Water Audits and Loss Control Programs

MANUAL OF WATER SUPPLY PRACTICES

M36

Third Edition

American Water Works Association

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Water Audits and Loss Control Programs

AWWA MANUAL M36

Third Edition

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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. The closing years of the 20th century, however, began to witness changes not seen before on the continent. The fastest growing cities in the United States are now located in sunbelt areas—even centered in deserts, such as Las Vegas and Phoenix. Limited water resources exist in these areas, therefore supplies must be 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 compromise system efficiency and disrupt 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 toilets and showerheads. It is essential that these successful efforts continue because all water users have a responsibility to use water wisely. In the broader context of *demand management*, water suppliers also have a responsibility to wisely manage the valuable water resources under their purview. This tenet—*the accountable and efficient management of water supplies by utilities*—is the central focus of 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, 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 1991 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. Perhaps the greatest strength of this manual has been the clear step-by-step instructions for data gathering to compile the water audit. This feature is retained in this third edition. However, the third edition includes a major advancement in water audit methodology, giving water utilities greater guidance in improving accountability and economically controlling water and revenue losses.

Historically, standard methods to audit water supplies and control losses were lacking throughout most of the world. In 2001, a survey of United States state and regional water oversight agencies revealed that inconsistent definitions for water loss (most using the imprecise label "unaccounted-for" water) abound with few reliable water auditing or loss control measures in place. Regulatory requirements are unusually sparse on this issue in the United States more recently. Reliable data is being collected and along with many case study and anecdotal accounts, suggest 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 1997–2000, AWWA participated on the Water Loss Task Force organized by the International Water Association (IWA). The Water Loss Task Force 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 gives detailed instruction on the water audit process. Chapter 3 describes ways to recoup missing revenues by controlling apparent (nonphysical) losses. Chapters 4 and 5 discuss the impacts of real (physical) losses which are largely leakage, and methods to control these losses. Chapter 6 gives guidance on the organizational steps a water utility can take to manage and sustain the water loss control program, while Chapter 7 offers valuable insights for small systems in managing their losses. A glossary of terms and definitions is also provided. Appendices include blank worksheets and forms, water resources considerations, a description of AWWA Water Loss Control Committee's free Water Audit Software, and useful case study accounts from a spectrum of North American water utilities. For water utilities just getting started, the 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, steps well-described throughout this manual. Examples are included throughout 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.

Acknowledgments

This 3rd edition of the manual is a substantial revision of the previous M36 publications. It details significant developments and methods on water accountability and proactive loss control. This edition presents innovations being diligently forwarded by the American Water Works Association (AWWA) Water Loss Control Committee in cooperation with the Water Loss Task Force of the International Water Association (IWA).

This edition was written through the persistent, dedicated work of a standing subcommittee. Members of this subcommittee included

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In Memoriam

This 3rd edition of *Water Audits and Loss Control Programs* is dedicated to Louis F. Aiello III of West Virginia American Water, Charleston, W.V., who passed away shortly before the Water Loss Control Committee completed the final draft. We thank Lou for his work on the committee and recognize his commitment to his family and profession, and his contributions to this publication.

This manual was also reviewed and approved by the Distribution & Plant Operations Division and Conservation Division who had the following personnel at the time of review.

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Chapter 1

Introduction: Auditing Water Supply Operations and Controlling Losses

Community drinking 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 good hygiene, 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 drinking 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
- Worksheets and sample calculations for each step of the water audit
- Definitions and implications of apparent (nonphysical) losses and real (physical) losses
- Specific techniques to identify, measure, and verify all water sources, consumption, and losses
- A roadmap 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

Many water utilities suffer a variety of losses. Most operators recognize piping distribution system leakage, categorized under the heading *Real Losses*, as a primary type of loss. However, water suppliers also suffer losses from poor accounting, meter inaccuracy, 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.

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. An audit has been defined as "an examination of records or financial accounts to check their accuracy."[1] The *water audit* typically traces the flow of water from the site of withdrawal or 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 consumption and losses that exist in a community water system. The *water balance* summarizes the 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*.[2] This publication included a description of a water audit methodology developed during the period of 1997–2000 by the IWA Water Loss Task Force, a five-country group that included participation by the American Water Works Association (AWWA). Because a multitude of different water auditing practices existed around the world, 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 that could be applied worldwide, across the spectrum of differing system characteristics and units of measure. Many of the features of the IWA/AWWA 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 Water Loss Task Force published its new method, the AWWA Water Loss Control Committee 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*.[3]

The IWA/AWWA Water Audit Method is detailed in Chapter 2, and it is recommended as the current best management practice by the AWWA Water Loss Control Committee for drinking water utilities to compile a water audit of their operations. Free Water Audit Software can be used to compile the water audit and is described in Appendix C. 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 methods and technologies has occurred since the early 1990s. Many of these techniques are given in Chapters 3 and 5. The final chapters of this manual provide guidance on planning and sustaining the loss control program and considerations for small systems.

THE IMPORTANCE OF WATER AUDITS AND LOSS CONTROL

Strong water loss control produces benefits in four primary manners:

1. 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. System integrity, by reduction of potential for contamination.

Drinking water suppliers have obligations in all of the previous areas: they must act as stewards of the valuable water resources that 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

- *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 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 as 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 water audit and 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, create 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.
- *Favorable reviews from the financial community.* Effective operations and accountability instill credibility for the water utility in the eyes of the lending 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, and society at large, while good accountability and loss control offer many benefits. It is likely that many, if not most, North American drinking 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 drinking water utilities.

GETTING STARTED

Regulatory requirements for water audits have customarily been very limited in North America; hence, most drinking water utilities do not compile a regular audit of their water supply operations. For water utilities just getting started, the best practice water audit method given in this manual is an excellent tool to quickly obtain quantities of losses and their costs. 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!*

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, entitled *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.[4] The results of the survey found that widely varying language existed throughout many regulations and statutes of these agencies. Many did and still do define water losses as some form of *unaccounted-for* water but leave the components included in this parameter subject to interpretation *and manipulation*. As an example of the latter, many utilities have routinely included volumes from known leaks in *accounted-for* water categories, thus underestimating actual leakage or real losses. 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.[5] 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 drinking water utilities."

The AWWA Water Loss Control Committee supports the methods offered in this manual as the "better system of accounting" called for in the States Survey report. The Committee recommends against continued use of the imprecise term *unaccounted-for* water as it does not exist in the best practice water audit method, and its continued use will only serve to confuse. The committee holds that the methods in this manual are workable, meaningful, and offer the greatest potential to bring about improved accountability and water efficiency in drinking water utilities. The methods can assist better service for drinking water customers, an improved bottom line for water utilities, and better management of water resources for the common good. It is recommended that these methods become the standards for quantitative management of drinking water resources in North America for water utilities, professional organizations, regulatory agencies, and all stakeholders who support safe and reliable drinking water.

Water accountability and loss control will garner increasing prominence in water resources management in coming years. 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. 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 have the tools to meet the growing challenges.

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Chapter 2

Conducting the Water Audit

This chapter details the best practice 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.[1] 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's Water Loss Control Committee 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. 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 component analysis are given in Chapters 3 and 5.

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* A DMA is a small zone of the distribution system—typically encompassing between 500–3,000 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 4 and 5 for details.

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 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 type and amounts of loss occurring in the utility. Launching a water audit also 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 a recommended water audit approach, which includes example data from the fictitious water utility—County Water Company (CWC). Step-by-step instruction is given to compile the water audit, including the required information, how to get that information, how to enter it on the worksheet, and how to calculate the performance indicators. The user may instead employ the AWWA Water Loss Control Committee’s free Water Audit Software described in Appendix C to quickly compile a preliminary water audit and then augment it via the methods in this chapter.

