a pump failure and lack of water supply to the zone, not a data outage from a malfunctioning instrument. In the above scenario, however, since the operator confirmed that all other hydraulic indicators are normal, water supply is being maintained and customers are reliably receiving water service. Hydraulically, the system is fine, but no flow data is being transmitted to the SCADA system.

As shown in Table A-8, the flow reading went to zero at 4:00 a.m. on August 15. Most water utilities do not have technicians working at that hour of the morning. Hence, the reading remained zero until the start of the workday around 7:00 a.m. or 8:00 a.m.

Table A-8 Example of a data gap and adjustments for pumped water flow to a typical pressure zone operated by a large water utility

8/15/2014 (hours)	Column A Pumping Rate (mgd) (raw data transmitted to the SCADA system, showing a data gap)		Column B Pumping Rate (mgd) (actual flow through the flowmeter)	Column C Pumping Rate (mgd) (with corrective adjustments incorporated)	
0:00	8.69		8.69	8.69	
1:00	8.65		8.65	8.65	
2:00	8.32		8.32	8.32	
3:00	8.11		8.11	8.11	
4:00	0		7.94	8	
5:00	0		8.02	8	
6:00	0		8.44	8	**Approximate values entered**
7:00	0	**Data Gap**	8.98	9	
8:00	0		9.34	9.3	
9:00	0		9.25	9.3	
10:00	0		9.17	9.3	
11:00	9.12		9.12	9.12	
12:00	9.27		9.27	9.27	
13:00	9.22		9.22	9.22	
14:00	9.08		9.08	9.08	
15:00	8.99		8.99	8.99	
16:00	9.14		9.14	9.14	
17:00	9.18		9.18	9.18	
18:00	9.25		9.25	9.25	
19:00	9.22		9.22	9.22	
20:00	8.82		8.82	8.82	
21:00	8.78		8.78	8.78	
22:00	8.75		8.75	8.75	
23:00	8.71		8.71	8.71	
0:00	8.68		8.68	8.68	
Total of readings	159.98		221.12	220.88	
Average pumped volume	6.40		8.84	8.83	
Difference			2.44	–0.01	

Technicians were provided a work order to investigate the disruption of the flowmeter reading. Over the next several hours, the technicians traveled to the flowmeter site, investigated the failure, and corrected the problem. The correct flow reading was restored to SCADA operations by 11:00 a.m.

Column A in Table A-8 shows the *registered* flow readings recorded in the SCADA system. Column B shows the *actual* flow passing through the flowmeter just downstream of the pump. (Note: These actual values are shown here for illustrative purposes. However, such readings might be available from a local data recorder or flow totalizer at the pumping station.) Unfortunately, because of the 7-hour equipment outage, the pumped total for the day listed at the bottom of Column A greatly understates the actual flow into the zone, registering only 6.40 mil gal instead of the actual pumped volume of 8.84 mil gal listed in Column B. Thus, the outage understates the flow by 2.44 mil gal. If left uncorrected, the daily flow for the pressure zone will be averaged into the yearly flow balance and will create an understatement of the Water Supplied volume. Fortunately, a straightforward approach exists to correct the data in Column A to create final, archived data that is close to the actual flow supplied to the zone. Corrected hourly values of the flow are included in Column C of Table A-8. These values are approximate flow values that are taken as typical flow rates occurring at the respective hours of 4:00–11:00 a.m. on a typical day. Most system operators are very familiar with the typical water supply data trends on a daily basis. By looking at pumped flow on several previous days, the operator can enter approximate values for the hours of 4:00–11:00 a.m. The approximate flow rates entered into Column C result in an adjusted 24-hour total of 8.83 mil gal, a difference of only 0.01 mil gal from the actual flow listed in Column B, and much more accurate than a difference of 2.44 mil gal if the data were left uncorrected.

The above example shows how data gaps can create inaccuracies in supply data. Because a data gap, or skewed data (as discussed previously in the discussion of the mass balance technique) can occur at any time, water utility personnel must be vigilant in monitoring supply data on a business-day basis and making corrective adjustments for data that are known to be inaccurate. If a water utility does not routinely review and correct supply data in the SCADA system archive, it will inevitably incur errors in the Water Supplied volume for the year. It will be very time-consuming and inefficient for utility personnel to attempt to review the entire year's records at the end of the year; thus, it is best to review and correct data in an ongoing manner throughout the course of the year.

GRADING VALIDITY OF PRODUCTION VOLUMES IN AWWA FREE WATER AUDIT SOFTWARE

By using the AWWA Free Water Audit Software (Audit Software), water utilities can quickly assemble a reliable annual water audit that reflects the quantitative management of their operations. The key data inputs to the Audit Software include measured or estimated volumes of water production, authorized consumption, and apparent losses, as well as system attribute and cost data. In addition to these inputs, the Audit Software also requires that the auditor enter a data grading value next to each data input value. The grading is a rating of the validity, or trustworthiness, of the data, and is based on a simple 1–10 scale. A grading of 1 reflects that the quantity input is of low validity, equivalent to a "wild guess." At the opposite end of this spectrum, a grading of 10 means that quantity input is very reliable and based on a measured, verifiable data source that is routinely reviewed and corrected as needed. All other grading values fall incrementally between these two extremes. The gradings of all of the input values are aggregated into a single Data Validity Score (DVS) for the water audit. The DVS is based on a scale with a range up to 100 and reflects the overall level of trust in the results. The Audit Software features a Water Loss Control Planning Guide worksheet that gives guidance to the auditor on the use of the results. For water utilities with a DVS of 50 or less, recommendations are provided that focus the auditor on means to improve the validity of the data before moving to targeted loss control efforts. Utilities that have a DVS higher than 50 can simultaneously target specific loss control initiatives while they also continue to improve the validity of the data. See chapter 3 for a more detailed discussion of data validity and the water auditing process.

The Audit Software features an extensive Grading Matrix worksheet that provides objective criteria that auditors can use to assign gradings for their inputs into the software. The criteria effectively represent the processes and practices that water utilities can employ to produce and verify data of increasing validity. In addition to the individual grading criteria, the Grading Matrix offers guidance for the water utility to improve the validity of each data input. These improvements represent advancement in a particular process or practice that manages the data. For example, a water utility that does not meter their production sources and relies on estimates to generate the Volume From Own Sources quantity can improve its data validity by installing flowmeters and obtaining measured, rather than estimated, data. Systems employing flowmeters, but with no regular meter accuracy testing, can further improve data validity by starting a program to test flowmeters on a regular basis to reliably determine the degree of inaccuracy that exists.

The Grading Matrix sections for the water audit components Volume From Own Sources, Water Imported, Water Exported, and Master Meter Error Adjustments for each of these components guide the water auditor in assessing the current practices of the utility and assigning a grading that is representative of those practices. The auditor can then target actions to improve the validity of the data as feasible. The reader will note that much of the grading criteria and recommended process improvements shown in the software for these components align with the recommended processes and practices detailed in this appendix.

Water utilities that employ best practices will produce valid data that support optimal system operation. Thus, good operating practice and reliable, trustworthy data go hand in hand in progressive water utility operations. Unfortunately, the converse is also true. Poor operations are also usually accompanied by poor or incomplete data. The Grading Matrix offers highly detailed and useful guidance, in step-by-step fashion, for each component of the water audit. Water utilities can benefit greatly if they use this feature of the Audit Software to the fullest extent. The auditor should strive to objectively select gradings that most accurately reflect the level of validity in each component. Auditors should resist the temptation to overly flatter themselves with a higher-than-warranted grading if they know that the processes and practices defined in the Grading Matrix are not fully in place in their operations. By using the Grading Matrix in an objective, self-reflective manner, the water utility has the best opportunity to direct its efforts to improve both its data validity and the effectiveness of its operations.

EVALUATING PRODUCTION FLOW DATA FOR COUNTY WATER COMPANY

Chapter 3 instructs auditors on the step-by-step means to compile the annual water audit of a water utility. The example of the fictitious water utility—County Water Company—is used throughout chapter 3 and other sections of this manual, including this appendix. The Audit Software Reporting Worksheet (Figure 3-5) is used as the means to enter the data that populates the water audit and allows standardized performance indicators to be calculated and displayed in Figure 3-6. Chapter 3 provides step-by-step instruction to water utilities on gathering and grading the data inputs for CWC. The detailed guidance on the processes listed in the Grading Matrix worksheet, which serve as the criteria for the data gradings, is provided in this appendix. The DVS for CWC is 62 and is displayed at the bottom of the Reporting Worksheet shown in Figure 3-5.

While the limited instructions provided in chapter 3 allow for a reasonable quantification of water production values, the *validity* of the data will be much higher if the water auditor employs the more precise methods described in this appendix. For example, the audit takes into account data adjustments from changes in distribution system water storage volumes over the audit period, as shown in Table 3-5. This cursory approach only looks at water storage tank levels at the beginning and end of the water audit year. This approach will fail to take into account any data gaps, tank overflows, draining/refilling operations, and other changes in the normal operation of storage tanks during the year. As described in this appendix, water utilities will obtain a more accurate adjustment quantity if they monitor water storage tank data on a daily basis and take into account storage data variations that invariably occur throughout the year. If data are reviewed only once annually, the audit will miss these data anomalies and, ultimately, the Water Supplied volume will be a less accurate and less valid quantity.

SUMMARY

A variety of means for testing the accuracy of production flowmeters is described in this appendix. Similarly guidance is given on calibration of secondary instrumentation, balancing flows across the entire water distribution system, and accounting for data upsets. In the example of CWC, the auditor for this utility could launch the more extensive efforts to use these approaches to data quantification. In doing so, all of the values entered into the Audit Software will be more accurate and representative of utility operations.

The reliability of the water audit improves in evolutionary fashion if the water utility takes a continuous improvement approach. Monitoring and correcting data on a daily basis certainly involves more effort than more cursory reviews on a quarterly or annual basis. Flowmeter accuracy testing requires effort in time and money. But, if the water utility can gradually implement best practices for production flow data management—even if this occurs slowly over a period of years—the resulting data will be more accurate, trustworthy, and representative of utility operations. The water audit will be a more reliable accountability tool, and it will allow for astute planning of loss control activities and tracking of improvements.

The data generated by production meters and conveyed through the subsequent data trail produce the most important volumes that are entered into the annual water audit: the *Volume From Own Sources, Water Imported volume and Water Exported volume*. Thus, it is essential that water utility managers give priority to the management of primary production flowmeters, secondary instrumentation, data communications and water storage facility data, and accurate reporting that properly balances flows across the water distribution system. The failure to address any of these functions can result in some degree of error in the annual Water Supplied volume quantified in the water audit. Since these volumes are the largest in the water audit, even small degrees of error can represent significant water volumes, and every effort should be made to ensure that the data are as accurate as possible. The guidance provided in this appendix gives water utility personnel the tools and approaches that will allow them to manage production metering equipment and data to produce highly accurate data for the annual water audit.

REFERENCES

AWWA (American Water Works Association). 2006. Manual M33. *Flowmeters in Water Supply*. Denver, Colo.: AWWA.

AWWA (American Water Works Association). 2012. Manual M6. *Water Meters—Selection, Installation, Testing and Maintenance*. Denver, Colo.: AWWA.

Department of Ecology, State of Washington. 2015. *Liquid Flowmeters—A Guide for Selecting a Flowmeter for Pressurized Systems*. www.ecy.wa.gov/programs/wr/measuring/images/pdf/gsfps.pdf (accessed Jan. 29, 2015).

Thornton, J., R. Sturm, and G. Kunkel. 2008. *Water Loss Control*. New York: McGraw-Hill.

Walski, T. 1984. *Analysis of Water Distribution Systems*. New York: Van Nostrand Reinhold.

This page intentionally blank.

Appendix B

Blank Forms

This appendix includes blank forms for use in planning a water loss control program. The Revenue Protection Plan is a means to economically control apparent losses due to systematic data handling errors in the customer billing system, customer metering inaccuracies, and unauthorized consumption. The Leakage Management Plan is a means to economically control real (leakage) losses and better manage system pressure levels. A package of blank forms for each program is given in this appendix. The reader can copy these forms and use them to detail a program for their water utility. Specific forms include

- Revenue Protection Plan,
- Leakage Management Plan,
- Leak Detection Survey Daily Log, and
- Leakage Management Program Cost-Effectiveness Summary.

See Figures 3-4 to 3-7 for screenshots of the worksheets in the AWWA Free Water Audit Software and the AWWA Compiler Software. See appendix D for additional discussion of these software tools. Instructions for completing the Revenue Protection Plan are given in chapter 5. Instructions for completing the leakage management forms are discussed in chapter 7.

REVENUE PROTECTION PLAN TO CONTROL APPARENT LOSSES

Name of Water Utility:	Audit Year:	Date:	Manager:
______________________	________	____/____/______	______________________

I. Revenue Protection Plan Approach

I-a. List below the apparent loss volumes and costs from the water audit Reporting Worksheet (Figure 3-5) and discussion in chapter 3.

	Volume, units	Volume, units	Costs
Residential meter under-registration			
Industrial/commercial/agricultural meter under-registration			
Customer metering inaccuracies (sum of above two items)			
Systematic data transfer error			
Systematic data analysis error			
Data policy/procedure impacts			
Systematic data handling errors (sum of above three items)			
Unauthorized consumption (note 0.25% default value if used)			
	TOTAL		

I-b. From the water audit Reporting Worksheet, list the retail unit rates charged to customers. Note: A single composite unit retail charge for all accounts can be used if individual unit rates are not available.

	Charge/Unit
Customer retail unit rate—residential accounts—applied to Apparent Losses (cost/volume)	
Customer retail unit rate—industrial, commercial, and agricultural accounts—applied to Apparent Losses (cost/volume)	
Customer retail unit rate—composite unit rate—applied to Apparent Losses (cost/volume)	

I-c. Assigning priority actions for apparent loss control

The recommended first action that water utilities should take in the Revenue Protection Program is an analysis of the customer billing system to come to understand its workings and reveal the extent of systematic data handling errors that exist in the billing process.

Following the customer billing system analysis, create a priority list of actions to address the components of apparent loss. The priority might not be based solely on the cost impact of the loss component. It might instead be based on scheduling logistics (e.g., meter replacement might be scheduled to coincide with automatic meter reading installation). Include target years, even if they are tentative and subject to change at a later time.

Priority	Action	Cost Impact (Revenue Recovery Potential)	Target Year
First	______________________	______________	______
Second	______________________	______________	______
Third	______________________	______________	______
Fourth	______________________	______________	______
Fifth	______________________	______________	______

REVENUE PROTECTION PLAN TO CONTROL APPARENT LOSSES (continued)

II. Customer Billing Process Analysis

Most water utilities catalog customer consumption in a customer billing system, and systematic data handling errors occurring in these systems can corrupt data generated by accurate metering and meter reading systems. The water utility should flowchart or otherwise analyze the billing system process to identify data gaps that should be addressed before moving into other areas of apparent loss control. From the initial findings, areas of apparent loss that are deemed to be readily correctable should be implemented. Immediate corrections can include minor procedural or programming changes (e.g., a programming lapse that inadvertently leaves a new housing development off of the meter reading/billing roles. The utility can readily create billing accounts for these properties and back-bill according to prevailing policy.)

List the costs of the customer billing system analysis; typically, human resources/consulting costs.

II-a. Staffing costs, including wages and benefits for utility personnel:

Number of Utility Staff: ______ Cost, $/hour ______ $/d ______

Number of Consultant Staff: ______ Cost, $/hour ______ $/d ______

Total Staff: ______ Total Cost, $/d ______

II-b. Duration:

Days, per project task	Flowcharting/ Analysis	Corrections	Total Days	Total Project Costs, $
Utility				
Consultant				
Total				

III. Customer Meter Accuracy Evaluation

III-a. Customer water meters must be carefully selected and appropriately sized to provide accurate measures of customer consumption, which is the basis for billing for most North American water utilities. The status of customer metering should be evaluated to determine if customer metering inaccuracies are a significant source of apparent loss. Meter inaccuracy can occur from meter wear from high cumulative consumption, inappropriate sizing, use of the wrong type of meter for the application, or malfunction. It is recommended to perform meter accuracy testing of a sample of customer meters. Select meters in several size categories; including some meters selected at random and some meters that have registered high cumulative consumption. List the anticipated meter test schedule and costs.

III-b. List meters for accuracy testing:

Randomly Selected Meters			High Consumption Meters		
Meter No./Address	Size	Test Results	Meter No./Address	Size	Test Results

REVENUE PROTECTION PLAN TO CONTROL APPARENT LOSSES (continued)

III-c. List utility staffing costs for meter accuracy testing, including wages and benefits:

Number of Utility Staff: _________

Supervisor: Cost, $/hour _______ $/d _______ # of days _______ Cost, $ _______

Service Worker: Cost, $/hour _______ $/d _______ # of days _______ Cost, $ _______

Utility Staff Cost, $ _________

III-d. Estimated costs of meter testing service, if outside test facility is employed:

Meter Testing Services Cost, $/small meter _______ # of tests _______ Cost of small meter tests, $ _______

Meter Testing Services Cost, $/large meter _______ # of tests _______ Cost of large meter tests, $ _______

Total Meter Testing Service Cost, $ _________

III-e. Total Cost for annual meter testing program (utility and testing service), $ ________

IV. Customer Account Investigations for Systematic Data Handling Errors Correction and Recovery of Unauthorized Consumption

IV-a. All customer populations encounter some amount of consumption that is lost to inefficiencies of the billing process (systematic data handling errors) and illegal activities (unauthorized consumption). The Customer Billing Process Analysis (Section II) gives insight into suspect billing trends (e.g., accounts that show many consecutive months of zero consumption due to meter tampering or a flaw in the billing system programming). The Revenue Protection Program should individually investigate a sample of suspect accounts to assess the potential of apparent losses due to the above causes and to recoup revenue from these accounts.

IV-b. Identify trends of suspect accounts, as well as a sample of individual accounts to be field inspected for apparent losses. Trends might include multiple billing cycles of zero consumption or the same consumption, unusually low consumption, or other suspect data.

List Suspect Apparent Loss Trends (e.g., multiple billing cycles at zero consumption)	List Billing Accounts (by number) to Be Field Inspected				

IV-c. List utility staffing costs for suspect account investigations, including wages and benefits:

Number of utility staff: _________

Supervisor: Cost, $/hour _______ $/d _______ # of days _______ Cost, $ _______

Service Worker: Cost, $/hour _______ $/d _______ # of days _______ Cost, $ _______

Utility Staff Cost, $ _________

IV-d. For accounts discovered to be a source of apparent loss, list the total revenue recovered for the initial field investigations. Total recovered revenue will depend on the volume of missed consumption that is recouped and the water utility's policy on back-billing.

Number of Accounts Investigated	Total Consumption Volume Recouped	Revenue Recovery, $

REVENUE PROTECTION PLAN TO CONTROL APPARENT LOSSES (continued)

V. Revenue Protection Program Summary

V-a. List the summary data of the Revenue Protection Program here to determine its cost-effectiveness.

Corrections to Apparent Loss Component	Volume Recovered, units	Revenue Recovered, $	Costs to Recover Apparent Loss, $
Residential meter under-registration			
Industrial/commercial/agricultural meter under-registration			
Customer metering inaccuracies (sum of above two items)			
Systematic data transfer error			
Systematic data analysis error			
Data policy/procedure impacts			
Systematic data handling errors (sum of above three items)			
Unauthorized consumption			
TOTAL			

The findings of the activities in Sections I through IV will reveal sources of apparent loss. Corrections to accounts that are incurring loss include replacement of inaccurate meters; procedural, programming, or billing process corrections for systematic data handling errors; and field investigations to detect/thwart unauthorized consumption. The costs of these corrections should be shown in the right column above, along with the investigative costs (meter accuracy testing, etc.).

V-b. Revenue Protection Program cost-effectiveness

Calculate the cost-effectiveness of the Revenue Protection Program as a benefit–cost ratio:

$$\text{benefit–cost ratio} = \frac{\text{annual revenue recovery, \$}}{\text{annual program costs, \$}}$$

If the benefit–cost ratio is greater than one (benefit is greater than cost), the Revenue Protection Program gives a successful payback by recouping its costs within the first year. The inverse of the above ratio gives the payback period, in years.

LEAKAGE MANAGEMENT PLAN TO CONTROL REAL LOSSES

Name of Water Utility: ______________________ Audit Year: __________ Date: ____/____/________ Manager: ______________________

I. Describe the Leakage Management Approach

A-1. Describe the general approach to be employed to create or refine the leakage management strategy for the water distribution system: ____

____

____

II. Leak Survey and Repair Plan

A. Leak Survey Area and Frequency

A-1. Based on records of previous leaks, type and age of piping, soil conditions, high pressure and faulty installation practices, list the portion of the distribution system to be surveyed. List the survey frequency.

List percentage of system to be surveyed: __________ List frequency of surveys: ____________________

Describe each area to be surveyed under item B-2 of this plan.

A-2. Total miles of main to be surveyed: __________

When calculating pipeline length, include the total length of pipe and exclude customer service connection piping. If only a portion of the system is surveyed, calculate the benefit-to-cost ratio for only the portion surveyed.

A-3. Average length of pipeline surveyed per day: __________

The average survey crew can survey about 2 miles of main per day. Factors include distances between services, traffic and safety conditions, and number of listening contact points. Explain if more than 3 miles per day are surveyed: __________

____

A-4. Number of working days needed to complete survey (divide line A-2 by line A-3): __________

A-5. Describe personnel deployment: ____

____

B. Procedures and Equipment

B-1. Describe the procedures and equipment for detecting leaks. The best results are obtained by listening for leaks at all system contact points (such as water meters, valves, hydrants, and blow-offs).

____

____

B-2. Describe why the areas noted on the map in step A-1 have the greatest recoverable leakage potential.

____

____

B-3. If listening for leaks will not include all contact points, describe your plan for detecting leaks.

____

____

B-4. Describe the procedures and equipment you will use to pinpoint the exact location of detected leaks.

____

____

LEAKAGE MANAGEMENT PLAN TO CONTROL REAL LOSSES (continued)

B-5. Describe how the leak detection team and the repair crew will work together. How will they resolve the problem of dry holes?

____

____

B-6. Describe the methods you will use to determine the flow rates for excavated leaks of various sizes.

____

____

C. Staffing

C-1. How many agency staff will be used? _________

Staffing costs including wages and benefits:

Person 1: $/hour _________ $/d _________

Person 2: $/hour _________ $/d _________

TOTAL $/d _________

C-2. How many consultant staff members will be used?

Cost of consultant staff:

Person 1: $/hour _________ $/d _________

Person 2: $/hour _________ $/d _________

TOTAL $/d _________

D. Leak Detection Survey Costs

Leak detection surveys	$/d	# of days	Cost, $
D-1. Utility crew costs:	__________	__________	__________
D-2. Consultant crew costs:	__________	__________	__________
D-3. Vehicle costs:	__________	__________	__________
D-4. Other:	__________	__________	__________
D-5. Total survey costs:	__________	__________	__________

E. Leak Detection Budget

E-1. Cost of leak detection equipment: $ __________________

E-2. Leak detection team training: $ __________________

E-3. Leak detection survey costs: $ __________________

E-4. Total leak detection costs: $ __________________

F. Leak Survey and Repair Schedule

Indicate realistic, practical dates:

F-1. When will the leak survey begin? _______________

F-2. When will the leak survey be completed? _______________

F-3. When will the leak repairs begin? _______________

F-4. When will the leak repairs be completed? _______________

LEAKAGE MANAGEMENT PLAN TO CONTROL REAL LOSSES (continued)

III. Pressure Management Plan

Optimizing water pressure by removing excessive pressure levels and pressure surges is an effective strategy to sustain water infrastructure by minimizing background leakage, maintaining low leakage levels, and reducing water main ruptures and resulting damage. The water utility should assess the potential to improve pressure management in the water distribution system as a means of controlling leakage and better sustaining the water distribution system.

A-1. List the average pressure across the water distribution network: ___________________

A-2. List any discrete areas of the water distribution system (pressure zones, district metered areas) that experience average water pressure over 80 psi and/or exhibit poor infrastructure condition. These areas should be considered for optimized pressure management:

Zone #1		Zone #2		Zone #3		Zone #4	
Name	Pressure	Name	Pressure	Name	Pressure	Name	Pressure
___________	___________	___________	___________	___________	___________	___________	___________

A-3. Describe the pressure optimization potential across the distribution system. First, list the pressure reduction potential for each zone (e.g., none, 15 psi reduction, 30 psi reduction). Next, describe the method to be employed to attain the improved pressure management (e.g., create/reconfigure pressure zone or DMA, install pressure reducing valves, install variable frequency drives on pumps).

Pressure Reduction	List Pressure Management Method
Zone #1: __________________	________________________________
Zone #2: __________________	________________________________
Zone #3: __________________	________________________________
Zone #4: __________________	________________________________

A-4. List the Pressure Management Project Costs:

	Size	Number	Unit Cost	Costs
Pressure-Reducing Valves:	______________	______________	______________	______________
Variable-Frequency Drives:	______________	______________	______________	______________
Flowmeters:	______________	______________	______________	______________
Electronic Controllers:	______________	______________	______________	______________
Precast Manholes/Chambers:	______________	______________	______________	______________
Misc. Piping & Hardware: List	______________	______________	______________	______________
Construction: Labor workers, ___ days × _______ workers × _______ hr/d				______________
Equipment, Truck: ______________ × _______ days				______________
			Total Cost:	______________

IV. Leakage Management Plan Summary

A-1. List the Leakage Management Plan Cost for the initial year = Leak Detection & Repair Cost + Pressure Management Cost = ______________

A-2. List the anticipated reduction in leakage and cost savings: Volume ______________ Cost Savings ______________

Prepared by: ____ Date: ______________

LEAK DETECTION SURVEY DAILY LOG

Name of Water Utility: ______________________ Date: ______________

Leak Detection Team Members: ______________________

Equipment Used: ______________________

Area Surveyed: ______________________ Map Reference: ______________

Street and Block Numbers: ______________________ Page & Coordinates: ______________

Leak Number	Location or Address of Suspected Leak	Utility or Customer (U or C)	Leak Pinpointed? (Y or N)	Leak to Be Rechecked? (Y or N)	Leak Repaired (Y or N)	Not a Leak? (Date)

	Meters	Hydrants	Valves	Test Rods	Other
Indicate number of manual listening points used					
Indicate number of leak noise logger listening points used					
Miles of mains surveyed		Survey time			Hours
Number of leaks suspected		To be rechecked			(Number)
Number of leaks pinpointed		Pinpointing time			Hours

Remarks

____

____

____

LEAKAGE MANAGEMENT PROGRAM COST-EFFECTIVENESS SUMMARY

Name of Water Utility: ______________________ Date: ______________

Name of Report Preparer: ______________________

Leak Detection Survey

Total Number of Days Leak Surveys Were Conducted: ________

Survey Start Date: ________ Survey End Date: ________

	Meters/Curb Stops	Hydrants	Valves	Test Rods	Other
Number of listening points:	________	________	________	________	________

Number of Suspected Leaks: ________ Number of Pinpointed Leaks: ________

Survey Time: ________ hr Miles of Main Surveyed: ________

Pinpointing Time: ________ hr

$$\text{average survey rate} = \frac{\text{miles of main surveyed} \times 8\ \text{hr/d}}{\text{total survey and pinpointing hours}} = \_\_\_\_\_\_\_\_\ \text{mi/d}$$

Total number of visible leaks reported since survey started, from other sources (not discovered during leak detection surveys): ________

Leak Repair Summary

Date of First Leak Repair: ________ Date of Last Leak Repair Completed: ________

Number of Repairs Needing Excavation: ________ Number of Repairs Not Needing Excavation: ________ Total Number of Repaired Leaks: ________

Total Water Losses From Excavated Leaks: ______ gpm Total Water Losses From Non-Excavated Leaks: ______ gpm Total Water Losses: ______ gpm

	Excavated Leak Repair Costs	Non-Excavated Leak Repair Costs	Total Repair Costs
Materials	$ ________	$ ________	$ ________
Labor	$ ________	$ ________	$ ________
Equipment	$ ________	$ ________	$ ________
Other	$ ________	$ ________	$ ________
Subtotal	$ ________	$ ________	$ ________

LEAKAGE MANAGEMENT PROGRAM COST-EFFECTIVENESS SUMMARY (continued)

A. Leak Survey Program

Step 1. Calculate the value of water recovered, Vwr, from all repaired leaks.

Vwr = (total leakage recovered, gpm)(average leak duration)(water cost, Wc)

Leak duration = ½ of leak survey interval, days

Wc = short-term variable cost of water

Vwr = _________ gpm × 1,440 min/d × _________ days × $ _________ /mil gal × 1 mil gal/1,000,000 = $ _________

Step 2. Assemble Leak Survey Program Costs: $__________________

Step 3. Divide Vwr (from Step 1) by the total costs (calculated in Step 2).

$$\text{benefit–cost ratio (B/C)} = \frac{\text{value of water recovered}}{\text{total cost of leak detection survey}} = \_\_\_\_\_\_\_\_\_\_\_\_$$

For planning continuing leak detection efforts, you can calculate average survey costs per mile.

Step 4. Determine average survey costs per mile of main surveyed (C/mi).

$$\text{C/mi} = \frac{\text{total cost of leak detection survey}}{\text{total number of miles surveyed}} = \$\ \_\_\_\_\_\_\_\_\_\_\_\_\text{/mile}$$

B. Pressure Management Program

Step 1. Calculate the value of background leakage recovered, Vbr, from optimized pressures.

Vbr = (total leakage recovered, gpm)(average leak duration)(water cost, Wc)

Vbr – Obtain a measured value of background leakage recovered from DMA metering, or by estimation.

Average leak duration: because the background leakage reduction occurs all year, the average background leak duration is 365 days.

Vbr = _________ gpm × 1,440 min/d × _________ days × $ _________ /mil gal × 1 mil gal/1,000,000 = $ _________

Step 2. List Pressure Management Costs from Pressure Management Plan $ _________

Step 3. Divide Vbr (from Step 1) by the total costs (calculated in Step 2).

$$\text{benefit–cost ratio (B/C)} = \frac{\text{value of water recovered}}{\text{total cost of pressure managment}} = \_\_\_\_\_\_\_\_\_\_\_\_$$

Step 4. Payback period for pressure control equipment = $\frac{\text{program costs}}{\text{Vbr}}$ = ____________ , year

This page intentionally blank.

Appendix C

Assessing Water Resources Management

One of the key benefits of water loss control is to realize the efficient utilization of precious and often limited water resources. In the field of water resources management, the entire hydrologic cycle of water is considered: from rain and other precipitation events placing water into watersheds, to humankind's use—and reuse—of water, its arrival in oceans and return to the clouds. Humans intervene in the hydrologic cycle in numerous ways to provide benefit to society while hopefully maintaining a sound environment. These activities include extracting water from natural sources such as rivers, lakes, or aquifers and treating (drinking water treatment), storing, distributing, collecting, treating again (wastewater treatment), recycling, or reusing water and returning it to rivers, lakes, aquifers, or oceans. Throughout these various processes, water may change quality several times (with an expense incurred in doing so at each step), it may be transported across watershed boundaries, and it may provide multiple benefits to society while creating a variety of environmental impacts. Unfortunately, a portion of the water managed by water utilities is lost from its infrastructure (real losses) and provides no benefit to society as it returns to the water table.

The primary focus of this manual is to assess the use of water in only a portion of the human-made processes mentioned above: that of the drinking water supplier who is typically withdrawing raw (untreated) water from a natural source, treating it to drinking water standards, and conveying it to customers through piping systems to the point of customer use of the water. Water audits performed in accordance with guidelines in this manual are generally conducted on the portion of this process from water leaving the water treatment plant to water passing the customer meter. However, a broader assessment of supply efficiency can be considered by first tracking the volume of water where it is extracted from its source, then monitoring the volume passing through the treatment process, and to the customer's end use. In this way, accountability and losses can be assessed on both source water upstream of the treatment plant and losses within the distribution and customer metering systems. General considerations are discussed here; however, more detailed information is available to the reader in other references noted in this appendix.

AUDITING THE UNTREATED (RAW) WATER SUPPLY VOLUME

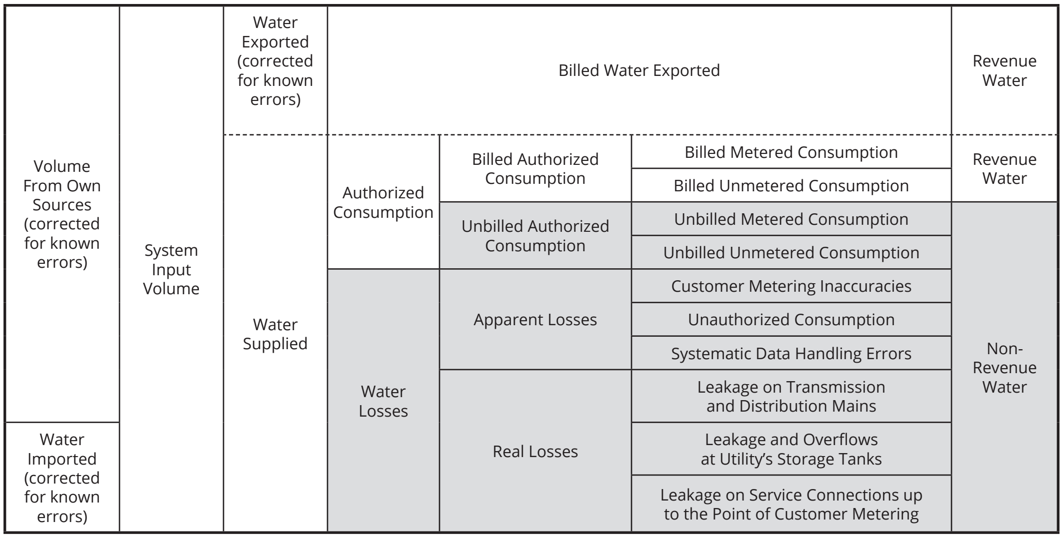
Most water utilities obtain untreated (raw) water volumes from a natural water source or water that is provided by a regional water system scheme such as a large water supply reservoir. AWWA provides strong guidance on the management of water resources for regions and communities in its guidance manual *Water Resources Planning* (M50; AWWA 2007). AWWA Manual M50 provides strong insight to the value of water resources, resource development, water reuse, and recycling.

Water utilities that obtain untreated water typically convey the water through a water treatment process to produce water of acceptable drinking water quality that is then sent through the water distribution system to consumers. Figure C-1 is the standard water balance used throughout this manual. While its left column starts with the measured volume of untreated water abstracted or withdrawn from source waters, this balance does not necessarily take into account the fact that a certain amount of untreated or raw water may be lost or inaccurately measured in the raw water transmission system conveying water from source to treatment. Likely for the majority of water systems, the treatment works are located within close proximity to the raw water source, and losses in raw water conveyance structures are minimal. However, a number of large water supply networks feature aqueducts or transmission pipelines conveying untreated water for long distances—up to hundreds of miles—with losses of untreated water occurring in these systems. For such sizeable systems, the magnitude of the bulk raw water volumes is a factor, in that even relatively low rates of loss can translate to a significant volume of missing water. Thus, there may be considerable benefit in looking more closely at raw water supply and conveyance systems.

Depending on the specific system configuration, and distances and magnitude of the supply volume, the water auditor has the option to either (1) perform an audit on the raw water process separately from the treated water system (as shown in Figure 3-3a), or (2) compile a single audit that takes into account the losses in the raw water network as well as the treated water network. In the latter case, a modified water balance applies, as shown in Figure C-2. In either approach, supply and production metering accuracy, apparent losses, and real (leakage) losses should be considered in the audit. The auditor should be mindful to calculate a separate cost to value the raw water losses, because raw water has less value than treated water. The water balance in Figure C-2 closely matches that used by a number of state and regional water oversight agencies in the United States.

Though not common, a portion of the raw water may be withdrawn for specific uses prior to reaching the water treatment plant. These volumes might include raw water supply sold to neighboring water utilities, water used in flushing operations or maintenance of the raw water transmission system, or other authorized uses. Similarly, a portion of raw water entering water treatment plants is not recovered as treated water leaving the treatment plant. This water is used or purged in the treatment process for backwashing filters, flushing, chemical process feed water, and other process uses. These are not losses, and some of this process water may be recycled back to the plant influent or pretreatment basins, but all such volumes should be quantified in the water balance to distinguish the volumes going to such consumption from the final treated water volume. Only then can a reasonable approximation of raw water losses be determined.

When should a water utility take the raw water system into account in its auditing? Again, this depends largely on the configuration of the water supply system, magnitude of the volume supplied, distance between source and treatment facilities, and also the relative scarcity or value of the source water. In terms of configuration, consider how extensive the raw water transmission network is. Closed systems (zero discharge facilities) do



Note: All data in volume for the period of reference, typically one year.

Figure C-1 Standard AWWA water balance

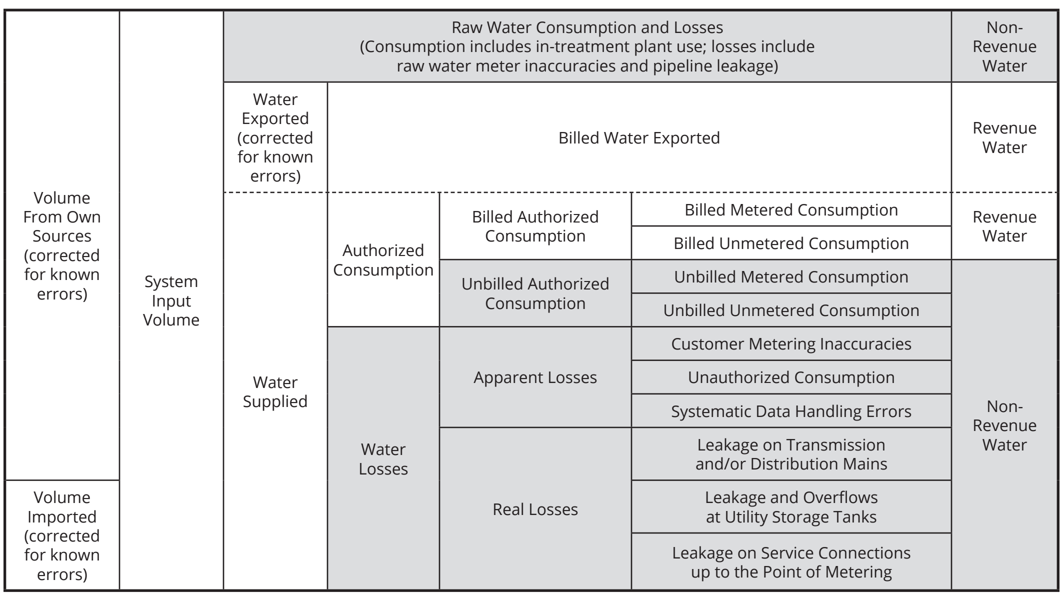


Figure C-2 Modified AWWA water balance showing raw water withdrawal, utilization, and losses

not need to consider this approach unless the potential for wasting energy from pumping water repeatedly is significant. If raw water is transported many miles, over varying terrain, or in open conduits subject to evaporation and leakage, an audit of the network should be performed, perhaps as a separate water audit from the treated water system. If raw water is purchased, efficient use of this supply increases in importance because the cost of the water is likely to be significant. Similarly, an audit of raw water may be performed in more limited piping configurations if the value of the raw water is high because of scarcity, growing economic development, or other drivers.