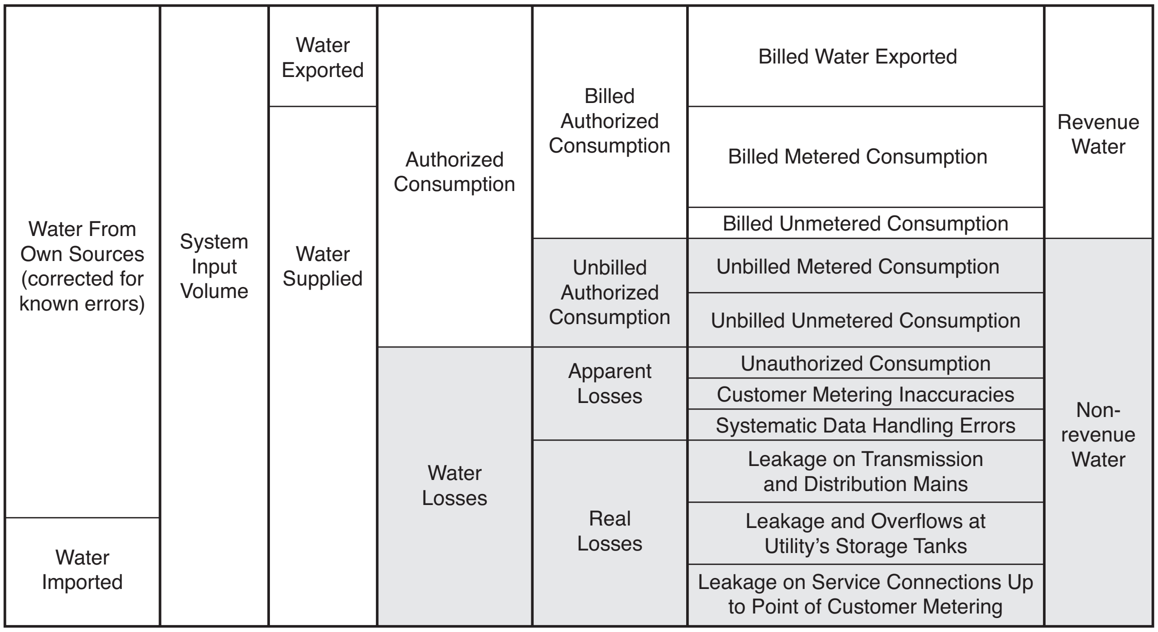
THE WATER BALANCE CALCULATION

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 *balance* as shown in Figure 2-1. The water balance for CWC is given in Figure 2-2. 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 as to how much water is lost as a result of customer meter inaccuracy, systematic data handling error, and unauthorized consumption (apparent losses), as well as leakage (real losses).

The two most powerful features of the best practice water audit methodology are its rational terms and definitions (Table 2-1) and standard set of performance indicators (as shown later in Table 2-19). On the broadest level, water system input volume goes to two places: authorized consumption or losses. The 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*.

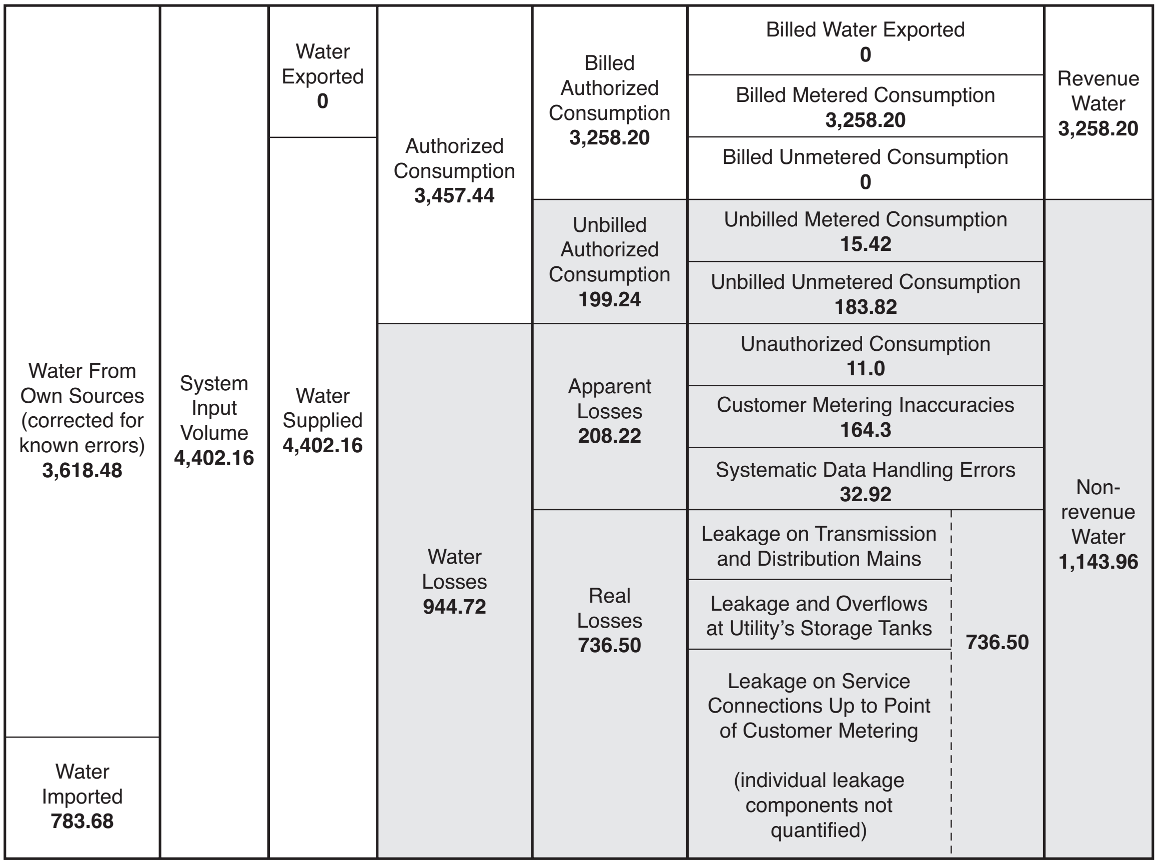
It is recommended that water utilities, state agencies, and drinking water stakeholders avoid use of the imprecise term *unaccounted-for water*. See instead the term *nonrevenue water* (NRW) defined in Table 2-1.

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



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

Figure 2-1 Water balance



NOTE: All data in million gallons volume for the period of reference, calendar year 2006.

Figure 2-2 Water balance for County Water Company—2006 calendar year

Table 2-1 Water balance terms and definitions

Water Balance Component	Definition
System Input Volume	The annual volume input to the water supply system
Authorized Consumption	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	The difference between System Input Volume and Authorized Consumption, consisting of Apparent Losses plus Real Losses
Apparent Losses	Unauthorized Consumption, all types of customer metering inaccuracies and systematic data handling errors
Real Losses	The annual volumes lost through all types of leaks, breaks, and overflows on mains, service reservoirs, and service connections, up to the point of customer metering
Revenue Water	Those components of System Input Volume that are billed and produce revenue
Nonrevenue Water	The sum of Unbilled Authorized Consumption, Apparent Losses, and Real Losses. Also, this value can be determined as the difference between System Input Volume and Billed Authorized Consumption