A specific audit of raw water is typically not necessary where the raw water is extracted from a source within close proximity to a water treatment facility or circulated in a closed system. Many water utilities have water treatment facilities located adjacent to the source waters (wells, river, lakes, etc.). Because the raw water is drawn directly into the water treatment plant, a separate assessment of raw water operations is usually not needed in such cases. However, consumption during plant operations and recycling of process water might still be considered, unless the water utility has meters on the treated water distribution pipelines exiting the plant. Similarly, if water resources are not greatly limited, the auditor may choose to audit only the treated water distribution system.

When auditing is performed on the raw water supply as a separate and distinct audit, volumes of the raw water supplied and raw water losses—both apparent and real losses—should be compiled. The cost of the raw water—if the water utility must purchase this water—should be included, as well as the cost impacts of the real and apparent losses. If water resources are not limited in the region, both apparent and real losses can be valued at the cost to transport the raw water to the water treatment plant. If resources are strained, however, these losses might both be valued at the retail costs charged to customers. The annual volume and costs of these losses should be evaluated within the scope of the water loss control program to determine steps to reduce such losses to acceptable economic levels. Particularly for large-diameter transmission pipelines, technologies now exist to assess pipeline condition and pinpoint defects with great accuracy. (See chapter 7 for descriptions of these leak detection technologies.)

Figure C-3 presents perhaps the most holistic water balance that can be applied for drinking water utilities. The graphic expands on the water balance shown in Figure C-2 by adding the left-most column that displays the volume of water allocation to the water utility. The top includes a bar representing the amount of the allocation that is not currently utilized; this is sometimes referred to as the *headroom* for the water utility. The auditor may consider assessing additional parameters to evaluate the utility's overall water resource standing. Because many fast-growing communities are approaching the limits of their water allocations, the following equations provide a measure of this standing:

$$\text{remaining allocation} = \text{allocation} - \text{withdrawal (vol)} \tag{C-1}$$

$$\text{percent remaining allocation} = \frac{\text{allocation} - \text{withdrawal (\%)}}{\text{withdrawal}} \tag{C-2}$$

Other aspects of the supply/demand balance to consider in fast-growing, resource-limited regions might include population and water demand growth rates, climate change impacts, water conservation efforts, implementation of water reuse or recycling, which components of potable water demand can be reduced by switching to recycled water, synergies from potential regionalization of water supplies, and other water resources considerations.

CONSUMER LOSSES

Although the water volume passed through the customer meter is measured and billed as consumption, a portion of this water is for beneficial use by the customer and a portion may go to waste, typically because of toilet and plumbing leaks or other inefficient use by the customer. Such waste can be evaluated by the water utility as part of a water conservation program, which focuses on the efficiency of the end user. The assessment of customer water efficiency, however, is beyond the scope of this manual. Instead, readers may consult excellent publications that provide current assessments and best practices in water conservation. AWWA's leading guidance manual *Water Conservation Programs—A Planning Manual* (M52; AWWA 2015) is the leading source of information on these programs. Extensive research work on residential customer consumption is available from the research report *Update and Expand the Residential End Uses of Water* (WRF 2015) project which greatly enhances the

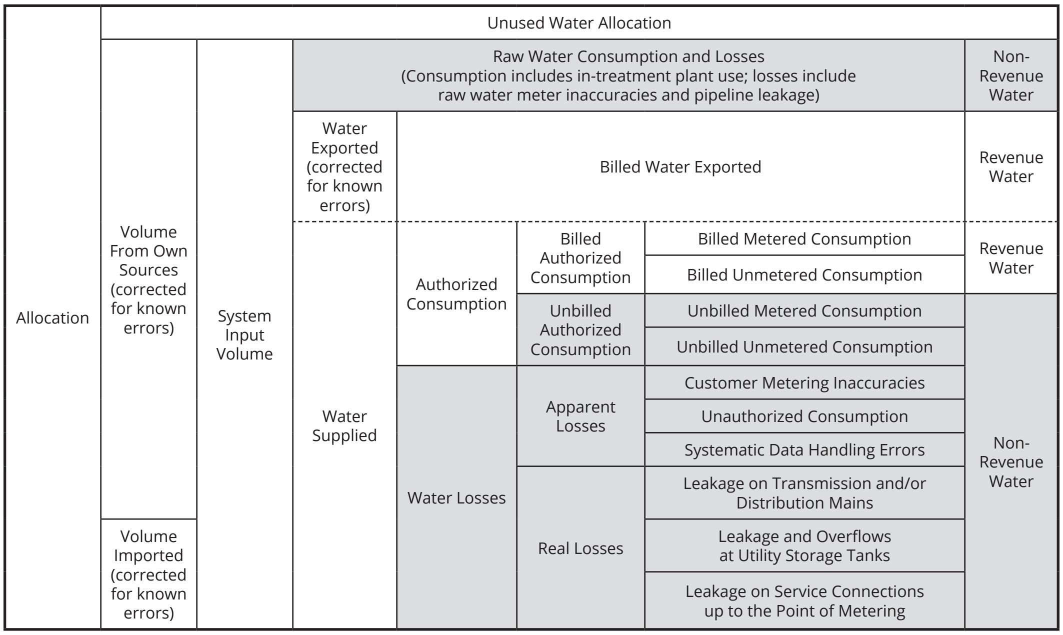


Figure C-3 Modified AWWA water balance showing the water allocation and unused water allocation that remain available

knowledge of residential water use. This project updates a 1999 project (AwwaRF 1999) that has been widely regarded as the seminal work on this topic.

SUMMARY

As populations increase regionally, especially in water-short areas of North America, it is critical that water resource planners and water utility managers address the sustainability of precious and often limited water resources. A robust, thorough, and holistic water audit includes investigation of use and loss components throughout the entire water cycle to protect and control these resources for the future. Currently, many drinking water utilities must balance competing demands regarding growing populations, economic development, water rights, climate change impacts, resource withdrawal/recharge imbalances, irrigation demands, and environmental protections; as well as political, social, and financial pressures. Having reliable data from a comprehensive water resource audit allows managers to make intelligent decisions on these complex issues.

REFERENCES

AWWA (American Water Works Association). 2007. Manual M50. *Water Resources Planning*. Denver, Colo.: AWWA.

AWWA (American Water Works Association). 2015. Manual M52. *Water Conservation Programs—A Planning Manual*. Denver, Colo.: AWWA.

AwwaRF (Awwa Research Foundation). 1999. *Residential End Uses of Water*. Denver, Colo.: AwwaRF.

WRF (Water Research Foundation). 2015. *Update and Expand Residential End Uses of Water*. Denver, Colo.: WRF.

This page intentionally blank.

Appendix D

Free Software Tools Available From AWWA and WRF

This AWWA Manual M36 provides water utilities with the detailed how-to information to launch and operate a successful water auditing process and water loss control program. Although AWWA's guidance manuals have long provided this type of comprehensive instruction, the AWWA Water Loss Control Committee recognized that water utilities could be greatly assisted in many of the activities of the water loss control program by employing software tools, particularly tools created in standard spreadsheet software. In a period of less than 10 years, work within AWWA and the Water Research Foundation (WRF) has led to the following tools becoming freely available to the drinking water industry:

- AWWA Free Water Audit Software (Audit Software)
- AWWA Water Audit Compiler (Compiler)
- WRF Leakage Component Analysis Model (LCA Model)

Work started in 2004 with a goal of producing a user-friendly spreadsheet software tool to compile a basic top-down water audit. The Audit Software was launched in 2006 and quickly gained success with thousands of downloads in its first two years and steady usage since. This effort was followed by the creation of the Compiler to assemble data from multiple water audits, and the LCA Model to conduct a leakage component analysis and set a comprehensive leakage management strategy. The LCA Model was created as part of a research project administered by WRF, with sponsorship by the United States Environmental Protection Agency (USEPA).

- The Audit Software and Compiler are available for free download from the AWWA Water Loss Control Resource Community Web page at www.awwa.org/resources-tools/water-knowledge/water-loss-control.aspx.

- The LCA Model is available for free download from the WRF Project 4372a Web site at www.waterrf.org/Pages/Projects.aspx?PID=4372.

A link to the LCA Model also exists on the AWWA Web site. With these effective and complimentary tools freely available, the drinking water industry has great opportunity to couple the detailed guidance of AWWA Manual M36 with the utility of the tools to create an effective water loss control program, at minimal upfront cost. This appendix provides an overview description of these software tools, and additional discussion is given in several other chapters of this manual. Readers are urged to visit the AWWA and WRF Web sites to obtain these tools, investigate them, and apply them. The AWWA Web site also provides an email address to which users can pose questions regarding the software packages. In this way, basic assistance is always available.

THE AWWA FREE WATER AUDIT SOFTWARE

In 2006, AWWA's Water Loss Control Committee launched its first AWWA Free Water Audit Software (Version 2.0) to provide the drinking water industry with a workable tool to conduct a basic top-down water audit quickly and inexpensively. In 2010, Version 4.0 of the Audit Software was released and included a new approach to assess the validation, or trustworthiness, of the data inputs of the water audit. The simple "estimated" or "measured" approach of the early Audit Software versions was replaced with a numerical grading (1 to 10) that reflected detailed descriptions of utility practices with respect to each of the data inputs. A low grading reflects less confidence in the data input, such as use of a subjective estimate for a water volume. A high grading reflects good confidence in the data input. For example, water volume data generated as a measured value from a current-model water meter that is tested regularly should be assigned a high grading. Conversely, water volume data obtained as a crude estimate or from older meters that have not been recently tested warrant a low grading.

The purpose of the data validation capability is to describe the confidence and accuracy of the data input values and to serve as a basis for validation checks on the water audit inputs (essentially *auditing* the water audit). Each input value has a corresponding scale fully described in the Grading Matrix worksheet. The Grading Matrix also describes the actions that a water utility can take to move to a higher grading score. In this way, process-based guidance is provided to the user on ways to improve his or her utility's operations to produce data of a high degree of validity and confidence and, in doing so, to improve overall operations and water efficiency.

A weighted composite of the individual data gradings is calculated by the Audit Software to produce the Water Audit Data Validity Score (DVS), a rating value with a range of 1–100. Priority areas for attention are also displayed by the Audit Software to guide the user to the most important areas needing data validity improvement. Additional guidance is provided in the Water Loss Control Planning Guide worksheet, which is based on levels of the DVS. In 2014, Version 5.0 of the Audit Software was released with key enhancements, including more appropriate volume-based weightings to some of the data gradings, clarifications and additions within the Grading Matrix language, the addition of a dashboard tab for visualization of performance indicators, and the addition of a comments sheet to allow the user to record notes about their data sources, assumptions, and additional references.

The Audit Software is the recognized standard water audit tool in the North American drinking water industry. It is the mandatory format of a growing number of water agencies that require water audit data collection, including the State of Georgia Department of Natural Resources–Environmental Protection Division, California Urban Water Conservation Council, the Delaware River Basin Commission, and the State of Tennessee Comptroller of the Treasury. As a standard tool in common use across the United States, the Audit Software provides water utilities with the ability to compile a reliable water audit and make reliable comparisons with utility peers. As more water audits are collected and validated using the Audit Software and its companion tools, the water industry will benefit greatly from the large pool of representative water utility data that is emerging.

Using the Audit Software

The Audit Software was designed with several key attributes:

- It includes user-friendly worksheets in a Microsoft Excel spreadsheet. It is easy to toggle to and from individual worksheets. No detailed computer knowledge is required of the users, and they need not be familiar with the water audit methods. Users only need to have access to the Excel software on their computers.
- The water audit format is designed as a basic top-down approach, thereby allowing the user to complete the primary worksheet quickly with information from readily available records.
- Instructions are built into the software, and terms and definitions are explained.
- The Audit Software operates with user-selected water volume units of gallons, megalitres, or acre-ft.
- Performance indicators and key statistics are automatically calculated for the user, thereby preventing mathematical errors.
- Logical checks and alerts are included in the Audit Software to notify the users to questionable data entry or results. For example, because it is impossible for a water utility's authorized consumption to exceed its volume of water supplied, a red-flag message appears if such data are input.
- The Audit Software requires that the user "grade" the validity of each input datum, from which a composite DVS (1–100 scale) is calculated, thereby providing an assessment of the degree of confidence of the water audit results and performance indicators. This powerful feature exists in Version 4.0 and the current (as of 2014) version 5.0 of the Audit Software. Note that the DVS does not calculate unless a Data Grading value is selected for all of the data inputs on the Reporting Worksheet.
- Having the ability to compile water audit data in a standard, electronic format (Compiler) allows water audit data from many systems to be easily compiled, transferred, and analyzed.

These features make the Audit Software very easy to access and use to quickly enter data and obtain a preliminary assessment of water loss standing. This is particularly attractive for water utilities that are just starting to compile a water audit and are hard pressed to dedicate significant staff time for auditing. The Audit Software allows water utilities to begin auditing in an expedient, inexpensive manner. Because all of the standard performance indicators are calculated by the Audit Software, the water utility has a means to make reliable performance comparisons with other utilities and to trend its own performance over time. Also, because the cost impacts of real and apparent losses are calculated, water utility managers can obtain a clear indication of the financial impact of their inefficiencies and a basis to justify expenditures to better control excessive losses.

The trade-off of the top-down simplicity of the Audit Software, however, is that less detail is provided than a bottom-up approach involving field studies and detailed analysis. Also, the Audit Software quantifies real losses in a "catch-all" manner, as the remainder of losses after apparent losses are quantified and subtracted. Fortunately, users can employ the LCA Model to further assess the catch-all leakage volume of the Audit Software and analyze it in its component volumes, allowing a cost-effective leakage management program to be established. Although the Audit Software is very easy to employ to launch the auditing process, it is recommended that the water utility eventually make efforts to go beyond the top-down audit provided by the Audit Software and conduct leakage component analysis and launch necessary bottom-up investigations. The water audit should be compiled on an annual basis. Thus, after the initial top-down water audit, utilities should gradually incorporate bottom-up auditing investigations to better quantify loss volumes so that a more accurate water audit evolves—and losses are more effectively controlled over time. The Audit Software is an excellent tool that provides water utilities a quick look into the water supply efficiency of their operations and provides the basis for ongoing water efficiency improvements.

Version 5.0 of the Audit Software exists as a Microsoft Excel workbook that includes twelve distinct worksheets, five of which are shown in Figures D-1 through D-5. Figure D-1 serves as both the Instructions worksheet and the header worksheet where general information about the water utility is input. The key worksheets of the package are shown in Figures D-2 and D-3, the Reporting Worksheet and the System Attributes and Performance Indicators worksheet, respectively, which are shown in this appendix with completed water audit data for the City of Asheville, N.C. The Audit Software also includes a worksheet with example data (not shown in this appendix) from the Region of Peel in Ontario, Canada, in the metric units of megalitres. Figure D-4 displays a portion of the Grading Matrix worksheet (giving data grading guidance), and Figure D-5 displays the Water Loss Control Planning Guide worksheet, which allows water utilities to assess the DVS that they obtain in their water audit. Other worksheets (not shown in this appendix) also exist in the Audit Software, including a dashboard for visualization of the performance indicators, a Definitions worksheet with key terms and definitions, a comments worksheet, and several other worksheets providing additional information. The use of the Audit Software is explained in detail in chapter 3 with data from the fictitious County Water Company.

What is the best approach to water auditing if a water utility has not previously performed a water audit? The following is a two-step recommendation:

1. Perform a quick top-down water audit using the Audit Software. This will easily provide a preliminary assessment of water loss standing and cost impacts, and will serve as a basis for comparisons with other water utilities.
2. Once a preliminary water audit is developed and recorded in the software, the methods prescribed in this manual can be followed to form a team (chapter 8), develop a more detailed worksheet (chapter 3), and start bottom-up activities and interventions to more accurately quantify and control apparent and real losses (chapters 4 through 7).

Water utilities should compile a standard water audit—preferably using the Audit Software—on an annual basis as a standard business process. Most utilities will find this process highly effective in quantifying their losses and directing their activities to cost-effectively reduce lost water and recover uncaptured revenue.

THE AWWA WATER AUDIT COMPILER

As the Audit Software quickly gained widespread use, it was soon realized that a need existed to develop a compiler tool to provide for easy compilation and analysis of data from multiple water audits. The AWWA Water Audit Compiler (Compiler) was launched in 2011 and can be used to quickly assemble water audit data from multiple water utilities,

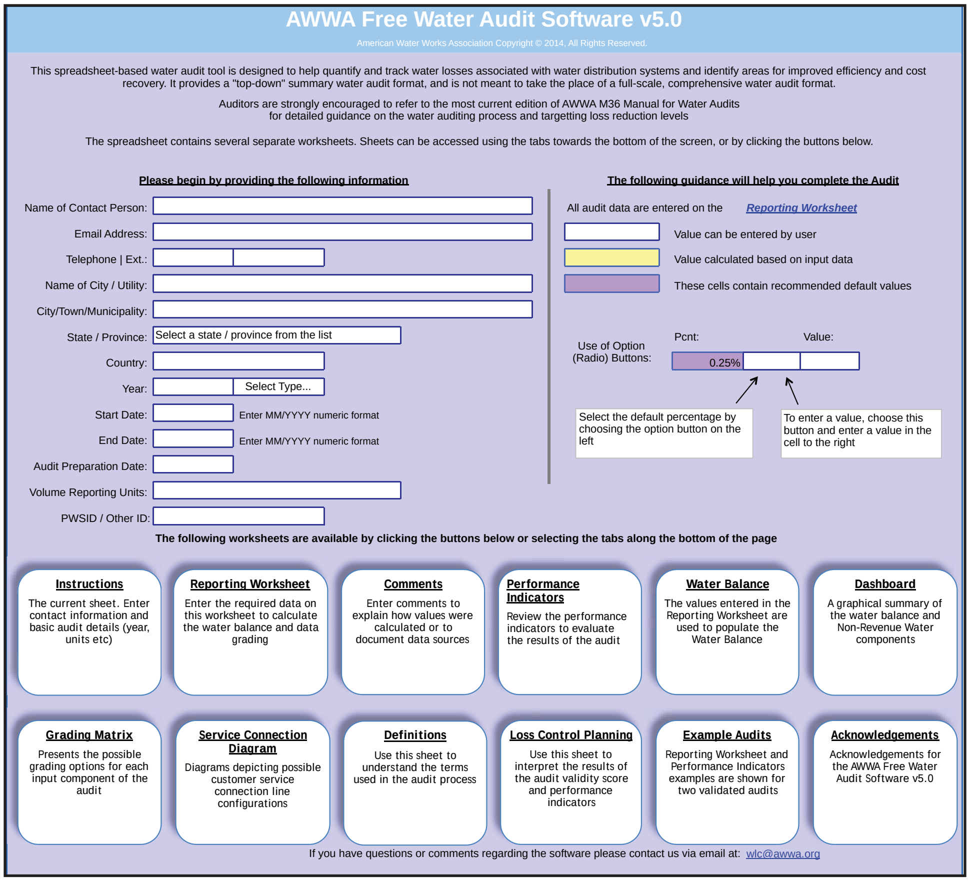


Figure D-1 AWWA Free Water Audit Software—Instructions Worksheet

allowing for comparisons of data across water utilities. The Compiler can also be used to compile multiple years of water audit data for a single utility, allowing the water efficiency history of a water utility to be viewed at a single glance. The current versions of the Audit Software (Version 5.0) and Compiler (Version 5.0) were both released in 2014 and are available for free download from the AWWA Water Loss Control Resource Community Web page on the AWWA Web site (see link at beginning of this appendix).

Like the Audit Software, the Compiler was created in a Microsoft Excel spreadsheet format and the Compiler works hand in hand with the Audit Software. The Compiler was developed to improve the management of water audit datasets containing multiple water audits in small or large number. It was originally devised to help state and regional water resources agencies to easily aggregate and analyze large datasets and to provide trending and analysis tools to guide the process.

During data assembly in the Compiler, different units of measurement can be automatically converted to other units to facilitate direct comparisons. If some of the water audit data of a group of utilities are given in metric volumes (megalitres) while the majority of utility data are given in gallons, the Compiler can convert the metric units to gallons so that all of the data gathered into the Compiler are in consistent units for analysis. Once data are assembled in the Compiler, graphics can be displayed and sorted easily with any of the audit inputs and outputs. The data gathered into the Compiler can also be exported to a separate Microsoft Excel spreadsheet where the user can conduct further analysis of their own design using standard Excel features.