COMPILING THE TOP-DOWN WATER AUDIT DATA

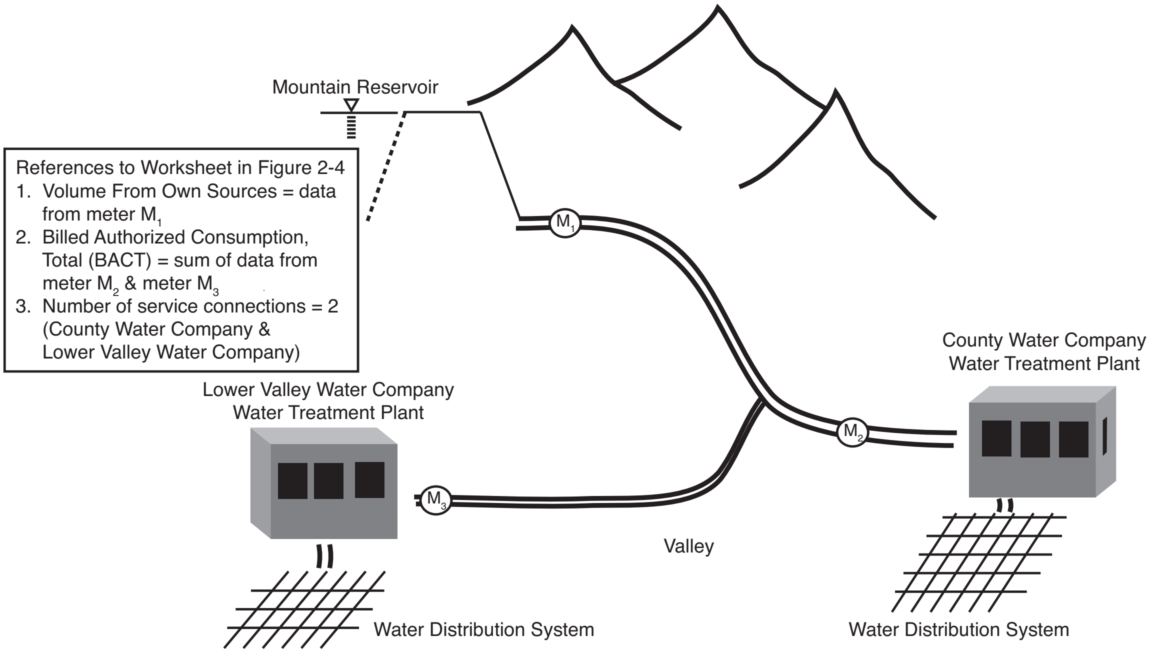
This section provides step-by-step instructions on the means to compile the top-down water audit. Major tasks are listed as well as individual steps, under these tasks.

Before Starting the Water Audit

At the outset of the water audit, it is important to define several key parameters for the water audit.

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. The water audit can be performed for treated or untreated water transmission (wholesale) systems, distinct treated water distribution systems, or sectors of distribution systems, such as pressure districts or district metered areas. Illustrations of such example configurations are given in Figures 2-3a, 2-3b and 2-3c. It is important that the system boundaries be identified to match the justification put forward for compiling the water audit. Water audits are most commonly performed on distinct treated water distribution systems (Figure 2-3b), and the example given in this chapter follows this configuration. Appendix B 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 meters or new meters that are proposed for installation at the input location.

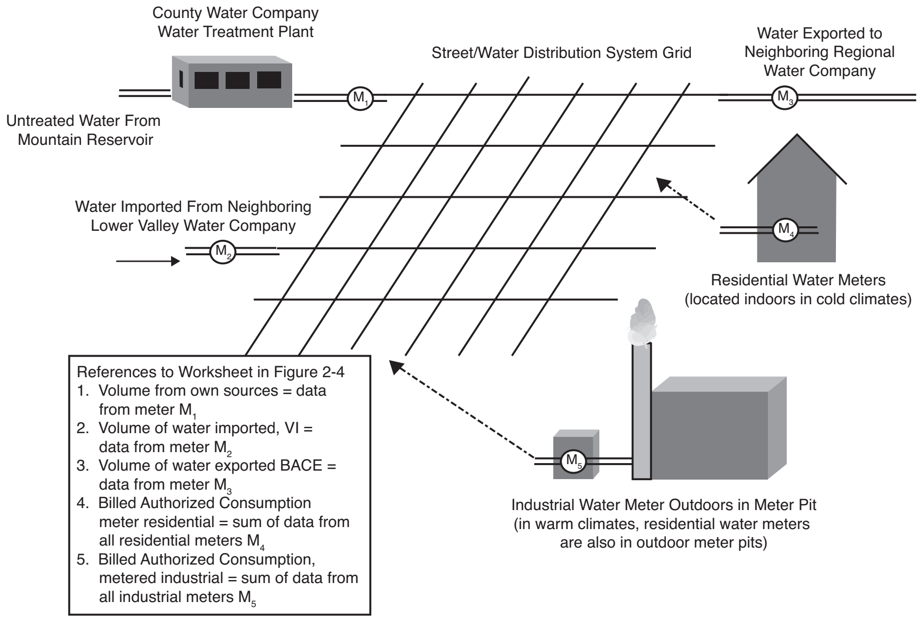
The boundary limits should be defined by points of metering of the water supply. Typical metering locations for drinking water supply and distribution are given in Table 2-2. A water audit of the raw water system utilizes metering data of the source water withdrawals as the system input and the water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



References to Worksheet in Figure 2-4

1. Volume From Own Sources = data from meter M_1
2. Billed Authorized Consumption, Total (BACT) = sum of data from meter M_2 & meter M_3
3. Number of service connections = 2 (County Water Company & Lower Valley Water Company)

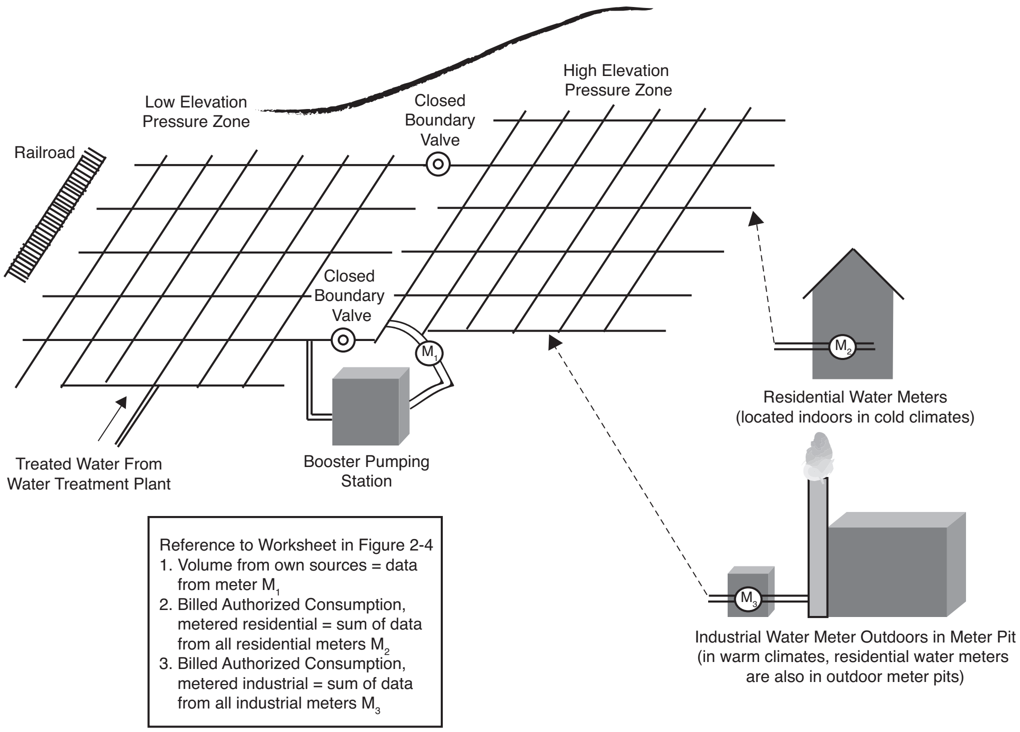
Figure 2-3a Identifying system boundaries for a water audit conducted on a wholesale transmission water supply system



References to Worksheet in Figure 2-4

1. Volume from own sources = data from meter M_1
2. Volume of water imported, VI = data from meter M_2
3. Volume of water exported BACE = data from meter M_3
4. Billed Authorized Consumption meter residential = sum of data from all residential meters M_4
5. Billed Authorized Consumption, metered industrial = sum of data from all industrial meters M_5

Figure 2-3b Identifying system boundaries for a treated water distribution system



Reference to Worksheet in Figure 2-4

1. Volume from own sources = data from meter M_1
2. Billed Authorized Consumption, metered residential = sum of data from all residential meters M_2
3. Billed Authorized Consumption, metered industrial = sum of data from all industrial meters M_3

Figure 2-3c Identifying system boundaries for a discrete pressure zone or DMA

Table 2-2 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 Areas	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-end 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

For water audits conducted on treated water distribution systems (the typical example in this manual), metered water at the water treatment plant effluent 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 study over time. Choose a time period that allows analysis and evaluation of total system water supply. 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. 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.