AWWA's Water Loss Control Committee has made good use of the Compiler to assemble validated water audit data from several dozen volunteer water utilities across North

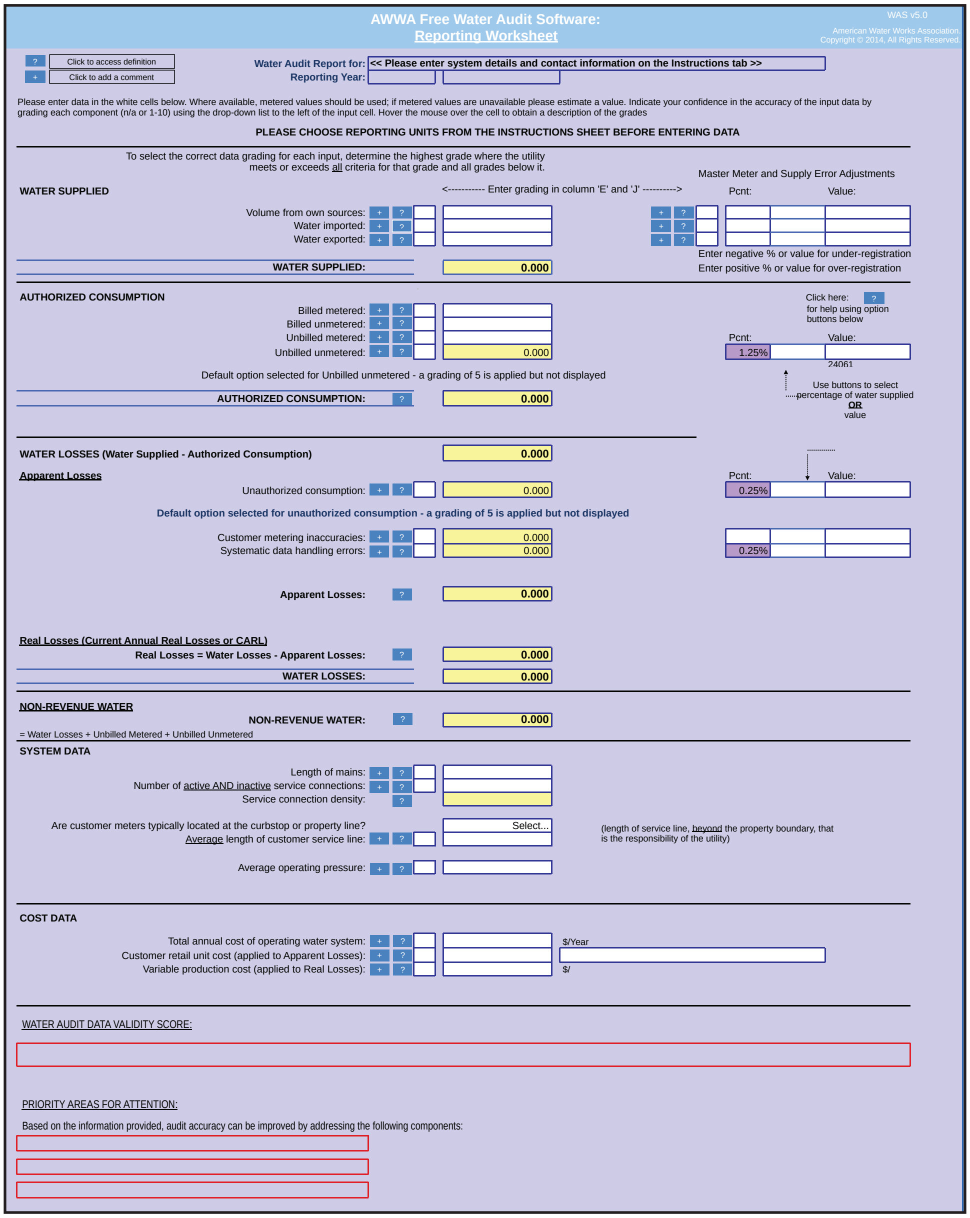


Figure D-2 AWWA Free Water Audit Software—Reporting Worksheet

America. Each year since 2011, the Water Audit Software Subcommittee has enlisted 20–30 volunteer water utilities, collected their water audit data, discussed the data in detail with utility representatives to validate it, and then posted it in the Compiler on the AWWA Web site. This dataset for each year since 2011 is available for free download from the Web site.

Figure D-6 shows a screenshot from the data page of the Compiler, which lists some of the validated water utility data from the 2014 Water Audit Data Initiative. Figures D-7 and D-8 display just two of many graphs that can be quickly generated by the Compiler, once data are input into the Compiler. Additional information on the data collected by AWWA, and other validated water audit data from water utilities in the state of Georgia, are given in appendix E. The Compiler is a highly complementary tool to the Audit Software, and together these software tools give users strong capabilities to compile the water audit, assess data, and make comparisons with other water utilities.

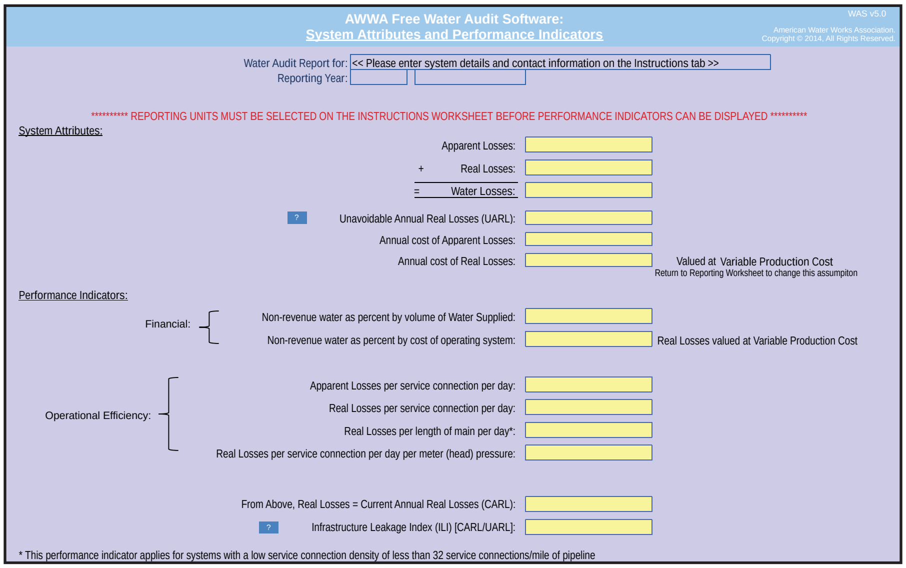


Figure D-3 AWWA Free Water Audit Software—System Attributes and Performance Indicators Worksheet

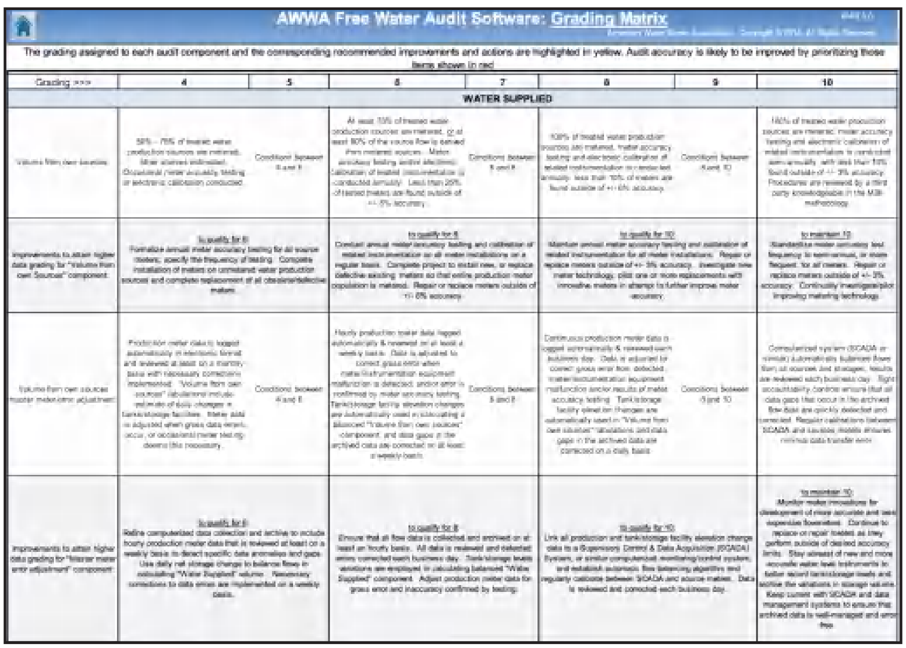
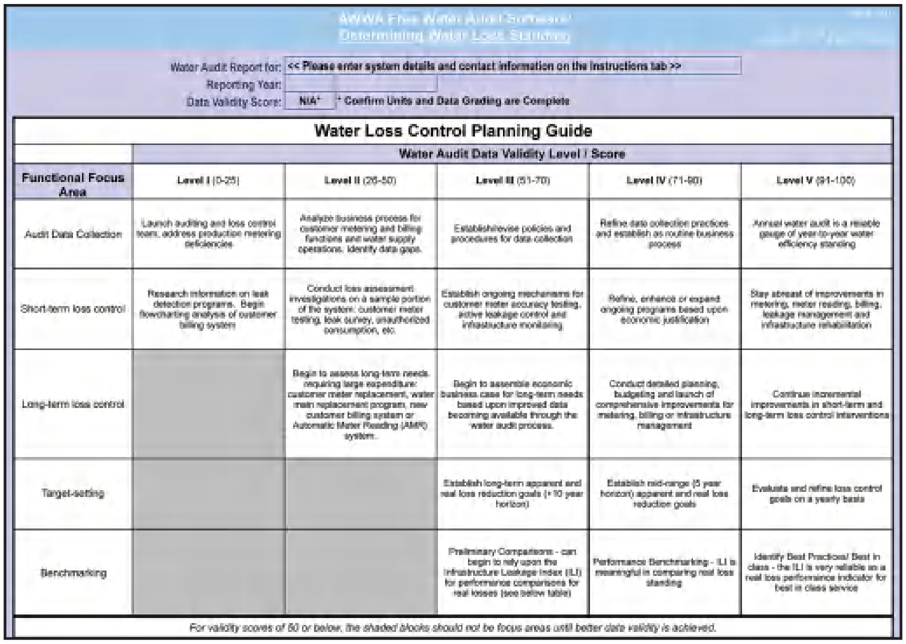


Figure D-4 AWWA Free Water Audit Software—Grading Matrix Worksheet (excerpt)

THE WATER RESEARCH FOUNDATION LEAKAGE COMPONENT ANALYSIS MODEL (PROJECT 4372A)

In 2014, WRF, with support from USEPA, published the final report and spreadsheet software tool for Project 4372a titled *Real Loss Component Analysis: A Tool for Economic Water Loss Control* (WRF 2014). The software tool—the LCA Model—is available for free download from the WRF Web site (which can be reached via a link from the AWWA Web site.) The purpose of research project 4372a was to identify the best methods for conducting a


AWWA Free Water Audit Software:
Determining Water Loss Standing

Water Audit Report for: << Please enter system details and contact information on the Instructions tab >>
Reporting Year:
Data Validity Score: N/A* * Confirm Units and Data Grading are Complete

Water Loss Control Planning Guide

	Water Audit Data Validity Level / Score				
Functional Focus Area	**Level I** (0-25)	**Level II** (26-50)	**Level III** (51-70)	**Level IV** (71-90)	**Level V** (91-100)
Audit Data Collection	Launch auditing and loss control team; address production metering deficiencies	Analyze business process for customer metering and billing functions and water supply operations. Identify data gaps.	Establish/revise policies and procedures for data collection	Refine data collection practices and establish as routine business process	Annual water audit is a reliable gauge of year-to-year water efficiency standing
Short-term loss control	Research information on leak detection programs. Begin flowcharting analysis of customer billing system	Conduct loss assessment investigations on a sample portion of the system: customer meter testing, leak survey, unauthorized consumption, etc.	Establish ongoing mechanisms for customer meter accuracy testing, active leakage control and infrastructure monitoring	Refine, enhance or expand ongoing programs based upon economic justification	Stay abreast of improvements in metering, meter reading, billing, leakage management and infrastructure rehabilitation
Long-term loss control		Begin to assess long-term needs requiring large expenditure: customer meter replacement, water main replacement program, new customer billing system or Automatic Meter Reading (AMR) system.	Begin to assemble economic business case for long-term needs based upon improved data becoming available through the water audit process.	Conduct detailed planning, budgeting and launch of comprehensive improvements for metering, billing or infrastructure management	Continue incremental improvements in short-term and long-term loss control interventions
Target-setting			Establish long-term apparent and real loss reduction goals (+10 year horizon)	Establish mid-range (5 year horizon) apparent and real loss reduction goals	Evaluate and refine loss control goals on a yearly basis
Benchmarking			Preliminary Comparisons - can begin to rely upon the Infrastructure Leakage Index (ILI) for performance comparisons for real losses (see below table)	Performance Benchmarking - ILI is meaningful in comparing real loss standing	Identify Best Practices/ Best in class - the ILI is very reliable as a real loss performance indicator for best in class service

For validity scores of 50 or below, the shaded blocks should not be focus areas until better data validity is achieved.

Figure D-5 AWWA Free Water Audit Software—Water Loss Control Planning Guide Worksheet

leakage component analysis to be used to set a cost-effective leakage control strategy in a water utility (see chapter 7). The project was also charged to employ these best practices in the creation of a spreadsheet software tool that works in complementary fashion with the Audit Software, and the LCA Model meets this need. Since the Audit Software results provide an annual real loss volume that is determined as a catch-all quantity remaining after all of audit components are input, very limited insight is given for leakage control purposes when compiling the top-down water audit in this manner. The LCA Model was designed to pick up where the Audit Software leaves off, in terms of leakage assessments. The LCA Model provides the water industry with an easy-to-use spreadsheet tool to conduct a leakage component analysis, determine the water utility's failure frequency, provide guidance to set the economic leakage control intervention strategy, and display key water loss performance indicators.

The LCA Model was designed using Microsoft Excel spreadsheet software. The LCA Model was developed with the needs of the utility users in mind to provide a water loss analysis software tool that is accessible, user friendly, and has a limited level of complexity. The outputs of the LCA Model enable utilities to establish data collection guidelines for proper documentation of all leakage occurrences, plan cost-effective leakage control interventions in a proactive manner, and preliminarily evaluate the potential for pressure management benefits. Figure D-9 shows a screenshot from LCA Model that graphically summarizes the volumes by percentage of real losses occurring in a water utility, broken down into the individual leakage components. Numerous additional screenshots from the LCA Model are given in chapter 7 as part of the detailed instructions to conduct the leakage component analysis.

SUMMARY: THE VALUE OF WATER LOSS CONTROL SOFTWARE TOOLS

The AWWA Water Loss Control Committee maintains AWWA Free Water Audit Software and the AWWA Water Audit Compiler, and coordinates with WRF to maintain the WRF

Include on Chart	Name of City / Utility:	Customer Metering Inaccuracies	Systematic Data Handling Errors	Systematic Data Handling Errors Default Use	Apparent Losses	Real Losses	Water Losses2	Non Revenue Water	Length of Mains	Number of Active and Inactive Service Connection
Yes	City of Asheville	111.220	11.956	Yes	140.844	1,958.789	2,099.633	2,285.180	1236.5	55,256
Yes	Augusta Utilities	202.735	71.603	No	307.087	2,694.886	3,001.973	3,552.620	1213.3	72,235
Yes	Austin Water Utility	828.761	0.001	No	945.924	4,024.607	4,970.531	5,095.921	3707.0	215,960
Yes	Birmingham Water Works Board	557.467	0.001	No	645.000	11,242.159	11,887.159	12,339.569	3941.0	230,018
Yes	The City of Calgary	334.291	82.627	Yes	525.552	8,526.084	9,051.636	9,476.994	3072.7	312,075
Yes	Chesterfield County Rural Water Co., Inc.	6.456	1.598	Yes	9.978	115.171	125.149	130.422	732.0	8,243
Yes	Greater Cincinnati Water Works	308.039	696.500	No	1,096.716	4,873.730	5,970.446	6,972.146	3135.8	246,044
Yes	Consolidated Utility District	17.943	0.300	No	27.152	813.118	840.270	902.268	1301.0	50,510
Yes	City of Cranbrook	0.000	0.000	No	2.798	172.402	175.201	189.193	101.5	6,696
Yes	Cobb County Water System	341.584	16.730	No	404.568	1,347.804	1,752.372	1,764.294	3150.0	178,130
Yes	Dalton Utilities	195.846	15.831	Yes	231.343	1,204.651	1,435.995	1,534.328	1251.0	37,023
Yes	DC Water and Sewer Authority	527.700	1789.500	No	2,449.800	5,621.951	8,071.751	8,748.651	1350.0	134,284
Yes	Ellijay Gilmore Water & Sewer Authority	11.638	1.000	No	15.169	218.215	233.384	283.102	227.0	5,527
Yes	Eatonton Putnam Water and Sewer Authority	2.281	0.511	Yes	5.792	74.506	80.298	101.609	145.0	8,350
Yes	City of Griffin	18.795	1.798	Yes	23.769	510.230	533.999	551.539	212.7	11,733
Yes	Halifax Regional Water Commission	129.981	0.264	No	158.629	1,504.514	1,663.143	1,763.626	1017.2	85,957
Yes	Las Vegas Valley Water District	2638.000	100.000	No	2,998.997	3,025.078	6,024.075	6,030.775	4515.0	397,526
Yes	Louisville Water Company	973.100	150.000	No	1,123.200	4,123.662	5,246.862	7,839.099	4156.0	306,079
Yes	Macon Water Authority	119.744	6.252	No	132.247	1,551.136	1,683.383	1,779.733	1400.0	65,200
Yes	Orange County Utilities Department	104.165	32.920	No	191.107	1,841.418	2,032.525	2,144.747	1745.5	90,402
Yes	Philadelphia Water Department	1490.200	3579.300	No	7,495.000	21,267.500	28,762.500	30,721.500	3178.0	527,205
Yes	The Region of Peel	725.152	1.321	No	855.072	4,717.505	5,572.577	6,079.497	2793.9	315,617
Yes	Village of Santa Clara	1.254	0.250	No	1.740	20.613	22.353	24.947	25.0	752
Yes	South Jordan City	63.709	9.664	Yes	84.822	289.389	374.211	714.143	333.0	19,074
Yes	City of Wilmington	171.726	500.000	No	701.726	1,832.707	2,534.433	2,631.175	410.0	37,751
Yes	Water & Wastewater Authority of Wilson County	5.228	0.020	No	6.170	58.944	65.114	66.494	326.5	7,052
Yes	Washington County Service Authority	14.449	3.485	Yes	24.269	1,047.489	1,071.758	1,139.856	852.5	22,500
Yes	Cherokee County Water & Sewerage Authority	87.701	4.162	Yes	103.643	310.021	413.664	549.551	1234.2	62,708

Figure D-6 AWWA Water Audit Compiler—Data sheet displaying an excerpt of data from the 2014 AWWA Water Audit Data Initiative

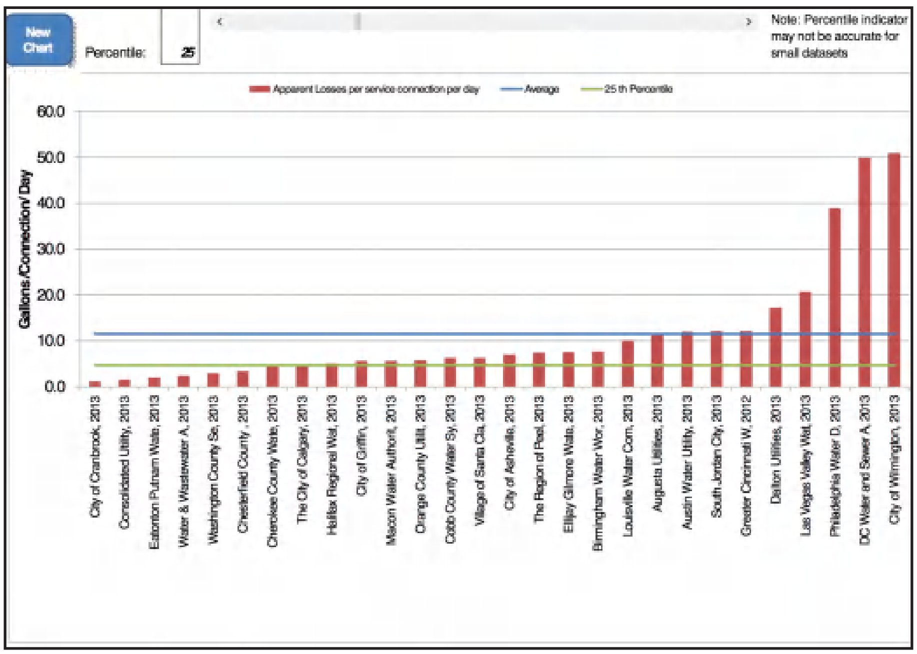


Figure D-7 AWWA Water Audit Compiler—Graph of the Apparent Losses Performance Indicator (Op23) for the 2014 AWWA Water Audit Data Initiative

Leakage Component Analysis Model, providing ongoing enhancements to these software tools based on user feedback and the developing needs of the North American drinking water industry.

The primary objective of these free software tools is to promote the use of best-practice industry standards for compiling the annual water audit, setting rational and cost-effective loss control strategies, and launching successful intervention programs. The drinking water industries in many countries can greatly benefit from having a consistent structure for water accountability. It is essential that standardized, rational auditing and reporting structures exist to identify the greatest areas of loss in a water system

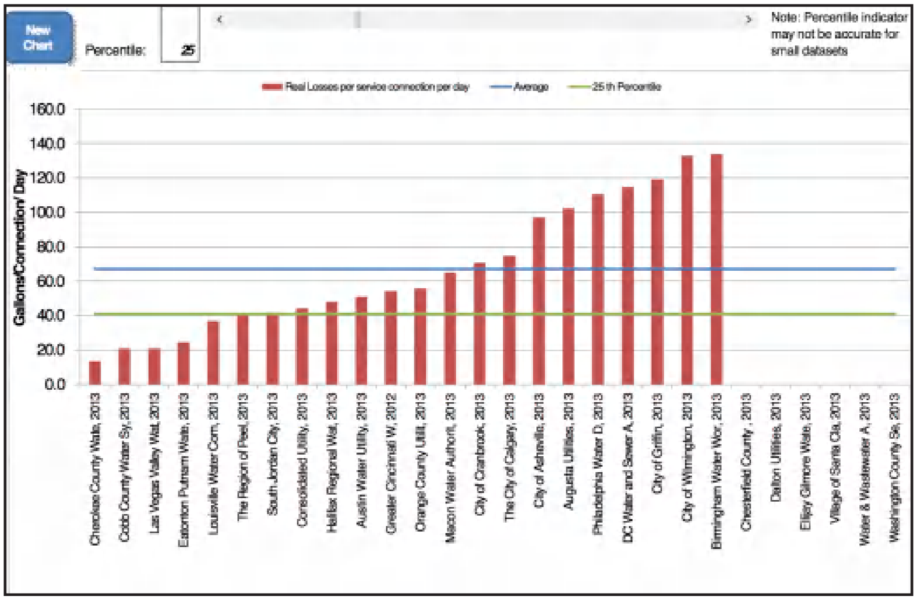


Figure D-8 AWWA Water Audit Compiler—Graph of the Real Losses Performance Indicator (Op24) for the 2014 Water Audit Data Initiative

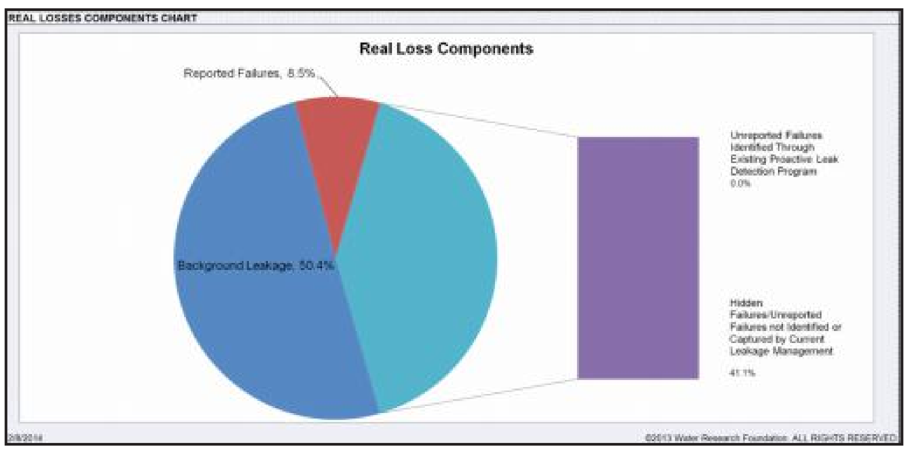


Figure D-9 Water Research Foundation Project 4372a, Leakage Component Analysis Model—Real Losses component chart

and strategically implement effective interventions to economically control losses. This AWWA Manual M36 and the tools described in this appendix give users all of the capabilities they need to achieve these goals.

REFERENCE

WRF (Water Research Foundation). 2014. *Real Loss Component Analysis: A Tool for Economic Water Loss Control*. Denver, Colo.: WRF.

Appendix E

Validated Water Audit Data Collection and Analysis

Since 2011, the AWWA Water Loss Control Committee (WLCC) has annually assembled validated water loss metrics from utilities in North America. This is an entirely voluntary effort on behalf of the participating utilities and the committee members and is referred to as the Water Audit Data Initiative (WADI). Additionally, with the increasing number of regulatory agencies in North America requiring the annual submission of an AWWA standard water audit, the volume of publicly available water audit data has been growing rapidly. One of the challenges, however, is that only a small fraction of this available data is systematically validated for quality control. Large amounts of water audit data are now collected annually by state and regional agencies (see chapter 2), but at the time of this writing, the water audit data from the State of Georgia are the only regulatory-mandated audits subject to the validation method developed and used by the AWWA WLCC. Both the State of Georgia program and the AWWA WADI use the AWWA Free Water Audit Software (Audit Software) to produce their validated datasets.

The AWWA validation method focuses primarily on the appropriateness of the gradings assigned to the data inputs of the Audit Software, which calculates the composite Data Validity Score (DVS) to assess the overall reliability of the water audit data. A secondary focus of the validation method is finding and correcting gross errors in the data inputs. The validation method uses a top-down approach, with water audit experts conducting interviews with representatives from the participating utility and reviewing available records where appropriate. Validation to date of the AWWA WADI and the State of Georgia water audits consider data inputs and gradings at a high level. These efforts typically do not extend to in-depth analysis of bottom-up activities such as source meter testing, customer meter testing, or detailed billing data analytics. As such, the validated water audit results presented herein are not guaranteed to be free of embedded data input errors. They are, however, confirmed to have a representative DVS, reflecting appropriately the reliability of each audit's results.

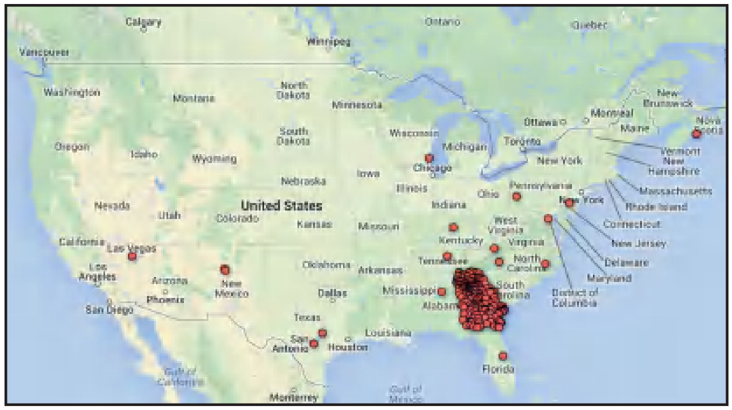


Figure E-1 Map of 2014 North American Dataset of participating water utilities

THE 2014 NORTH AMERICAN WATER AUDIT DATASET

The water audit data that is presented herein represents the most recently published validated results from Georgia Department of Natural Resources–Environmental Protection Division (2011) and WADI (AWWA 2013), and is referred to as the 2014 North American Dataset. A map of utilities included in this dataset is given in Figure E-1. DVSs for validated water audit results in the 2014 North American Dataset are shown in Figure E-2.

Several performance indicators of the 2014 North American Dataset have been assessed and are presented below. The Infrastructure Leakage Index (ILI) is a performance indicator designed for benchmarking of leakage standing among water utilities over a certain size, at a system's existing pressures (i.e., before pressure management). The lower the ILI value, the closer the utility's leakage volume is to its unavoidable annual real losses volume. The ILI data from the 2014 North American Dataset are presented in Figures E-3 and E-4. Figure E-3 gives a histogram of the ranges of ILI values of the dataset. Figure E-4 plots the ILI against the respective value of the normalized real loss (Op24) performance indicator, which reflects real (leakage) losses expressed in gallons per service connection per day. Other performance indicators and cost data are presented in subsequent figures.

While the ILI is used in the "County Water Company—Preliminary Leakage Loss Reduction Target-Setting Analysis" sidebar in chapter 7 to establish an initial leakage reduction target range and develop an initial budget justification, leakage target-setting established in this manner should be considered preliminary and should be refined by a more comprehensive economic analysis to determine a utility's economic level of leakage. The Leakage Component Analysis Model (LCA Model), which is also discussed in chapter 7, is a more rigorous means for leakage target-setting and defining cost-effective strategies for leakage control. Additional research is needed to better refine the leakage management target-setting methodology in a user-friendly manner. Figure E-4 does not reveal a discernible trend between the ILI and the Op24 indicators for the dataset, and further assessments are needed to better understand trends in loss control among the dataset utilities. The Op24 is a solid performance indicator for water utilities to use to track their progress in leakage control from year to year. The existence of validated water audit datasets is relatively new, and further analytic assessments of the data and performance indicators will be conducted and should lead to a better understanding of the loss control assessments in water utilities.

Figures E-5 and E-6 display a graph of the normalized performance indicators for apparent losses (Op23) and real losses (Op24), respectively, for the 2014 North American Dataset. Both of these performance indicators are useful for tracking performance in loss control within the water utility. For water utilities with a low density of customer service

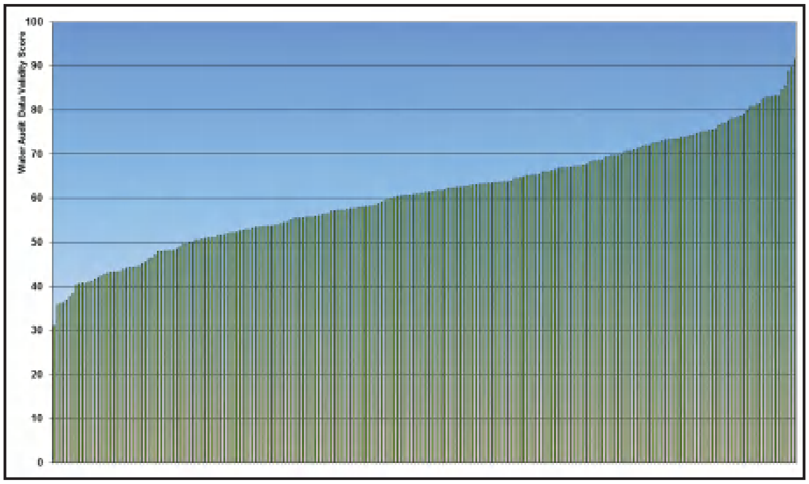


Figure E-2 Data Validity Scores of the 2014 North American Dataset

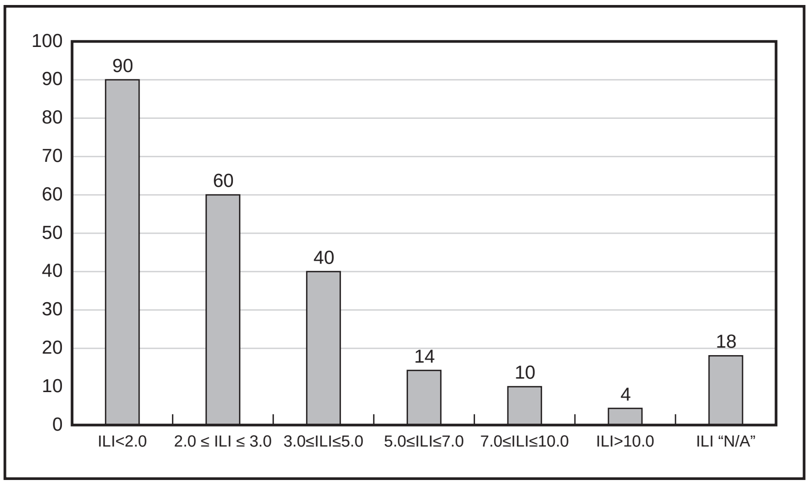


Figure E-3 ILI histogram of the 2014 North American Dataset

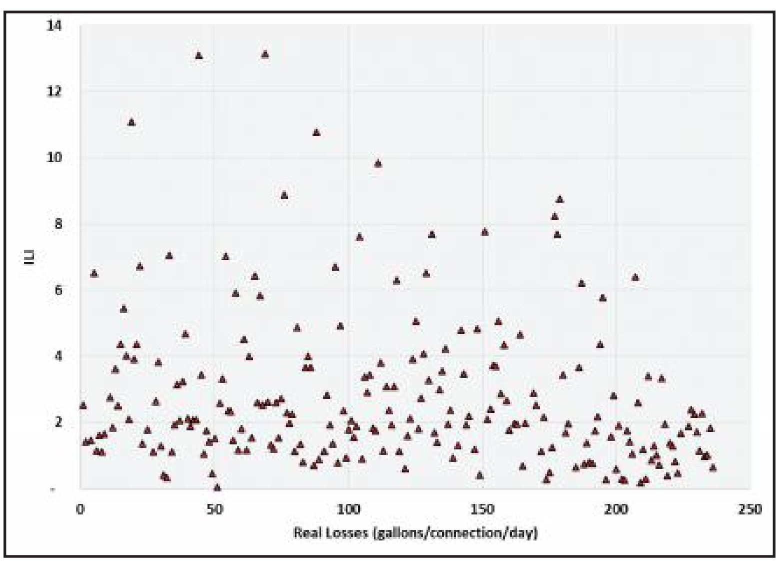


Figure E-4 ILI vs. real losses for the 2014 North American Dataset

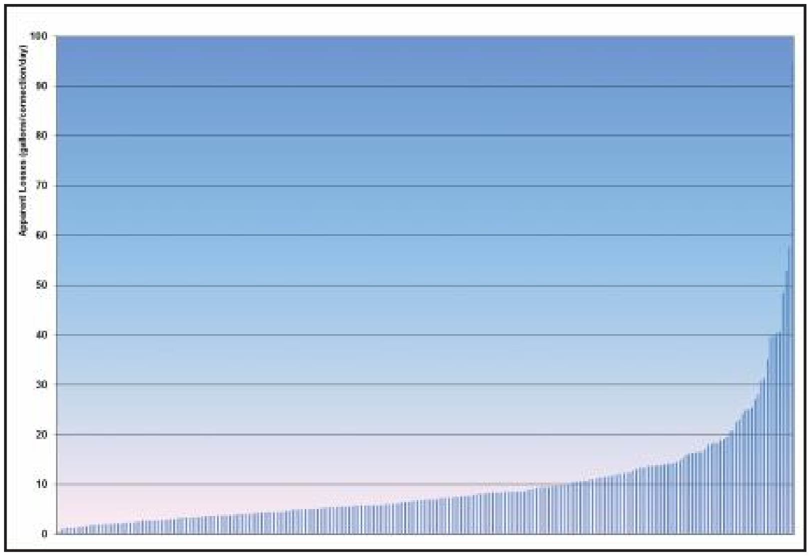
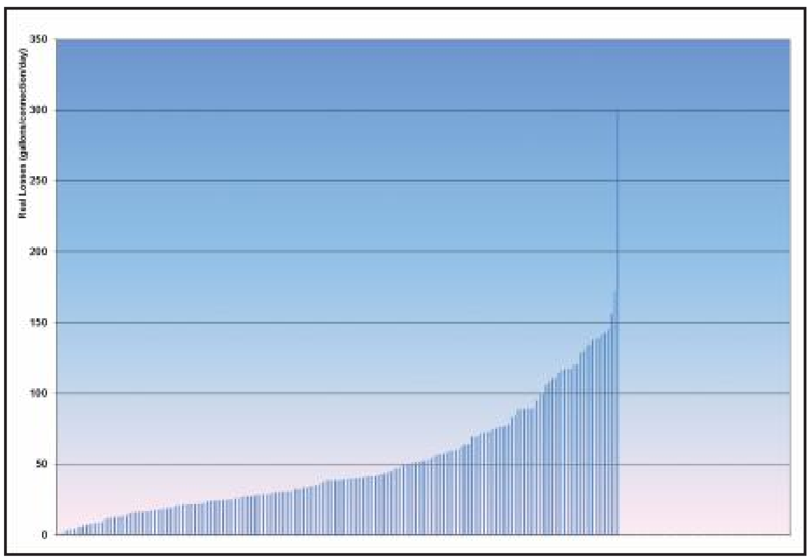


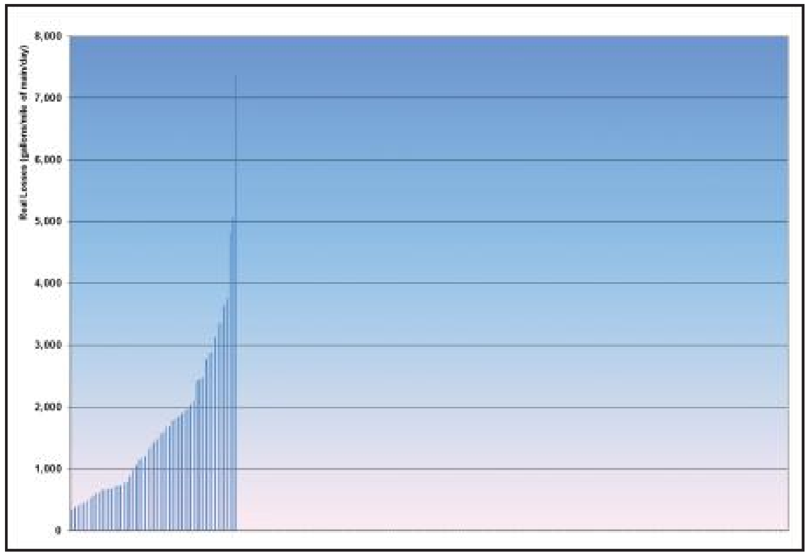
Figure E-5 Apparent losses for the 2014 North American Dataset



Note: Performance indicator calculates only for utilities with a connection density ≥32 connections per mile.

Figure E-6 Real losses for the 2014 North American Dataset

connections (less than 32 connections per mile of pipeline), the Op24 performance indicator is expressed in units of gallons per mile of pipeline per day. The graph of these values for low-density utilities is shown in Figure E-7. The trend of Op23 and Op24 performance indicators in Figures E-5 through E-7 shows a steady variability of values across the dataset of more than 200 water utilities. Apparent loss rates range from notably low to notably high levels. Analysis of this data to date has been limited, and additional analysis will likely be conducted in the future to better define any discernible trends in the data. For instance, the dataset might be segregated by cohorts of system size to determine whether the performance indicator ranges vary with the size of the system. Systems might also be segregated and analyzed based on geographical or climatic regions. Having a large pool



Note: Performance indicator calculates only for utilities with a connection density <32 connections per mile.