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). While a variety of units are used by North American water utilities (million gallons, acre-feet, cubic feet, megaliters), million 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. If the auditor desires, an additional column can be added in the worksheet in Figure 2-4 to show the data in daily average units of million gallons per day (mgd).

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, distribution system pressures, leak detection and repair, customer metering and billing, authorized consumption from flushing, fire-fighting and related activities, water conservation activities, the cost of water (water rates and production costs), infrastructure rehabilitation, and a host of related data. Distribution system maps or geographical information systems, 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 the needed data.

Establishing procedures and contacts for the routine, annual collection of this data is an important function. The auditor should be cognizant during the auditing process of the caliber of information sources: who provides the data, in what format and what degree of confidence does the data exist? 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 next year's water audit. 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.

Starting the Water Audit

Figure 2-4 provides a standard water audit worksheet. The figure provides an example of the fictitious County Water Company, and the means to complete the worksheet is explained throughout Chapter 2. A blank form for this figure is given in Appendix A. In the first section, 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. (Note: while Figure 2-4 serves as the example in Chapter 2, the auditor may alternatively use the AWWA Water Loss Control Committee's free Water Audit Software, which is described in Appendix C.)

WATER AUDIT FOR THE PERIOD	January 1, 2006	TO	December 31, 2006
UTILITY NAME & ADDRESS	County Water Company, Anytown, USA	POPULATION SERVED	37,000
COMPILED BY	John Smith, Manager	DATE COMPILED	March 23, 2007

DATA TO BE ENTERED SHOWN IN WHITE, CALCULATED VALUES SHOWN IN DARK GRAY, SUGGESTED DEFAULT VALUES IN MEDIUM GRAY

DISTRIBUTION SYSTEM DESCRIPTION INFORMATION

SYSTEM CONFIGURATION TYPE (underline your selection)	Raw Water Transmission	Bulk Treated Transmission	[✓ Retail Treated Distribution]	Pressure Zone or DMA (specify)

INFRASTRUCTURE DATA		FINANCIAL DATA	
250	Miles of Transmission & Distribution Mains, Lm	$9,600,000	Total costs to operate the water supply system
11,490	Number of service connections, residential accounts, Nr	$4,142	*Customer retail unit rate—residential accounts—applied to Apparent Losses ($/mil gal)
706	Number of service connections, commercial, industrial & agricultural accounts, Ni	$3,627	*Customer retail unit rate—industrial, commercial & agricultural accounts—applied to Apparent Losses ($/mil gal)
12,196	Total number of service connections, Nc = Nr + Ni	$3,945	*Customer retail unit rate—composite unit rate—applied to Apparent Losses ($/mil gal)
18	Average length of customer service connection from curb stop to customer meter, Lp, ft	$190	Short-term variable cost to produce the next unit of water—applied to Real Losses ($/mil gal)
2,750	Number of fire hydrants, Nf	OPERATIONAL DATA	
12	Average length of fire hydrant leads, Lh, ft	365	Days in water audit period
65	Average operating pressure, P, psi	100%	Percent of time that system is pressurized

*Be certain to calculate the retail customer rate charges in dollars/million gallons to keep units of measure consistent.

WATER BALANCE CALCULATIONS			Water Volume		Costs Rate Applied & Total	
			Unit	Mil Gal	Currency	US$
1.	Volume From Own Sources (raw data)			3,480.76		
1A.	Adjustment: Sources meter error (+/–)	+136.89				
1B.	Adjustment: Changes in reservoir and tank storages (+/–)	+0.83				
1C.	Other Adjustments (specify)	0				
1D.	Total Adjustments = Lines 1A +1B + 1C	+137.72				
2.	VOS: Volume From Own Sources (adjusted) = Lines 1 +/– 1D			3,618.48		
3.	VI: Volume of Water Imported (adjusted)			783.68		
4.	SIV: System Input Volume = VOS + V1			4,402.16		
5.	BACE: Volume of Water Exported (adjusted)			0		
6.	WS: Water Supplied = SIV – BACE			4,402.16		
7.	BACM1: Billed Authorized Consumption: Metered (uncorrected) Type 1 (specify)	Residential Accounts		2,318.80		
8.	BACM2: Billed Authorized Consumption: Metered (uncorrected) Type 2 (specify)	Industrial Accounts		488.60		
9.	BACM3: Billed Authorized Consumption: Metered (uncorrected) Type 3 (specify)	Commercial Accounts		97.20		
10.	BACM4: Billed Authorized Consumption: Metered (uncorrected) Type 4 (specify)	Agricultural Accounts		353.40		

Figure 2-4 Water audit worksheet: Top-down approach

	WATER BALANCE CALCULATIONS				Water Volume		Costs Rate Applied & Total	
					Unit	Mil Gal	Currency	US$
11.	BACT = (BACM1 + BACM2 + BACM3 + BACM4) (uncorrected)			3,258.00				
11A.	Adjustment due to customer meter reading lag time (+/–)			+0.20				
12.	BACTAD = BACT +/– Line 11A					3,258.20		
13.	BACU: Billed Authorized Consumption: Unmetered					0		
14.	NRW: NONREVENUE WATER = WS – (BACTAD + BACU)					1,143.96	= Lines 15 + 16A + 17 = $1,764,296	
15.	UACM: Unbilled Authorized Consumption: Metered					15.42	@ $3,945/mil gal = $60,831	
16.	UACU: Unbilled Authorized Consumption: Unmetered	Estimated as	1.250%	of WS		(55.03)		
16A.	UACU: Unbilled Authorized Consumption: Unmetered	Use instead of Line 16 if greater than Line 16				183.82	@ $3,945/mil gal = $725,170	
17.	WL: WATER LOSSES = NRW – (UACM + UACU)					944.72	= Lines 24 + 25 = $978,295	
18.	ALMUR1: Apparent Loss – residential meter under-registration					134.33	@ $4,142/mil gal = $556,395	
19.	ALMUR2: Apparent Loss – industrial/commercial/agricultural meter under-registration					29.97	@ $3,627/mil gal = $108,701	
20.	ALDHE1: Apparent Loss – systematic data transfer error (specifiy)					12.57	@ $3,945/mil gal = $49,589	
21.	ALDHE2: Apparent Loss – systematic data analysis error (specifiy)					8.72	@ $3,945/mil gal = $34,400	
22.	ALDHE3: Apparent Loss – data policy/procedure impacts					11.63	@ $3,945/mil gal = $45,880	
23.	UC: Unauthorized Consumption	Estimated as	0.250%	of WS		11.00	@ $3,945/mil gal = $43,395	
23A.	UC: Unauthorized Consumption	Use instead of Line 23 if greater than Line 23				—		
24.	AL: Sum of Apparent Losses = ALMUR1 + ALMUR2 + ALDHE1 + ALDHE2 + ALDHE3 + UC					208.22	Sum = $838,360	
25.	CARL: Current Annual Real Losses = WL – AL (In the top-down water audit approach, Real Losses are taken as the losses remaining after Apparent Losses are subtracted from the Total losses)					736.50	@ $190/mil gal = $139,935	
26.	Normalized CURRENT ANNUAL REAL LOSSES: CARL per day					2.02		

WATER AUDIT—PERFORMANCE INDICATORS

Category	Description	*IWA Code	Expressed as:	Calculation	Indicator Value
Financial	Financial: Non-revenue water by volume	Fi36	Volume of Nonrevenue Water as % of System Input Volume	= (1,143.96/4,402.16)% = 25.9%	25.9%
	Financial: Non-revenue water by cost	Fi37	Value of Nonrevenue Water as % of annual cost to operate the water supply system	= ($1,764,296/$9,600,000)% = 18.3%	18.3%
Operational	Water Losses		mil gal	= WL	944.72
	Apparent Losses		mil gal	= AL	208.22
	Current Annual Real Losses		mil gal	= CARL	736.50
	Apparent Losses Normalized	Op23	[gal/service connection/d]	= (AL/Nc/D) = (208,220,000/12,196/365)	46.8
	Real Losses Normalized (1)	Op24	[gal/service connecion/d] or [gal/mi of mains/day] (only if service connection density is less than 32/mi)	Service connection density = (12,196/250) = 48.8/mile Op24 = (736,500,000/12,196/365)	165.4

Figure 2-4 Water audit worksheet: Top-down approach (continued)

WATER AUDIT—PERFORMANCE INDICATORS

Category	Description	*IWA Code	Expressed as:	Calculation	Indicator
Operational	Real Losses Normalized (2)		[gal/service connecion/d/psi] or [gal/mil of mains/d/psi] (only if service connection density is less than 32/mi)	Service connection density = 48.8 connections/mile Real Losses Normalized (2) = (736,500,000/12,196/365/65)	2.54
	Unavoidable Annual Real Losses	UARL	UARL (gal/d) = (5.41Lm + 0.15Nc + 7.5Lc) × P, where: Lm = length of water mains, miles (including hydrant lead length) Nc = number of service connections Lc = (Nc × Lp)/5,280, mi Lp = average service connection piping length, ft (See Figures 2-9–2-11 for guidance) P = average pressure in the system, psi	Lm = miles of main + total hydrant lead length (miles) = 250 + [(2,750 × 12)/5,280] = 256.25 Lc = (12,196 ×18)/5,280 = 41.6 UARL = [(5.41 × 256.25) + (0.15 × 12,196) + (7.5 × 41.6)] × 65 = 229,300 gal/d = 83.69 mil gal/yr	83.69
	Infrastructure Leakage Index (ILI)	Op25	CARL/UARL (dimensionless)	= 736.50/83.69 = 8.80	8.80

* Descriptors assigned to the performance indicators are from the International Water Association publication *Performance Indicators for Water Supply Services*, 2000.

Figure 2-4 Water audit worksheet: Top-down approach (continued)

Task 1—Collect Distribution System Description Information

This section of the worksheet provides for the entry of pertinent distribution system characteristics that are necessary to describe the utility and calculate the performance indicators. The information is provided under three headings: infrastructure data, financial data, and operational data. The operational data includes default values that assume 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.

Most of this information should be readily available to utility managers. Several of the requested parameters will be new to many water utilities, however, including the average length of customer connection piping from the curb stop to the customer meter or property boundary if customers are unmetered (see later in Figures 2-9–2-11). This parameter, labeled Lp, separates the repair responsibilities for customer service connection piping leaks; that is, the delineation of water utility responsibility vs. repairs arranged by the customer. 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, as well as the average length of fire hydrant leads, can be approximated if they are not known.

Three levels of costs from the utility should be entered to generate a cost assessment of losses in the system. First, the total costs to operate the water supply system should be entered. These costs include those for operations, maintenance, and long-term upkeep of the system. They include employee salaries and benefits, materials, equipment, insurance, fees, other administrative costs, and all other costs that exist to maintain the water supply. These costs should not include any costs to operate wastewater, biosolids, or other systems outside of drinking water.

Next, the retail rate charged to customers for water supplied should be tabulated. These unit costs will be applied to the components of apparent loss, because these losses represent water reaching customers but not (fully) paid for. It is important to compile these costs per the same unit cost basis as the volume measure included in the water audit. For example, if all water volumes are measured in million gallons, the unit cost should be dollars per million gallon ($/mil gal). This usually requires a conversion because most water utilities bill customers in cubic feet or gallons. A single retail rate can be used, or separate retail rates for different customer rate classes (residential, industrial, etc.) can be employed. Charges for wastewater and stormwater may also apply. If these additional costs apply, an aggregate unit cost will also likely be needed (an estimate between the previous values can be used) to value those apparent losses where the breakdown of customer consumption categories is unknown.

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, plus variable treatment and pumping costs;
- 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.

This variable, or marginal, cost includes the basic costs to provide the next unit (mil gal) of water, 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 water. Most drinking water utilities compile all of these costs, and this data is readily available. If any costs are missing, an estimate can be used until a separate cost assessment can be performed at a later time.

The data requested in the Distribution System Description Information section of the water audit worksheet shown in Figure 2-4 should be provided.

Task 2—Measure Water Supplied to the Distribution System

Proceed to the section of the worksheet in Figure 2-4 labeled Water Balance Calculations. This task demonstrates how much water enters the distribution system and where it originates.

Step 2-1. 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 into the distribution system. Such sources can include raw water that is treated adjacent to sources such as wells, rivers, streams, lakes, reservoirs, or aqueduct turnouts. However, most water audits are performed on the potable water distribution system (see Figure 2-3b) so that the "source" is often the location where *treated* water enters the distribution system. The effluent 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 and energized for delivery. All volumes from such sources should be metered with routine meter testing and calibration conducted so that volumes of water taken from all sources are registered accurately. Data from these meters should also be archived in a computerized 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. Meter information can be kept in a table similar to Table 2-3.

Perhaps one or more water sources are unmetered, or have meters that are not routinely monitored. In such cases the following situations apply:

- *No meters at a water source.* A portable meter should be used or the flow estimated. Portable meters can be insertion types 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. Such methods give an approximate volume measurement, and unmetered sources should ultimately be designated for metering when possible.

- *Source water meters have not been routinely calibrated.* An inspection of the source structures 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 2-3 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. 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, or calibrated, there should be an effort initiated to calibrate the meter and institute routine reading or polling 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. Again, a portable meter can be utilized to obtain measurements to compare during any master meter calibration or verification activities.

Tables 2-3 and Table 2-4 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.

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. 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.

Enter the volume of water (3,480.76 mil gal) from own sources (raw data) on Line 1 of the worksheet in Figure 2-4.

Table 2-3 Source water measuring devices for County Water Company

	Water From Own Sources		Water Imported
Characteristics	Source 1 Turnout 41	Source 2 Well Field	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	Ft^3
Multiplier (if any)	1.0	1.0	100.0
Date of installation	1974	1990	1978
Size of conduit	24 in.	8 in.	11.5 in.
Frequency of testing	Annual	Every 2 years	Every 4 months
Date of last calibration	4/1/2006	8/21/2005	1/15/2006

Table 2-4 Total water supply in million gallons for County Water Company (uncorrected)

2006 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	130.34	290.52
December	160.18	0	160.18	97.76	257.94
Annual Total	2,600.95	879.81	3,480.76	783.68	4,264.44
Daily Average, mil gal/d					11.68

Step 2-2. 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 a number of factors, including

1. Meter inaccuracies.

2. Changes in reservoir and storage levels.

3. Any other adjustments such as losses that occur before water reaches the distribution system. One example would be losses incurred during the treatment process (filter backwashing, etc.) if the source meter is located influent to a water treatment plant.

These adjustments are made in the following steps, and they are aggregated into the Volume from Own Sources (VOS) on Line 2 of the worksheet in Figure 2-4.