Figure E-7 Real losses for the 2014 North American Dataset

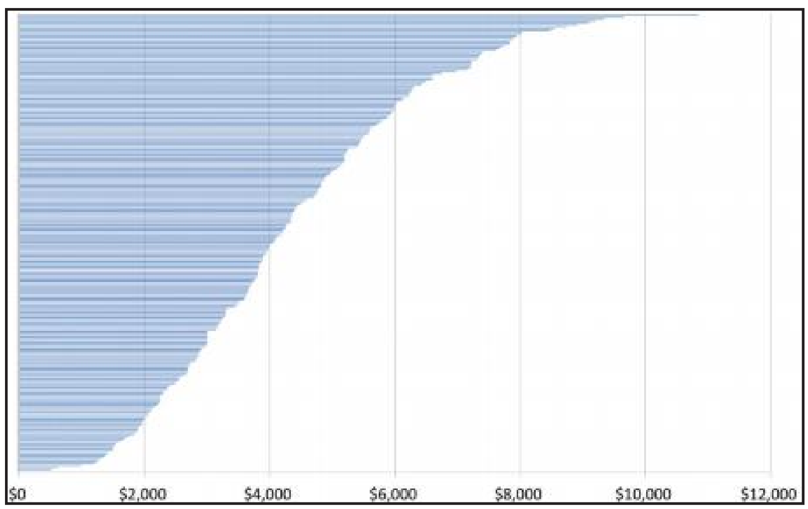


Figure E-8 Customer retail unit costs ($/mil gal) for the 2014 North American Dataset

of validated water audit data opens the door to many assessments that could not be previously executed on a reliable basis.

Figures E-8 and E-9 present cost data from the 2014 North American Dataset. Setting loss control strategies is highly dependent on the cost of water, and both variable production costs and customer retail costs come into play in this endeavor. Apparent losses are valued at the customer retail cost, as water lost at the customer endpoint means uncaptured revenue at the retail rate.

Figure E-8 shows a very wide range of values of customer retail cost, with some systems over $8,000 per million gallons and others less than $1,000 per million gallons. Utilities with very high customer retail costs might define a very stringent apparent loss target since even small volumes of apparent loss can result in significant uncaptured revenue. Utilities with lower customer retail costs may be able to tolerate a notably higher volume of apparent loss since less impact to revenue is encountered.

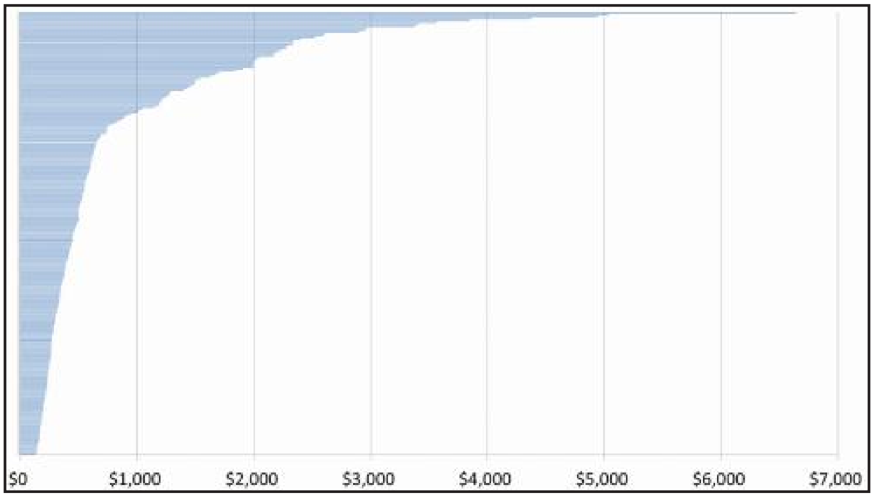


Figure E-9 Variable production (or import) cost ($/mil gal) for the 2014 North American Dataset

Similarly, Figure E-9 shows a very wide range of values of variable production cost, which is typically applied to value leakage. (Note: If water resources are constrained, the customer retail cost should be applied to leakage since water recovered from leakage control can be sold to current or new customers.) In general, water utilities with high variable production costs are motivated to set stringent leakage targets, while those with lower variable production costs can tolerate higher leakage levels. The LCA Model detailed in chapter 7 takes into account the variable production costs as well as leakage levels to set a cost-effective leakage reduction strategy.

Additional analysis of cost data will be conducted in the future. For example, water audit data can be segregated and analyzed based on cohorts of system size, geographic/climatic regions, and/or water resource availability.

Non-revenue water (NRW) volume as a percentage of water supplied and NRW cost as a percentage of cost of operating the water system are two indicators that are presented in the AWWA Free Water Audit Software. NRW volume as a percentage of water supplied tends to be a significantly higher percentage than NRW cost as a percentage of water system operating cost. However, it should be noted that these percentage figures are included in the AWWA Free Water Audit Software as high-level performance indicators only for general reference. Percentage indicators such as these should *not* be utilized for detailed assessments such as benchmarking comparisons between utilities or target-setting within a utility. As such, water loss and NRW metrics as a percentage of water supplied and cost of operating the water system have been *purposefully omitted* from this appendix. The use of percentages as a detailed performance indicator was formally abandoned by AWWA in 2003, as they do not provide a reliable indication of performance over time due to the variable nature of the calculation and its sensitivity to variation in customer consumption.

UTILITY PRACTICES SURVEY RESULTS FROM THE 2013 WADI

Another aspect of the WADI has been the collection of operational data from participating utilities through a Utility Practices Survey. This data is pertinent to water loss management and includes policies and practices related to source metering, customer metering, leak detection, and pressure management, among others. Presented in Figures E-10 through E-17 are selected results from the most recently completed survey efforts (2013, n=27).

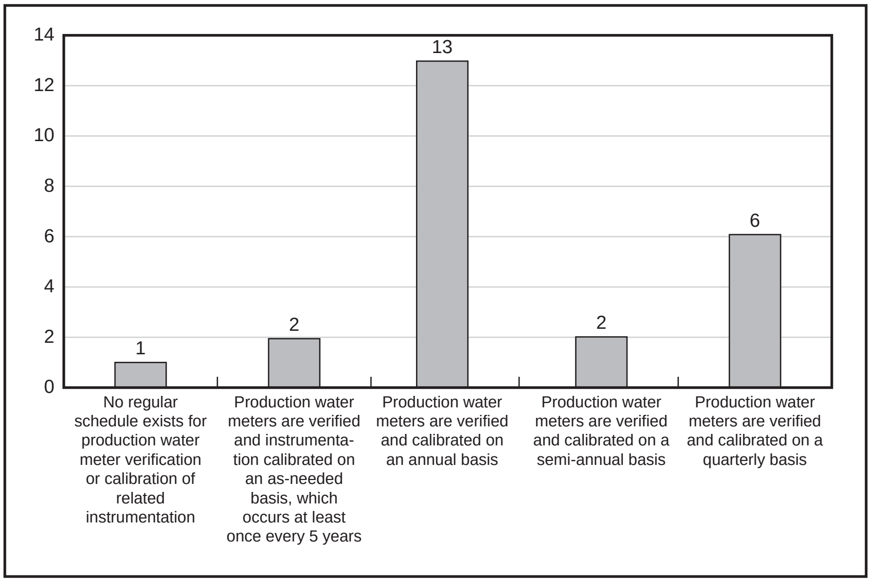


Figure E-10 Number of water utilities practicing production meter verification (accuracy testing)

Source: AWWA 2013

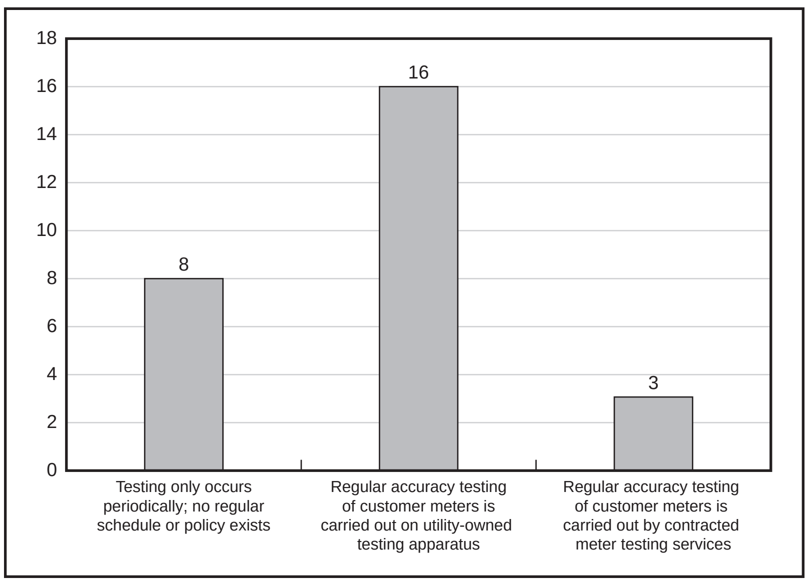


Figure E-11 Number of water utilities practicing customer meter accuracy testing

Source: AWWA 2013

SUMMARY

The 2014 North American Dataset is the first compilation of validated water audit data to serve as a foundation for water loss performance benchmarking by North American water systems. It should be noted, however, that the dataset at the time of this writing is still a relatively small population of validated water audits. While interesting relationships are emerging, considerably more validated water audit data and analytic work is needed to establish meaningful water benchmarks. Nevertheless, the value and impact of the powerful

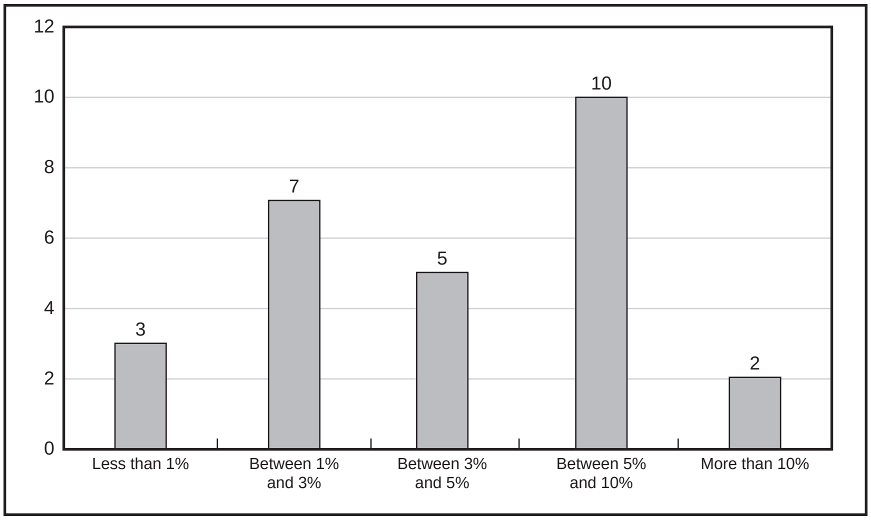


Figure E-12 Number of utilities practicing regular customer meter replacement showing percentage of meter population replaced annually

Source: AWWA 2013

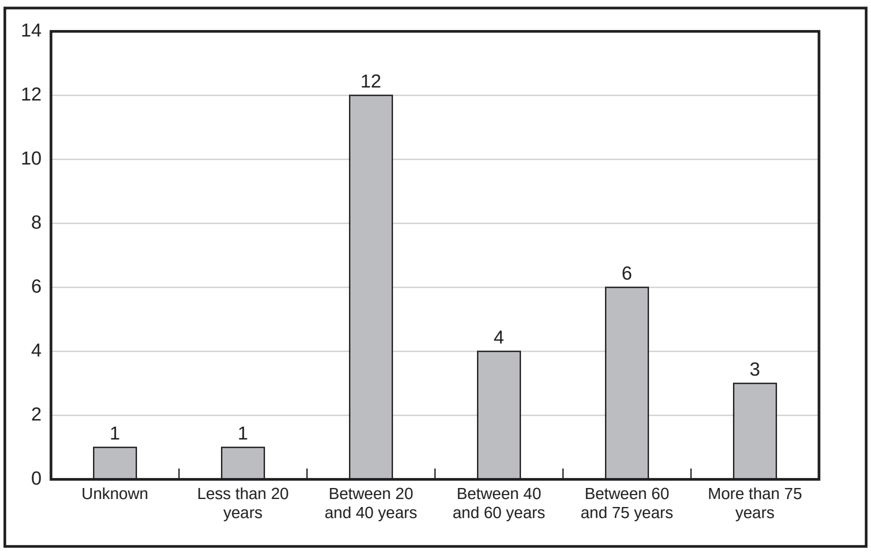


Figure E-13 Number of utilities in groupings of average age of water distribution system piping

Source: AWWA 2013

assessments of validated water audit data described in this appendix are significant and hold strong promise for the future of water loss control. As the North American water industry continues to expand its adoption of best practices for water auditing and loss control, improved insight will be gained about the nature and extent of water losses in water utilities and the best means to control losses to economic levels in individual water utilities.

A final word regarding benchmarking: It is a natural tendency to compare one utility's performance against the industry at large. However, in the field of water loss control, this is only meaningful once a robust level of validity has been achieved in the water audit data. And even then, the most meaningful comparison remains to be the comparison of one's own performance over time toward economically appropriate targets on a system-specific basis.

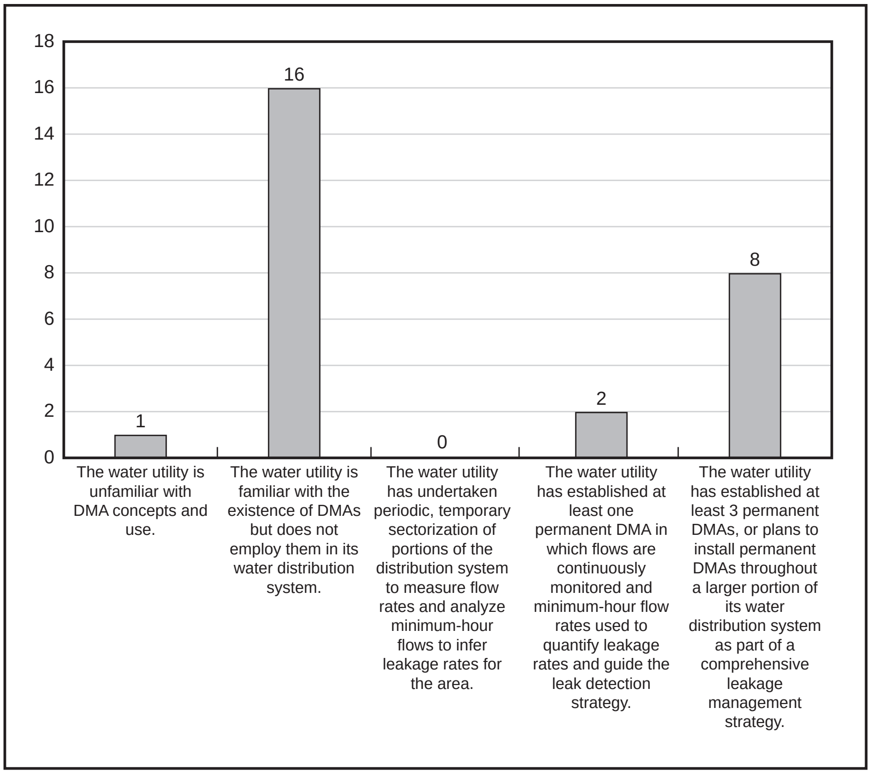


Figure E-14 Number of utilities in groupings of deployment of district metered areas for leakage monitoring and control

Source: AWWA 2013

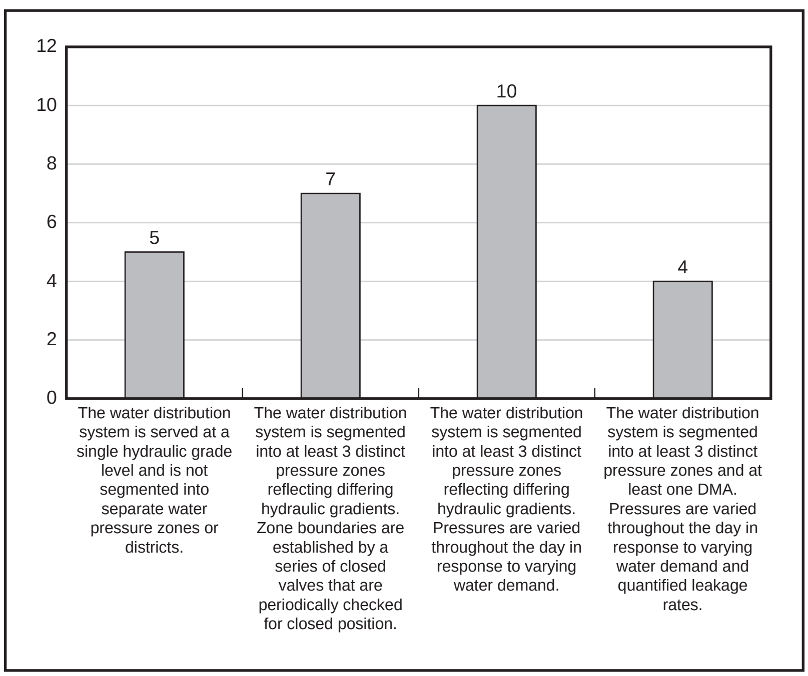


Figure E-15 Number of utilities in groupings of deployment of pressure management schemes for leakage monitoring and control

Source: AWWA 2013

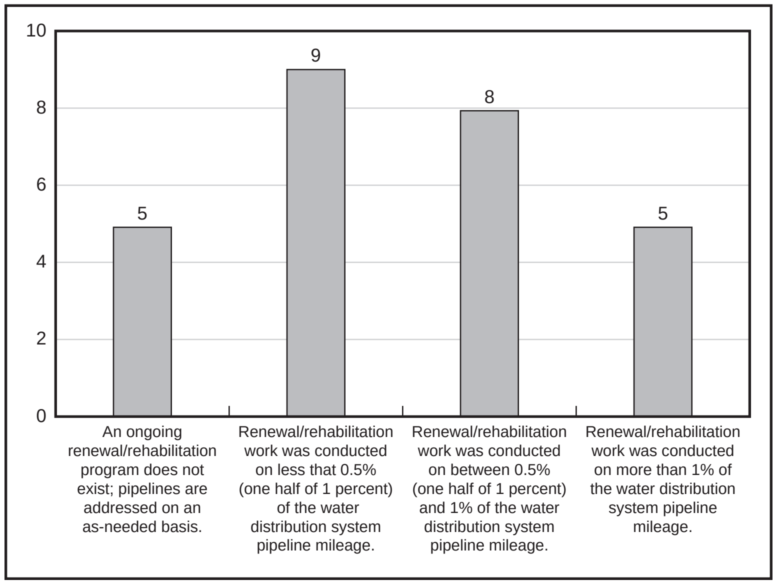


Figure E-16 Number of utilities in groupings based on the state of water distribution piping renewal

Source: AWWA 2013

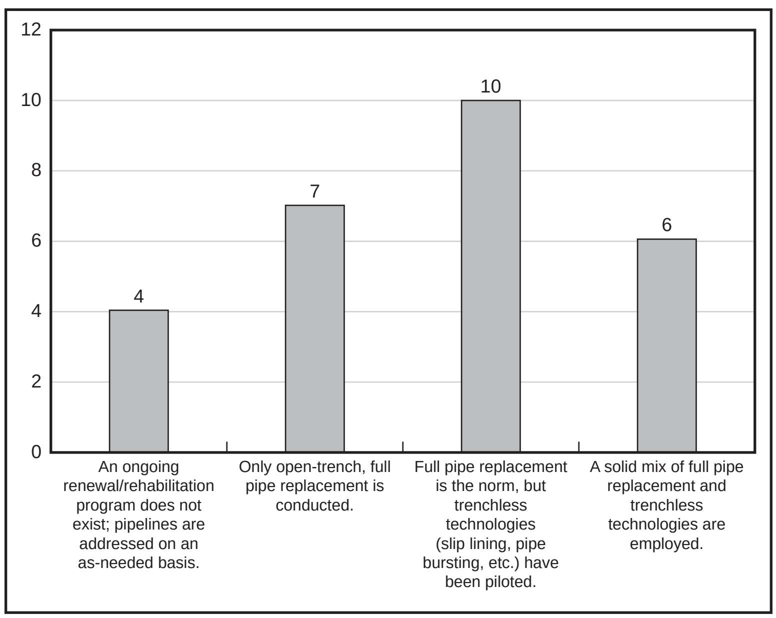


Figure E-17 Number of utilities in groupings based on the use of various water distribution piping renewal technologies

Source: AWWA 2013

REFERENCES

AWWA (American Water Works Association). 2013. Water Audit Data Initiative. Denver, Colo.: AWWA.