Step 2-2A. Verify meter accuracy. Although most source flows are measured by meters, some are measured by other devices, such as Parshall flumes or weirs. Water supply data (like those used in Table 2-4) are based on readings of these measuring devices. **Any unreasonable degree of error in a measuring device must be discovered and corrected; incorrect supply data compromises the water audit because any error in the source or production meters carry throughout the audit.**

To be sure that meters are accurate, the results of meter tests should be compared to applicable AWWA standards and guidance manuals. If a meter measures incorrectly and the error exceeds the standard for its category, the meter should be repaired and recalibrated to function within standard limits. If the meter has not been tested within the past 12 months, the meter should be tested immediately.

Possible causes of meter error. If source meters are inaccurate, inspect each one in the field. Normal wear is not the only cause of inaccurate meter readings. Check to be sure that the meter is the right type and size for the application and that it is installed correctly. See AWWA Manual M33, *Flowmeters in Water Supply*, for guidance on typical source meter types and applications.[2] The size should be checked against manufacturers' recommended ranges. The meter should be level; most meters are not designed for sloped or vertical operation. The meter should be 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 through 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 should be checked for blockages in the throats of the meters or in the sensing lines. The primary device should be tested by comparing it with a measurement taken from a pitot rod or other insertion-type meter. Testing the meter with a pitot rod shows whether or not 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 erroneously.

Testing meters. There are four ways meters may be tested. The following meter testing methods are listed in order of effectiveness, with the most effective first.

1. Test the meters in place. Some pipes may need to be replaced to make this possible.

2. Compare meter readings with readings of a calibrated meter installed in series with the original meter.

3. 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.

4. Test the meter at a meter testing facility.

Meters can be tested with portable equipment. Pump efficiency flow testing can be used to check meters; it is sometimes provided free of charge by electric utilities. Some utilities use an averaging rod meter or anubar to test meters, but results may be off by as much as 10 percent. A standard single-point pitot rod gives more accurate results, generally ±2 percent.

Meter testing may be done by an outside agency. Consultants, meter manufacturers, and special testing laboratories offer testing services.

Step 2-2B Adjust supply totals. The monthly and annual supply data should be adjusted from Table 2-4 for meter error. To do this, the uncorrected metered volume (UMV) should be divided by the measured accuracy of the meter (a percentage expressed as a decimal) and subtract the UMV as follows:

$$\frac{\text{uncorrected metered volume}}{\text{percent accuracy}} - \text{uncorrected metered volume} \qquad \text{(Eq. 2-1)}$$
$$= \text{corrected metered volume}$$

Table 2-5 shows how to adjust the supply totals from Table 2-4 to yield the adjusted measurements. *Enter the net meter error adjustment (±) on Line 1A of the worksheet in Figure 2-4. For County Water Company, this is +136.89 mil gal.*

Step 2-2C. Adjust reservoir and tank storage. If source meters are located upstream of reservoirs and storage tanks, stored water 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 metered supply. Conversely, if there is a net reduction in storage, then the decreased amount of stored water should be added to the metered supply. Table 2-6 shows how to figure the change in storage volume.

It should be noted that *decreases* in storage are *added* to the supply; storage *increases* are *subtracted* from the supply. *Enter the net reservoir and tank storage adjustment (±) of Line 1B of the worksheet in Figure 2-4. For County Water Company this is +825,580 gal or +0.83 mil gal.*

Large open reservoirs may require volume adjustments as a result of the effects of evaporation (water lost) and rainfall (water gained). See Task 5, Step 5-2E, for approaches to quantify such adjustments.

Step 2-2D. Other adjustments. Some water suppliers may be subject to other types of contributions or losses. For example, 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 accounted for as "other contributions or losses" on the worksheet. *Enter the net adjustment (±) for all other adjustment categories on Line 1C of the worksheet in Figure 2-4. For County Water Company, no such adjustments exist, so a value of zero is entered.*

Step 2-2E. Total all adjustments. *The worksheet totals Lines 1A + 1B + 1C to give the sum of all adjustments (±) as shown on Line 1D. Here Line 1D = +137.72 mil gal.*

Table 2-5 Volume of water from own sources in mil gal for County Water Company (adjusted for meter error)

Source	Yearly Total: Uncorrected Metered Volume (UMV)*	Meter Accuracy (MA), percent	Meter Error Calculation UMV/MA† – UMV	Meter Error	Adjusted Metered Volume‡
1 Turnout 41	2,600.95	95	(2,600.95/0.95) – 2,600.95	+136.89	2,737.84
2 Well field	879.81	100	(879.81/1.00) – 879.81	+0.0	879.81
				+136.89	

* Based on Table 2-4.

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

‡ The 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 2-4. This is a way to double-check the arithmetic. The new total is not recorded on the worksheet—the "total adjustment due to meter error" is. This is only one of three adjustments that must be made to the raw data given in Table 2-4.

Table 2-6 Changes in reservoir storage for County Water Company

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

Step 2-2F. Determine the adjusted volume of water from own sources. *The worksheet calculates Line 2 = Line 1 ±1D to give the adjusted Volume from Own Sources listed as 3,618.48 mil gal.*

Step 2-3. Compile the volume of water imported from outside sources or purchased from other water utilities. Tables 2-3 and 2-4 include Source 3, which is an interconnection flowmeter on the "City Intertie." This meter registers water purchased from a neighboring water utility by County Water Company. Interconnections between water utilities usually 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. As with the data from "own sources," the data derived from "import" meters should be adjusted accordingly during the water audit. Often, however, these meter totals require no end-of-year adjustment because most water utilities monitor the data carefully and correct any inaccuracies as they are discovered throughout the year. A separate line is therefore not included for adjustments to the Volume of Water Imported on the worksheet in Figure 2-4. If this is desired, an adjustment can be created for "City Intertie" in the same manner as shown in Table 2-5. *Enter the Water Volume Imported (VI) on Line 3 of the worksheet in Figure 2-4. From Table 2-4, obtain the value of 783.68 mil gal for the City Intertie imported volume to County Water Company and enter it on Line 3.*

Step 2-4. Calculate system input volume. *The System Input Volume (SIV) is the total amount of water supplied into the distribution system and is obtained by adding the water Volume from Own Sources (VOS) to the water Volume Imported (VI). This calculation is Line 2 + Line 3 = Line 4 on the worksheet in Figure 2-4. The SIV for County Water Company is 4,402.16 mil gal.*

Step 2-5. Compile the volume of water exported to outside water utilities or jurisdictions. Any water volumes sent outside of the distribution system to a neighboring water utility should be monitored and adjusted with the same scrutiny given to imported water, for the same revenue implications exist. As with Volume of Water Imported, a separate line for adjustments is not included on the worksheet in Figure 2-4. *Enter this volume on Line 5 (BACE) on the worksheet in Figure 2-4. County Water Company exports no water to neighboring water utilities, so the value entered on Line 5 is zero.*

Step 2-6. Calculate the volume of water supplied into the distribution system. *The volume of water supplied to the distribution system is then calculated as Water Supplied (WS) which equals System Input Volume (SIV) minus Water Exported (BACE) and is included on Line 6 of the worksheet in Figure 2-4. Because Water Exported (BACE) equals zero, the worksheet calculation gives the same value of 4,402.16 mil gal as WS on Line 6.*

Task 3—Quantify Billed 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. TASK 3 and TASK 5 both describe how to quantify authorized consumption. TASK 3 deals with *billed* authorized consumption while TASK 5 details *unbilled* 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 into the distribution system should go 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 or quarterly basis. Metered water can be categorized as residential, industrial, commercial, agricultural, governmental, and other uses. Not all water utilities, however, meter 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.

Unbilled authorized consumption describes water taken irregularly in a variety of manners from nonaccount connections that typically do not supply permanent structures. Withdrawing water from fire hydrants is the most common example of such nonaccount 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 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, 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 be tracked in a billed account in the customer billing system. In this way, water consumption is monitored even though the property is issued a "no-charge" bill.

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

Step 3-1. Compile the volume of billed authorized consumption—metered water. Modern metering, automatic meter reading (AMR), and customer billing management technologies offer outstanding capabilities to 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 utilize computerized customer billing systems to store customer account data. AMR systems are being implemented by a growing number of water suppliers because of their cost effectiveness in gathering metered consumption data. 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 2-7 and 2.8, where consumption is summarized by meter size and customer consumption category, respectively.

Caution: Chapter 3 discusses the potential impacts to the integrity of consumption data caused by customer billing system operations (see p. 72). The auditor should develop a sound understanding of the customer billing system workings in order to ascertain the true amount of customer consumption and identify any billing system functions that unduly modify consumption data.

Step 3-1A. 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 from 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. In order 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, etc.

Step 3-1B. Maintain customer meter and AMR data. All active accounts should include the meter identification number, meter size, and meter type. If an AMR system exists, the automatic meter reading 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 system is compatible, readings should be collected from connected meters at times that coincide with the beginning and end of the water audit.

Step 3-1C. Compile metered consumption volumes for the water audit period. First, assemble the total (uncorrected) water consumption for all accounts and connections for each size of meter by month (or other billing period) and for the entire study period, as shown in Table 2-8. The same unit of measure as supply should be used—this may require performing a conversion, for example, from cubic feet to million gallons.

Enter the total value for residential, industrial, commercial, and metered agricultural consumption shown in Table 2-8 into Lines 7, 8, 9, and 10, respectively, in Figure 2-4. The worksheet calculates the sum of these four values in Line 11 as total Billed Authorized Consumption: Metered.

Step 3-1D. Adjust for lag time in meter readings. Corrections must be made to metered use data when the source-meter reading dates and the customer-meter reading dates do not coincide with the beginning and ending dates of the water audit period.

Table 2-7 Number of customer accounts and metered consumption by meter size for County Water Company: January 1, 2006–December 31, 2006

Meter Size, in.	Number of Accounts	Percent of Total Accounts	Percent of Metered Consumption
⅝	11,480	94.1	71.2
¾	10	0.08	0.1
1	338	2.8	2.8
1½	124	1.0	2.8
2	216	1.8	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

Table 2-8 Total metered water consumption by category for County Water Company (uncorrected)

2006 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, mil gal/d	6.35	1.34	0.27	0.97	8.93

Adjusting for one-meter route. For 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. Because customer meter readings do not coincide neatly with the study period, 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

$$33.204 \text{ mil gal} \times \frac{10 \text{ days}}{31 \text{ days}} = 10.711 \text{ mil gal} \qquad \text{(Eq. 2-2)}$$

  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. If sales for that month are 36.66 mil gal, the amount applicable to the water audit period is

$$36.66 \text{ mil gal} \times \frac{21 \text{ days}}{31 \text{ days}} = 24.83 \text{ mil gal} \qquad \text{(Eq. 2-3)}$$

  Thus, 24.83 mil gal is added to the consumption read on December 10.

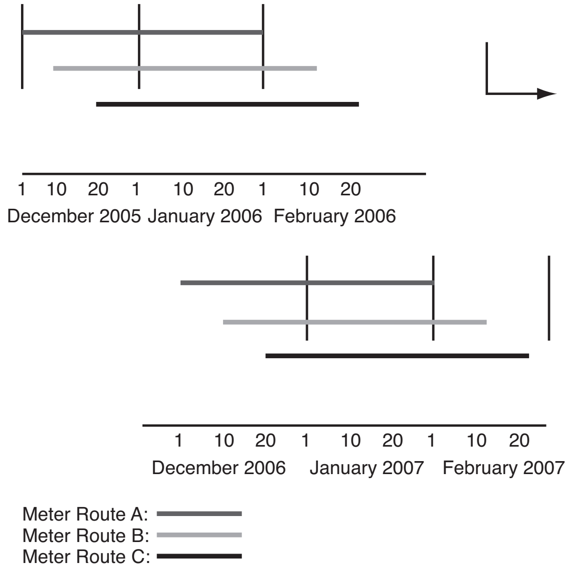
Adjusting for many-meter routes. The preceding discussion describes the basic method for correcting lag time in meter reading when all customers' meters are read on the same day. That seldom happens, however. Usually, meters are assigned to different routes and read on different days. Therefore, a meter lag correction should be used for each meter reading route, particularly if each customer's meter is read on the same date each month. Figure 2-5 gives an example of this.

A meter lag correction can involve a number of steps. In the example, County Water Company has three meter routes, each with its own reading date. The water audit period is one calendar year, and the consumption is prorated for each meter route or book. Meters are read bimonthly: route A on the first of the month, route B on the 10th of the month, and route C on the 20th of the month (see Figure 2-5).

The uncorrected total metered use (from step 3-1C, Table 2-8) is based on bills issued during the water audit period. However, because of the bimonthly billing schedule, these bills would not include all water consumed during the year. Some water shown as used in the first billing period (issued in February) actually occurred in the preceding December. The last set of bills, issued in November and December, would not include water consumed in December. Two corrections need to be made. First, water consumed in the month proceeding the water audit period 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 2-5 shows how to adjust sales figures for meter lag time. Many utilities combine accounting and billing procedures into a computerized format to make this procedure easier and quicker.

Prorate water sales figures to adjust for lag time in meter reading. Enter the net adjustment of +0.20 mil gal on Line 11A of the worksheet in Figure 2-4. The worksheet adds the net adjustment (±) in Line 11A to the total Billed Authorized Consumption:



The December through January billing period is 62 days long.

Route	Date Read	Sales	Adjustment
A	2/1/2006	4.0 mil gal	31/62 = 2.0 mil gal
B	2/10/2006	3.3 mil gal	21/62 = 1.1 mil gal
C	2/20/2006	3.6 mil gal	11/62 = 0.6 mil gal

Total adjustment to eliminate 2005 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	2/1/2007	4.2 mil gal	31/62 = 2.1 mil gal
B	2/10/2007	3.3 mil gal	21/62 = 1.1 mil gal
C	2/20/2007	3.9 mil gal	11/62 = 0.7 mil gal

Total adjustment to add December 2006 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 2-5 Detailed meter lag correction

Metered in Line 11 to give the adjusted Billed Authorized Consumption: Metered in Line 12. This value is 3,258.20 mil gal.

Step 3-2. Compile the volume of billed authorized consumption—unmetered water. The majority of North American drinking water utilities meter their customers and bill based on measured consumption. This is standard practice recommended by AWWA. However, not all utilities meter their customers; instead these 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;
- 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.

Without functional meters in place, the water auditor must devise an estimate of the water consumed by the unmetered population. A number of means exist to develop reasonable estimates. For instance, in an unmetered system, water meters could be installed in a small, representative sample of accounts (50 or 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. Any estimating process that is developed should be fully documented and based on current conditions. Unmetered accounts require the use of estimation that interjects a degree of error into the measure of customer consumption. For this reason, it is highly recommended that all customers be properly metered, read, and archived.

Include the total estimate of Billed Authorized Consumption: Unmetered on Line 13 of Figure 2-4. For County Water Company, this value is zero since the company meters and reads all accounts.

Task 4—Calculate Nonrevenue Water

Nonrevenue 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. Nonrevenue water consists of the sum of Unbilled Authorized Consumption (metered and unmetered), Apparent Losses, and Real Losses. In the top-down approach demonstrated in this chapter, nonrevenue water is calculated inversely as the remaining water into supply that is not recovered in Billed Authorized Consumption.