Georgia Department of Natural Resources–Environmental Protection Division. 2011. Validated Water Audit Data. https://epd.georgia.gov/water-loss-audits-results.

Glossary

active leakage control A proactive policy and program that a water utility implements to control unreported leaks in water distribution systems. Active leakage control includes regular soundings of the system to detect leak noise sounds. Leak noise monitors can be deployed to routinely record leak noise in a given area during optimum times for listening. Permanent flow monitoring to infer leakage rates can be established by creating district metered areas. (See *district metered area, leak noise monitor, passive leakage control, rate of rise of unreported leakage, and unreported leaks*.)

agricultural water consumption Water consumed in activities such as farming, operation of nurseries, and husbandry. In the United States, agriculture accounts for the largest portion of all freshwater withdrawals, although not all of this water is treated and distributed by water utilities.

apparent losses Losses in customer consumption attributed to inaccuracies associated with customer metering, systematic data handling errors, plus unauthorized consumption (theft or illegal use of water). Apparent losses represent nonphysical (paper) losses that result in uncaptured revenue for the water utility and distortion of customer consumption data (see *water audit* and *water balance*).

authorized consumption The volume of water taken by registered customers, the water supplier, and others who are implicitly or explicitly authorized to do so by the water supplier for residential, commercial, industrial, or agricultural purposes. In the AWWA Free Water Audit Software, this category of components does *not* include water supplied to neighboring water utilities (water exported), which is instead included in the *Water Supplied volume* component. Authorized consumption does include water consumed in such activities as fire fighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water, and so forth. Authorized consumption may be billed or unbilled, metered or unmetered (see *water audit* and *water balance*).

automatic meter reading (AMR) and ***advanced metering infrastructure*** (AMI) The electronic reading of customers' water meters and transfer of the data to a central location. These systems feature a meter interface unit, or meter reading device, attached to the water meter to read the meter and electronically transmit the data to a collection device. In the AMR environment, readings are typically collected by handheld devices used by meter reading personnel in the field, or by a mobile read system (located in vehicles traveling past the customer premises on a routine schedule). In the AMI environment, a permanent or fixed communication network (fixed or cellular-based network) is installed and meter readings are transmitted across the system on a schedule, or on demand, without dispatching personnel to the customer location. With AMI, meter readings can be gathered as frequently as every hour, thereby allowing customer consumption profiles to be created from the data. Also, two-way communications available in AMI allow signals to be transmitted from the central location to activate customer end-point devices such as an automatic shutoff valve. AMR/AMI technology has greatly expanded the technical capabilities around customer data and end-point management and has greatly reduced human error associated with visual manual meter reading.

average operating pressure In the distribution system, a value that is used as an input in the standard water audit. Average operating pressure is usually estimated through hydraulic model analysis of a distribution system under average daily demand conditions. When calculated using a hydraulic model, the pressure at every node or junction in the model is summed and divided by the total number of nodes or junctions to determine the average operating pressure. An alternative approach might be to use the average pressure in each pipe segment. It is up to the judgment of the modeler to determine the most appropriate approach to use to arrive at the final value. Other methods can be used to quantify the average operating pressure; thus, a hydraulic model is not essential to obtain this value.

average zone point (AZP) The pressure in a discrete zone or pressure managed area that is calculated or measured at a surrogate point and deemed to be the average of all the pressures in the area (see also *pressure managed area*).

awareness, location, and repair (ALR) The distinct time periods associated with response to a water distribution system failure (break or leak) broken into separate components, each of which should be measured and reported to conduct a leakage component analysis (see *bursts and background estimates [BABE] model*).

background losses Individual water loss events (small leaks and weeps at pipe joints) that will continue to flow, with flow rates too low to be detected by traditional sonic leak detection methods of an active leakage control program. They can be detected either by chance or when they gradually worsen to the point that they are detected acoustically, become disruptive, and are detected as reported leaks. Background leakage is sensitive to pressure levels and is often prevalent in water distribution systems with infrastructure in poor condition (see *pressure management*).

billed authorized consumption All water consumption that is billed and authorized by the water utility. This includes both metered and unmetered consumption. In the AWWA Free Water Audit Software, this component does not include water supplied to neighboring water utilities (water exported), which is instead included as the *Water Exported volume* used in the calculation of the *Water Supplied volume*.

billed metered consumption The part of billed authorized consumption that is metered and billed to retail customers, including all groups of customers such as domestic, commercial, industrial, or institutional. In the AWWA Free Water Audit Software, this component does not include water supplied to neighboring water utilities (water exported) which is metered and billed. The *Water Exported volume* is instead included in the *Water Supplied volume*.

billed unmetered consumption The part of billed authorized consumption volumes that are calculated based on estimates or norms from water usage sites that have been determined by utility policy to be left unmetered. In the AWWA Free Water Audit Software, this component does not include water supplied to neighboring water utilities (water exported) that is unmetered and billed. The *Water Exported volume* is instead included in the *Water Supplied volume*.

bottom-up water audit approach This approach involves the use of detailed investigations into individual loss components to describe the nature of the occurrence of the loss and accurately quantify the loss volume and cost impact. An example of a bottom-up approach for real losses is the analysis of minimum-hour flows in district metered areas to distinguish leakage from customer consumption. An example of a bottom-up approach for apparent losses is replacing a representative sample of customer meters and performing meter accuracy testing, the results of which can infer the degree of accuracy for the customer meter population. Because this approach investigates individual loss components in considerable detail, it is more costly and time-consuming than the top-down approach, but it provides highly accurate data to the water audit, greatly improving its effectiveness in gauging water loss standing and planning loss control activities (see *top-down water audit approach*).

break In most of North America, refers to a significant rupture in a pressurized pipeline that typically results in visible, disruptive aboveground water, frequently causing street or ground cover damage and interrupting vehicular traffic. Water main breaks may be better classified under the term *reported leaks*. Also referred to as *bursts* (see also *leakage management*).

bursts and background estimates (BABE) model A model used to assess leakage management practices. Published by Lambert in 1994, this was the first "component analysis" approach to model leakage components objectively, rather than empirically, thus permitting rational planning, management, and operational strategies for leakage reduction. The model segregates leakage events into separate awareness, location, and repair time periods and evaluates utility policies and response in each of the three leakage components—background losses, reported leaks, and unreported leaks. This approach is applied in the formulation of the unavoidable annual real losses calculation.

calibrate A procedure used to verify, and adjust as needed, the accuracy of a metering device or instrument. Production flowmeters should be regularly flow tested for accuracy, and their related instruments, or secondary devices, should be calibrated regularly.

commercial water consumption Potable water delivered to business customers. This is typically a higher rate of consumption than residential consumption, but less than industrial or agricultural consumption.

control The ability to monitor, regulate, or secure a process such as water treatment or water distribution via the use of data gathering, assessment, and supervision equipment. A control process can be established by using manual controls, such as an operator opening a valve, or by using automatic controls, such as a pressure-regulating valve that internally maintains downstream water pressure in a pipeline at a desired level. Use of a fully automatic control process is referred to as *closed loop* control, while a process that includes any part of manual controls is referred to as an *open loop* control process.

critical point (CP) The critical pressure point is the location in a zone or pressure managed area of the water distribution system with the lowest pressure caused by topography and/or hydraulic losses through the distribution system. It is critical to ensure that adequate pressures are maintained at this point when introducing pressure management.

current annual real losses (CARL) The volume of water lost from reported leaks, unreported leaks, background losses, and storage tank overflows during the water audit reporting period. The ratio of the CARL to the unavoidable annual real losses is the Infrastructure Leakage Index (see *Infrastructure Leakage Index* and *unavoidable annual real losses*).

customer metering inaccuracies Apparent losses caused by the collective under-registration or malfunction of customer water meters. Customer metering inaccuracies are a major component of apparent losses. Meter inaccuracy can occur as a result of meter wear, improper sizing or type of meter for the customer usage, or improper installation, aggressive water quality, malfunction, and other causes. Well-functioning mechanical meters will wear as volumes of water are passed through them over time, eventually under-registering the flow (see also *under-registration*).

customer retail unit cost Represents the charge that customers pay for water service. The unit cost is applied routinely to the components of apparent loss, because these losses represent water reaching customers but not (fully) paid for.

Data Validity Score (DVS) A measure of the overall trustworthiness of data entered in the AWWA Free Water Audit Software (Audit Software). This score can be assessed by the Water Loss Control Planning Guide worksheet in the Audit Software, which provides five groupings based on ranges of scores from low validity (questionable data integrity) to high validity (reliable data integrity). The DVS is a composite value calculated from Data Grading values (ratings from 1 to 10) of data integrity entered by the water auditor for each input component. The Audit Software gives detailed guidance in the Grading Matrix worksheet on the criteria to use in selecting the appropriate data grading for each input of the water audit. The DVS represents the validity of the water audit data and is a reflection of the level of best practices employed by the water utility.

demand The amount of water needed for delivery to sustain adequate flow and pressure levels in a certain time interval in a water distribution system. Components of demand include authorized consumption by customers or others permitted by the water utility to use water, real (leakage) losses, fire flow demands, and unauthorized consumption.

demand costs The costs associated with the facilities operated to meet incremental demands for water delivery, such as maximum-day, minimum-hour, or other rates.

demand management Strategic practices that optimize water supply, treatment, and delivery requirements to support long-term sustainability of water resources. Demand management measures include water conservation practices (low-flow plumbing fixtures, water-efficient landscaping), minimizing water waste and loss (leakage management), conservation-oriented pricing, changes in finished water consumption practices (using recycled water for irrigation), and public education. Some demand management measures can be implemented by consumers on their own, whereas others are implemented through utility-sponsored programs.

district metered area (DMA) A hydraulically discrete part of a water distribution system, with water supplied by one or more open supply mains that are metered and closely monitored on a permanent basis. Analysis of flows during minimum consumption periods (night flow analysis) is used to distinguish estimates of legitimate consumption from leakage occurring in the DMA. Data from DMAs can assist more reliable quantification of leakage volumes during the leakage component analysis.

domestic consumption Water consumption by the general population consumed in dwelling units (residential consumption).

economic level of apparent losses (ELAL) The level found by determining the level (volume) of apparent losses at which the sum of the cost of the apparent loss reduction actions (meter replacement, theft control, etc.) and the cost of lost revenue caused by apparent losses is at a minimum. Reducing apparent losses below the ELAL is not cost-effective because the cost of the loss abatement activities exceeds the value of water saved. ELAL is a concept that can be used for apparent loss reduction target-setting.

economic level of leakage (ELL) The level found by determining the level (volume) of real (leakage) losses at which the sum of the cost of the real loss reduction and the cost impact of the real losses is at a minimum. Reducing leakage levels below the ELL is not cost-effective because the cost of the leak abatement activities exceeds the value of water saved. ELL is used for leakage reduction target-setting and setting the frequency of leak survey investigations.

failure A general term used in the Leakage Component Analysis Model (LCA Model) of the Water Research Foundation project titled *Real Loss Component Analysis: A Tool for Economic Water Loss Control* (WRF 2014) to encompass the often-used terms *breaks* and *leaks* collectively. Since many water utilities have their own definitions of breaks and leaks, it is often difficult to make like comparisons among the data of different utilities. The LCA Model refers to the word *failure* to alert the user that he or she should be tracking data on both breaks and leaks, categorizing the data according to the model's requirements, and then using the model to conduct a rational leakage component analysis.

fixed and variable area discharge path (FAVAD) model A concept used to assess the relationship between pressure and discharges (leakage and consumption) from pressurized water pipes. Losses from fixed area leakage paths (cracks in metal pipe) vary according to the square root of the system pressure during the leak, while discharges from variable area paths (splits in plastic pipe that expand with increasing pressure, and background losses) vary according to pressure raised to the power of 1.5. Because there will be a mixture of fixed and variable area leaks in any distribution system, loss rates vary with pressure raised to a power that normally lies between the limits of 0.5 and 1.5. The simplest version of the FAVAD model, suitable for most practical predictions, is

leakage rate L (volume/unit time) varies with pressure P^{N1} or $L_1/L_0 = (P_1/P_0)^{N1}$

The higher the N1 exponent, the more sensitive existing leakage flow rates are to changes in pressure. The FAVAD concepts allow accurate forecasting of the increase or decrease of leakage loss rates in a pipe system caused by changes in operating pressure. The development of this model is the foundation for pressure management applications that are very economical in reducing leakage, particularly background losses, and slowing water main break rates under appropriate conditions (see *pressure management* and *step testing*).

flow test A test conducted to determine the volume of water available from the distribution system at a location of one or more particular fire hydrants; typically performed to quantify fire-fighting capability. In conducting the test, one or more fire hydrants are opened and flow rates measured. Drops in nearby water pressure are also measured. These data are input into standard calculations to determine the amount of water that can be expected at various pressures. Also known as a *fire flow test*.

geographic information system (GIS) A system that stores and links nongraphic attributes and geographically referenced data with graphic map features to allow a wide range of information processing and display operations, as well as map production, analysis, and modeling.

granularity A gauge of the units of consumption used in customer metering and billing systems. Data based on more frequent readings (monthly vs. quarterly) and smaller units of consumption (gallons vs. cubic feet) are considered more granular and usually more accurate for water loss control purposes.

hydrant Pitot gauge A simple device used to measure the velocity of a stream of water flowing from a fire hydrant, which can be input into an equation to calculate the flow rate. This device is often used in conducting fire flow tests. Also known as a *Pitot blade*.

industrial water consumption Water consumed in industrial activities such as power generation, steel manufacturing, pulp and paper processing, and food processing. These uses are typically the highest volume customers served by a water utility.

infrastructure condition factor (ICF) The ratio between the actual level (volume) of background leakage in a zone or district metered area and the calculated unavoidable background leakage volume of a well-maintained system. Several methods can be used to quantify the ICF. The more accurate methods require a greater data collection effort to calculate the ICF.

Infrastructure Leakage Index (ILI) A performance indicator quantifying how well a distribution system is managed (maintained, repaired, rehabilitated) for the control of real (leakage) losses at the current operating pressure. Mathematically, it is the ratio of current annual real losses (CARL) to unavoidable annual real losses (UARL), or ILI = CARL/UARL. A low ILI value indicates that the water utility has managed its leakage down toward the UARL, or the theoretical low limit of leakage technically achievable. As a dimensionless indicator, ILI is a leading benchmarking leakage performance indicator used in international performance comparisons (see also *current annual real losses* and *unavoidable annual real losses*).

leak noise monitor A device that measures sound characteristics of leak noise frequencies that can be deployed strategically in the distribution system. There are two types of leak noise monitors. Leak noise loggers store data that can be retrieved when the unit is interrogated, and leak noise transmitters transmit some or all of the data on a regular basis to a distant central location, usually the distribution office. The latter type uses fixed-network automatic meter reading systems or advanced metering infrastructure to send information.

leakage The water escaping from the pressurized distribution system caused by defects, ruptures, or failures in piping and pipe joints. Leaks are classified as reported leaks (visible, disruptive leakage), unreported leakage (leakage running sight unseen), and background leakage (small leakage not detectable by sonic methods) (see also *real losses*).

leakage component analysis A means to analyze the occurrence of leakage in water distribution systems. This analysis typically assesses leakage events in their three component phases—the awareness period, the location period, and the repair period.

This analysis is conducted for all three types of leakage—background leakage, unreported leakage, and reported leakage. While most often employed to assess leakage, a component analysis approach can also be employed to assess the individual components of apparent losses (see *bursts and background estimates [BABE] model* and *awareness, location, and repair*).

leakage management The collective activities that provide water utilities with the capabilities to economically minimize real losses. Specifically, it includes the capability to detect, quantify, and abate or minimize water distribution system leakage. It also provides insight into the means for preventing new leaks from occurring. Activities include leak detection surveys, use of district metered areas and minimum-hour (night flow) analysis, pressure management, system rehabilitation, and effective repair policies.

meter An instrument, mechanical or electrical, used for recording (in cubic feet, gallons, or cubic metres) the quantity of water passing through a particular pipeline or outlet.

minimum-hour flow The amount of water flowing into a discrete zone or district metered area during a 60-minute period of lowest demand, which may occur at any time of day, not necessarily at night. In drier regions, the use of nighttime irrigation systems often results in high night flows that are not suitable for leakage assessments. The analyst can identify the minimum-hour consumption and perform the analysis during this period. In such cases, this analysis is best conducted during the winter season when nighttime irrigation use is curtailed (see also *night flow analysis* and *minimum night flow*).

minimum night flow The amount of water flowing into a discrete zone or district metered area (DMA) during the period of lowest demand, typically between the hours of 2:00 a.m. and 4:00 a.m. In many nonindustrial areas, legitimate consumption is at the lowest proportion, and leakage is at the highest proportion, of the total flow during these hours. Minimum night flow is one of several parameters assessed in a small zone or DMA via night flow analysis to quantify amounts of existing leakage. Areas with continuously operating industries and those with widespread night irrigation systems may actually experience high flows at night. In these cases, the minimum-hour period of consumption should be assessed by taking industrial flows into account, or rescheduling assessments for seasons when nighttime irrigation systems are not in use (see also *night flow analysis* and *minimum-hour flow*).

night flow analysis A technique used to quantify leakage in a discrete zone of the water distribution system. In many water utilities, the minimum consumption occurs during night hours. By measuring flows into such a zone, less any change in storage volume if any storage facilities exist in the zone, the minimum night flow can be observed, usually occurring between 2:00 a.m. and 4:00 a.m. when legitimate water consumption is at a minimum and leakage is at the greatest proportion of the total flow. By accounting for legitimate night consumption by customers (any residential consumption, 24-hour industrial consumption, nighttime irrigation systems), night flow analysis distinguishes legitimate consumption from system leakage. By continuously monitoring discrete zone leakage, trends can be observed and leakage quantities gathered to assist the leakage component analysis (see *minimum night flow* and *minimum-hour flow*).

non-revenue water (NRW) Those components of system input volume that are not billed and produce no revenue. NRW equals unbilled authorized consumption plus apparent and real losses.

over-registration A condition in which a meter records more water than is actually flowing through the meter.

passive leakage control A reactive policy and program in which no systematic attempt is made by a water utility to be aware of, locate, or repair unreported leaks. With such a policy, only reported leaks and breaks are repaired, and unreported leakage losses mount over time (see also *reported leaks*, *unreported leaks*, and *rate of rise of unreported leakage*).

pressure managed area (PMA) Part of a district metered area (DMA), or the whole DMA, that is subject to pressure management.

pressure management A generally effective method for optimizing pressures in a water distribution system to minimize losses and surge impacts while maintaining adequate water service, including fire-fighting flows. Under appropriate conditions, pressure management is particularly effective in minimizing background losses. Pressure management is also recognized as a valuable strategy to inhibit new breaks or bursts from occurring, thereby better sustaining the life of the water distribution system infrastructure (see *fixed and variable area discharge path [FAVAD] model* and *step testing*).

pressure-reducing valve (PRV) A flow valve used to allow water to flow from a higher-pressure zone to a lower-pressure zone so as not to exceed a set maximum pressure in the lower-pressure plane. A PRV may be outfitted with a variety of settings, features, and controllers enabling it to provide a wide range of pressure management capabilities.

rate of rise of unreported leakage The rate at which leakage increases with time under a policy of passive leakage control at a specified average system pressure, or the rate at which leakage increases with time between periods of active leakage control interventions, such as leak detection surveys, at a specified average system pressure. The rate of rise is not necessarily linear, as it can change quickly because of seasonally changing temperatures and other impacts. This can be assessed from water balances in successive years (in the case of passive leakage control) or by analysis of night flows and/or repair records (in the case of active leakage control). It is usually expressed in volume per day in a year, or a volume per service connection per day in a year, or a volume per mile of mains per day in a year.

real losses The physical water losses from the pressurized system and the utility's storage tanks, up to the point of customer consumption, which is the customer meter in those utilities that meter their customers. In unmetered systems, the delineation is the point at which the customer is responsible for customer service connection piping maintenance and repairs. Real losses include leakage from mains and service connections (the largest component by volume for most systems), and storage tank overflows (see *water audit* and *water balance*).

reported leaks Those leakage events that are brought to the attention of the water utility by its employees (outside of a specific leak detection survey), the general public, or other parties as a result of water showing on the ground surface or other visible places, or of consumer complaints such as poor pressure or noise in plumbing systems. A break or leak that surfaces at the street or ground surface is most often reported to the water utility because it carries the potential for disruption. Water utilities tend to respond quickly to reported leaks and breaks because they represent a loss of water, a potential cause of damage to neighboring infrastructure and private property, and a disruption to the community that can have a negative impact on public perception of water utility efficiency. Where supervisory control and data acquisition (SCADA) systems exist, if some individual main breaks (depending on the size of the zone) are identified by SCADA and prompt action is taken to locate and repair them, such events should be classified as *reported* rather than *unreported*. Leak location efforts may still be required for pinpointing reported leaks.

revenue water The portion of authorized consumption that is billed and produces revenue, including billed metered consumption and billed unmetered consumption.

service connection The pipe connecting the water main to the measurement (customer metering) point or the customer curb stop, as applicable, and supplying water to a customer's premises. Where several registered customers or individually occupied premises share a physical connection, such as apartment buildings, this will still be regarded as one connection, irrespective of the configuration and number of customers on the premises. The "number of service connections" variable (Nc) in a water utility is required for the calculation of several performance indicators. The Nc variable is also used to calculate the unavoidable annual real losses (UARL) in a system by taking into consideration the unavoidable leakage expected to occur on service connections between the main and curb stop or property line. It is then added to the other components of UARL (on mains, and on pipes between the curb stop/property line and the customer meter) to calculate the total UARL.

sounding Seeking and discerning leak noise generated from pressurized water piping systems. Leaks escaping from pressurized piping give characteristic sounds with metal pipe leaks, providing more detectable sounds, and plastic piping leak noises being less discernible. Sounding is the most common technique used in leak detection and pinpointing. Modern electronic sounding equipment has capabilities to amplify, filter, graphically display, and record leak noises, leading to precise pinpointing of many types of leaks.

step testing A test performed by gradually closing a valve on the sole input supply main and measuring successive pressure reductions in an isolated zone or district metered area (DMA) of a water distribution system. Both pressure and flow should be monitored during step testing because leakage rates are affected by the change in pressure that occurs as sections of the test grid are closed. The data gathered in this test allows calculation of the N1 exponent of the fixed and variable area discharge path model that gives a measure of the pressure management potential existing in the zone or DMA. Step testing can also be performed to observe changes in flow rates to quantify existing leakage in a zone or DMA (see also *fixed and variable area discharge path [FAVAD] model* and *pressure management*).

supervisory control and data acquisition (SCADA) system A computer-monitored alarm, response, control, and data acquisition system used by staff of a drinking water facility to monitor its operations. SCADA systems used to monitor water distribution systems often monitor and store data on water flows, pressures, and storage volumes (levels). The system can also allow for remote operations of pumps, valves, and other equipment.

System Input Volume The volume of water input to that part of the water supply system to which the water balance calculation relates. It is equal to the water volume derived from the water utility's *Volume From Own Sources* plus the *Water Imported volume* or water purchased during the audit period, plus or minus the net change in water storage, where applicable (and significant). This volume is the water that has been treated and delivered (pressurized if needed) to the retail water distribution system. Therefore, it has attained a higher cost value than raw or untreated water coming from a water resource (see *water audit* and *water balance*).

systematic data handling errors Specifically defined in the AWWA Free Water Audit Software, this pertains to customer consumption and billing data error that occur in the water utility's business processes as a result of lax oversight, poor procedure, or gaps in information programming and archiving. These are apparent losses caused by structural or random errors existing in the meter reading, data transfer, accounting, or archival function of customer consumption management. Inaccurate estimates, extended periods where no meter readings are obtained, poor account adjustment protocols, and poor accountability allowing some consumers to exist without accounts in the billing system are common in many systems. These shortcomings distort the actual volume of water registered as customer consumption and cost utilities revenue to which they are entitled.

top-down water audit approach A method of compiling an annual water balance from available data and records—regardless of how complete and reliable they are—that represents a top-down approach. The top-down approach examines the entire water supply system in overview fashion and can be compiled relatively quickly. Because some records may be lacking, incomplete, or of poor accuracy, the top-down water audit is less accurate than the water audit compiled using a bottom-up approach, which provides more detail and accuracy, but at greater expense and time (see *bottom-up water audit approach*).

total annual cost of operating the water system Costs that include those for operations, maintenance, and any annually incurred costs for long-term upkeep of the system, such as repayment of capital bonds for infrastructure rehabilitation or renewal. Typical costs include employee salaries and benefits, materials, equipment, insurance, fees, administrative costs, and all other costs that exist to sustain the drinking water supply. Depending on water utility accounting procedures or regulatory agency requirements, it may be appropriate to include depreciation in the total of this cost. These costs should not include any costs to operate wastewater, biosolids, or other systems outside of drinking water. This figure is used to calculate the performance indicator non-revenue water by cost.

tracer gas method A nonsonic leak detection method often used for pinpointing small leaks in new pipelines undergoing hydrostatic testing but also applicable to leak pinpointing on pipelines in active service. A gas is injected into a section of water main that is believed to have a leak. At the point of leakage, the gas returns to its gaseous form, permeates directly to the surface, and can be detected above the surface of the pipeline, thereby indicating the location of the leak. Helium gas or a premixed, nonflammable hydrogen-in-nitrogen mixture can be used. A high degree of operator knowledge, training, and caution is needed to safely employ a tracer gas method for leak detection.

unauthorized consumption Any water taken from the water distribution system without the authorization of the water utility. This may include (unpermitted) water withdrawn from fire hydrants, illegal connections, bypasses to customer meters, meter or meter reading equipment tampering, or similar actions. Unauthorized consumption is one of the primary components of apparent losses (see *water audit* and *water balance*).

unavoidable annual real losses (UARL) A reference level of real (leakage) losses in water utilities that cannot be totally eliminated. UARL represents the lowest loss technically achievable in a water utility based on its key characteristics. The UARL calculation is based on leakage data gathered from well-maintained and well-managed systems. Equations for calculating the UARL for individual systems were developed and tested by the International Water Association's Water Loss Task Force (now Water Loss Specialist Group) and published in 2000. The equations take into account measured frequencies, flow rates and durations of background losses, reported leaks and unreported leaks, as well as the pressure–leakage relationship (assumed to be linear for most large systems). A straightforward equation for UARL was developed. This equation, expressed in gallons, is given below (adjusting for units):

$$\text{UARL (gal)} = (5.41\text{Lm} + 0.15\text{Nc} + 7.5\text{Lc}) \times \text{P} \times 365 \text{ days/year}$$

for systems operated continuously, or 365 days per year

Where:

Lm = length of water mains (miles, including hydrant lead length)
Nc = number of service connections
Lc = total length of private service connection pipe (miles)
= Nc × average distance from curb stop to customer meter, Lp (see Figures 3-13 through 3-15 to determine Lp)
P = average pressure in the system (psi)

The ratio of current annual real losses to the UARL is the Infrastructure Leakage Index, which is a primary leakage benchmarking performance indicator (see also *current annual real losses* and *Infrastructure Leakage Index*).

unavoidable background leakage (UBL) That portion of the background leakage (tiny weeps and seeps at pipe and customer service connection piping joints that are acoustically undetectable) that exists below the low threshold that current best pressure management technology can address. The UBL parameter multiplied by the infrastructure condition factor (ICF) gives the targeted background leakage (TBL) value, which represents a portion of the potentially recoverable leakage. The TBL is needed to set the leakage management strategy. The calculation for UBL is

$$\text{UBL (1,000 gal/d)} = [(0.20 \times \text{Lm}) + (0.008 \times \text{Nc}) + (0.34 \times \text{Lc})] \times (\text{Pav}/70)^{1.5}$$

Where:

Lm = total length of water mains (miles)

Nc = number of service connections (main to curb stop)

Lc = Nc × Lp, total length of private pipes, curb stop to customer meter (converted to miles) where Lp = average distance from curb stop to customer meter (see Figures 3-13 through 3-15 to determine Lp)

Pav = average system pressure (psi)

unbilled authorized consumption All consumption that is unbilled but still authorized by the water utility. This includes unbilled metered consumption and unbilled unmetered consumption. In the AWWA Free Water Audit Software, this component does *not* include water supplied to neighboring water utilities (*Water Exported volume*), which may be unbilled (an unlikely case). The *Water Exported volume* is instead included in the *Water Supplied volume*.

unbilled metered consumption Metered consumption that is authorized by the water utility, but, for any reason, is deemed by utility policy to be unbilled. This might include, for example, metered water consumed by the utility itself in treatment or distribution operations, or metered water provided to a civic institution free of charge. In the AWWA Free Water Audit Software, this component does *not* include water supplied to neighboring water utilities (*Water Exported volume*), which may be metered and unbilled (an unlikely case). The *Water Exported volume* is instead included in the *Water Supplied volume*.

unbilled unmetered consumption Any kind of authorized consumption that is neither billed nor metered. This component will typically include water used in activities such as fire fighting, flushing of water mains and sewers, street cleaning, fire flow tests conducted by the water utility, and so forth. In the AWWA Free Water Audit Software, this component does *not* include water supplied to neighboring water utilities (*Water Exported volume*), which may be unmetered and unbilled (an unlikely case). The *Water Exported volume* is instead included in the *Water Supplied volume*.

under-registration A condition in which a meter records less water than is actually flowing through the meter.

unreported leaks Leaks, usually hidden, that are found only if a water utility has an active leakage control program, or when they worsen and appear in some fashion and become reported leaks. With passive or very infrequent active leakage control, these leaks go undetected and run for long periods of time causing mounting water losses. Active leakage control interventions, carried out at an economic frequency that varies with local circumstances, enable the volume lost from unreported leaks to be managed economically.

variable production cost The costs to produce and supply the next unit of water (e.g., dollars per million gallons). This cost is determined by calculating the summed unit costs for ground and surface water treatment and all power used for pumping from the source to the customer. It may also include other miscellaneous unit costs (such as residuals disposal costs) that apply to the production of drinking water. It should also include the unit cost of bulk water purchased (*Imported Water volume*) if applicable.

Volume From Own Sources The volume of water withdrawn (abstracted) from water resources (rivers, lakes, streams, wells, etc.) controlled by the water utility and then treated for potable water distribution. Most water audits are compiled for utility retail water distribution systems, so this volume should reflect the amount of treated drinking water that entered the distribution system. Often the volume of water measured at the effluent of the treatment works is slightly less than the volume measured at the raw water source, because some of the water is used in the treatment process. Thus, it is most useful if flows are metered at the effluent of the treatment works. If metering exists only at the raw water source, an adjustment for water used in the treatment process should be included to account for water consumed in treatment operations such as filter backwashing, basin flushing and cleaning, and so forth. If the water audit is conducted for a wholesale water agency that sells untreated water, then this quantity reflects the measure of the raw water, typically metered at the source. Except for water utilities that import most or all of their water supply, this is the largest volume input to the standard water audit. Hence, this value carries great importance in the water audit process and a strong effort should be put forth by the water utility to ensure that this volume is highly accurate (see also *water supplied*).

volumetric flow test A procedure used to verify the accuracy of a water meter by passing a known volume of water through the meter and comparing it to the volume derived from the flow measurements of the meter for the test period. Customer water meters can be tested in this manner on a meter test bench where water is flowed into a tank of known volume. Water flowed past the meter during the test and released into the tank is weighed to determine the precise volume. For production flowmeters that measure flow from water treatment or pumping sources, a reservoir drop test can be performed in the field if the proper piping configuration exists. If production meters are located at the outlet of a storage reservoir or basin, supply into the basin can be temporarily halted and the water leaving the reservoir measured by the flowmeters. The drop in the reservoir over the test period is measured and, knowing the geometry of the reservoir, the volume loss occurring during the drop can be obtained to compare with the flowmeter measurement. Volumetric flow testing is a reliable means to confirm the flow measurement accuracy of the water meter, but should not be confused with calibration of secondary devices (such as differential pressure cells) that might be connected to the flowmeter. Also known as a *reservoir drop test*.

water audit A thorough examination of the accuracy of water utility data, records, accounts, policies, and practices regarding the volumes of water that are moved from source to treatment to distribution and customer consumption, ultimately distinguishing volumes reaching customers from volumes of loss. Water audits are essential to assess the quantitative efficiency of water utilities and their water resources, and operational and financial impacts. Water audits can be performed in top-down (desktop assessment of records) or bottom-up fashion (detailed field measurements and investigations to confirm records) (see also *water balance*).

water balance The summary of key water audit data that shows water management from source to customer, with the sum of quantities in all columns equal and thus balancing. The standard water balance is shown in the following figure:

<table>
<tr><td rowspan="9">Volume From Own Sources (corrected for known errors)</td><td rowspan="11">System Input Volume</td><td>Water Exported (corrected for known errors)</td><td colspan="3">Billed Water Exported</td><td>Revenue Water</td></tr>
<tr><td rowspan="10">Water Supplied</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="8">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="6">Water Losses</td><td rowspan="3">Apparent Losses</td><td>Customer Metering Inaccuracies</td></tr>
<tr><td>Unauthorized Consumption</td></tr>
<tr><td>Systematic Data Handling Errors</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and Distribution Mains</td></tr>
<tr><td rowspan="2">Water Imported (corrected for known errors)</td><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to the Point of Customer Metering</td></tr>
</table>

Note: All data in volume for the period of reference, typically one year.

water consumption Water that reaches the customer destination, including residential, commercial, industrial, or agricultural customers. Consumption is the volume registered by customer meters in those water utilities that provide customer meters. Consumption does not include water that is lost to leakage in the distribution system. However, it does include leakage and water waste that occurs inside the customer premises, downstream of the customer metering point. Consumption occurs in both authorized and unauthorized manners, and may be billed or unbilled (see *water audit* and *water balance*).

water exported The bulk water conveyed and sold by the water utility to a neighboring water system that exists outside of its service area. Typically, the water is metered at the custody transfer point of interconnection between the two utilities. Usually the meter(s) is owned by the utility that is selling the water, that is, the exporter (see *water imported*).

water imported The bulk water purchased by a water utility to become part of the Water Supplied volume. Typically, this is water purchased from a neighboring water utility or regional water authority and is metered at the custody transfer point of interconnection between the two utilities. Usually the meter(s) is owned by the utility that is selling the water, that is, the exporter (see *water exported*).

water loss The difference between the Water Supplied volume and authorized consumption, also equal to the sum of apparent and real losses. Water losses are considered as a total volume for the whole system, or for partial systems such as transmission or distribution systems, or individual zones during the water audit period, which is typically one year (see *water audit* and *water balance*).

water supplied The volume of treated and delivered (pressurized as needed) water supplied to the retail water distribution system of the water utility. It is equal to the Volume From Own Sources, plus the volume of water imported or purchased and supplied from a neighboring water utility or regional wholesale water authority, minus the volume of water exported or sold in bulk to other water utilities during the audit period (see *Volume From Own Sources*, *water audit*, and *water balance*).

water withdrawal The process of drawing, or abstracting, water from a water source such as a well, lake, stream, river, quarry, or other source in a given period of time.

WLCC The Water Loss Control Committee of the American Water Works Association.

REFERENCES

Lambert, A. 1994. Accounting for losses: The bursts and background estimates concepts. *Journal of the Institution of Water and Environmental Management*, 8(2):205–214.

WRF (Water Research Foundation). 2014. *Real Loss Component Analysis: A Tool for Economic Water Loss Control*. Denver, Colo.: WRF.

This page intentionally blank.

Index

NOTE: *t.* indicates table; *f.* indicates figure

E

F

G

H

I

J

K

L

M

N

O

P

Q

R

S

T

AWWA Manuals

M1, *Principles of Water Rates, Fees, and Charges*, #30001
M2, *Instrumentation and Control*, #30002
M3, *Safety Management for Water Utilities*, #30003
M4, *Water Fluoridation Principles and Practices*, #30004
M5, *Water Utility Management*, #30005
M6, *Water Meters—Selection, Installation, Testing, and Maintenance*, #30006
M7, *Problem Organisms in Water: Identification and Treatment*, #30007
M9, *Concrete Pressure Pipe*, #30009
M11, *Steel Pipe—A Guide for Design and Installation*, #30011
M12, *Simplified Procedures for Water Examination*, #30012
M14, *Backflow Prevention and Cross-Connection Control: Recommended Practices*, #30014
M17, *Installation, Field Testing, and Maintenance of Fire Hydrants*, #30017
M19, *Emergency Planning for Water Utilities*, #30019
M20, *Water Chlorination/Chloramination Practices and Principles*, #30020
M21, *Groundwater*, #30021
M22, *Sizing Water Service Lines and Meters*, #30022
M23, *PVC Pipe—Design and Installation*, #30023
M24, *Planning for the Distribution of Reclaimed Water*, #30024
M25, *Flexible-Membrane Covers and Linings for Potable-Water Reservoirs*, #30025
M27, *External Corrosion Control for Infrastructure Sustainability*, #30027
M28, *Rehabilitation of Water Mains*, #30028
M29, *Water Utility Capital Financing*, #30029
M30, *Precoat Filtration*, #30030
M31, *Distribution System Requirements for Fire Protection*, #30031
M32, *Computer Modeling of Water Distribution Systems*, #30032
M33, *Flowmeters in Water Supply*, #30033
M36, *Water Audits and Loss Control Programs*, #30036
M37, *Operational Control of Coagulation and Filtration Processes*, #30037
M38, *Electrodialysis and Electrodialysis Reversal*, #30038
M41, *Ductile-Iron Pipe and Fittings*, #30041
M42, *Steel Water-Storage Tanks*, #30042
M44, *Distribution Valves: Selection, Installation, Field Testing, and Maintenance*, #30044
M45, *Fiberglass Pipe Design*, #30045
M46, *Reverse Osmosis and Nanofiltration*, #30046
M47, *Capital Project Delivery*, #30047
M48, *Waterborne Pathogens*, #30048
M49, *Butterfly Valves: Torque, Head Loss, and Cavitation Analysis*, #30049
M50, *Water Resources Planning*, #30050
M51, *Air-Release, Air/Vacuum, and Combination Air Valves*, #30051
M52, *Water Conservation Programs—A Planning Manual*, #30052
M53, *Microfiltration and Ultrafiltration Membranes for Drinking Water*, #30053
M54, *Developing Rates for Small Systems*, #30054
M55, *PE Pipe—Design and Installation*, #30055
M56, *Nitrification Prevention and Control in Drinking Water*, #30056
M57, *Algae: Source to Treatment*, #30057
M58, *Internal Corrosion Control in Water Distribution Systems*, #30058
M60, *Drought Preparedness and Response*, #30060
M61, *Desalination of Seawater*, #30061
M63, *Aquifer Storage and Recovery*, #30063
M65, *On-Site Generation of Hypochlorite*, #30065
M66, *Actuators and Controls—Design and Installation*, #30066

This page intentionally blank.