Step 4-1. Calculate nonrevenue water: *The worksheet in Figure 2-4 calculates nonrevenue water as the volume of water supplied minus the sum of the adjusted Billed Authorized Consumption: Metered and the Billed Authorized Consumption: Unmetered. This is shown on Line 14 in Figure 2-4. In this case, nonrevenue water = 4,402.16 – 3,258.20 = 1,143.96 mil gal.*

At this point in the worksheet, the cost impacts of the various loss components and nonrevenue water shall be calculated. The cost for nonrevenue water is the sum of the cost impacts for Unbilled Authorized Consumption plus Apparent Losses plus Real Losses. In this approach, the cost impacts of these components must be determined first and then summed to give the total cost impact of nonrevenue water. The calculation is given as Nonrevenue Cost = Cost of Line 15 + Line 16 (or 16A) + Line 17 = $1,764,296.

Task 5—Quantify Unbilled Authorized Consumption

As discussed previously, *unbilled* authorized consumption describes water taken irregularly in a variety of manners from nonaccount connections that do not typically supply permanent structures. Water utilities often allow water to be taken from fire hydrants for firefighting (their primary purpose), flushing, testing, street cleaning, construction, and other 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 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 authorized consumption is usually a small portion of the volume of WS. Based on the findings of numerous water audits worldwide, the worksheet in Figure 2-4 defaults to a value of 1.25 percent of the volume of WS for the water audit period for unmetered, unbilled authorized 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 5-1. Compile the volume of unbilled authorized consumption—metered water. 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 zero. This would shift such consumption into the category of Billed Authorized Consumption: Metered. Metered properties should exist in the customer billing system to the greatest extent possible.

Certain uses of water—such as fire flow tests—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.

Include the total of all metered Unbilled Authorized Consumption documented for the water audit period on Line 15 of Figure 2-4. For illustration, the manager of County Water Company tabulates a total of 15.42 mil gal valued at the composite customer retail rate of $3,945 for a total cost impact of $60,831.

Step 5-2. Compile the volume of unbilled authorized consumption—unmetered water: The most common occurrences of Unbilled Authorized Consumption: Unmetered 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
- Water consumption at public buildings not included in the customer billing system

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. Process water at treatment plants should be metered and exist in a billed account because water treatment plants are permanent structures. 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, the auditor may choose to use the default value of 1.25 percent of water into supply (WS) to represent this category of consumption. In this case *the worksheet in Figure 2-4 calculates the volume of Unbilled Authorized Consumption: Unmetered as 1.25 percent of the WS or (4,402.16 mil gal) (0.0125) = 55.03 mil gal valued at the composite customer retail rate of $3,945 for a total cost impact of $217,093. However, the manager of County*

Water Company suspects that Unbilled Authorized Consumption is greater than the value that the default percentage gives and decides to perform an analysis of this consumption, as described in the following section.

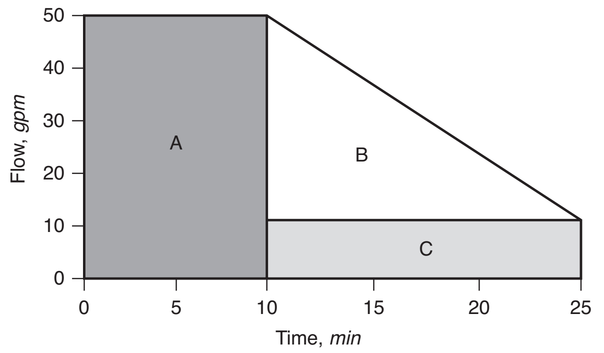
If the auditor feels that this consumption is notably greater than the default value, he or she can work to obtain detailed estimates of these components. This work can be time-consuming, and the auditor should use good judgment to determine whether the extra effort to analyze many undocumented occurrences of consumption is likely to lead to a consumption level greater than the default value. In most 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 Authorized Consumption: Unmetered greater than this amount.

To obtain reasonable estimates of Unbilled Authorized Consumption: Unmetered, the auditor can apply the most appropriate of the three estimating methods described in the following sections.

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.

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 2-6. Discharge is calculated as the area of the shapes in the graphic. Again, careful record keeping is necessary for accurate estimates.

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,



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 2-6 Calculation of water volume from variable-rate discharge 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 borrowed consumption figures will have to be adjusted considerably.

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

Step 5-2A. 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, flushing sprinkler systems, or hazardous-materials reduction performed by public safety crews. It also includes water for fire-fighter training, airport personnel, and other public safety employees and volunteers. This category does *not* include water drawn from ponds, rivers, or any water sources not connected to a piped water distribution system. It also excludes water used in separate, nonpotable fire 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 firefighting 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 under Step 5-2 earlier in this chapter. If the auditor has strong reason to believe that this consumption is significantly greater 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 greater than 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 firefighting 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 yield a good estimate of the water volume used by the fire department. 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 compete the survey, the more accurately the final estimate will reflect water used in testing, and in leaky or incorrectly connected sprinkler systems. However, the

Table 2-9 Sum of individual estimates of unbilled authorized consumption: unmetered

Item No.	Item Description	Volume, mil gal
5-2A	Fire fighting and training	9.70
5-2B	Flushing water mains, storm inlets, culverts, and sewers	2.55
5-2C	Street cleaning	1.75
5-2D	Landscaping/irrigation in large public areas	162.89
5-2E	Decorative water facilities	1.75
5-2F	Swimming pools	0.42
5-2G	Construction sites	0.56
5-2H	Water quality and other testing	1.2
5-2I	Water consumption at public buildings not included in the customer billing system	2.15
5-2J	Other	0.85
	Total unbilled authorized consumption: unmetered	183.82

auditor should be mindful to ascertain the time to conduct such a detailed survey; it should be well justified.

In the example of County Water Company, there are four fire companies in the service area. None of them make run reports. However, their logs show a total of 10 structural fires and a 5-day wildfire (for which water was airlifted from an open reservoir), plus 8 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 distribution system.

Add fire fighting and related consumption to determine the total consumption for fire fighting and training. Enter the sum of 9.7 mil gal on the first line in Table 2-9.

Step 5-2B. 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. 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. Flushing is also 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.

The County Water Company'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 on the second line in Table 2-9.

Step 5-2C. Street cleaning. Water is often used to clean roadways, walkways, boat ramps, bus stops, parking areas, bike paths, and similar areas. It 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 measure of water consumed in such practices. Table 2-10 shows how to calculate total street cleaning estimates using the batch procedure.

Table 2-10 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, gal		1,750,000

The manager for County Water Company estimates the amount of water consumed in street cleaning to be 1.75 mil gal. Enter the sum of 1.75 mil gal on the third line in Table 2-9.

Step 5-2D. 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 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 at each area. Time or moisture controlled irrigation systems make the calculation easier. When figuring the amount of time water is applied, the total time the service is discharging should be used, rather than the period for one lateral. Figure 2-7 demonstrates how to estimate the volume used for landscape irrigation.

The manager for County Water Company estimates the amount of water consumed in public landscaping irrigation to be 162.89 mil gal. Enter this value on the fourth line in Table 2-9.

Step 5-2E. 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 the category of billed metered consumption. Otherwise the following estimation methods can be used.

Evaporation is appreciative generally only in large, standing bodies of water. In most cases, decorative fountains, waterfalls, and similar facilities are relatively small, and therefore no calculation for evaporative loss is necessary. If large, standing bodies of water, such as large open water supply reservoirs, exist in warm climates with plenty of sunshine, evaporative losses should be determined. The auditor should 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 in order to determine this calculation.

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

$$V \times F = V_w \qquad \text{(Eq. 2-4)}$$

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:

$$Q_b \times T = V_b \qquad \text{(Eq. 2-5)}$$

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

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 2-7 Estimating landscape irrigation 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, 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 County Water Company 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 on the fifth line in Table 2-9.

Step 5-2F. 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 estimating 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 not uncommon 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 County Water Company estimates the amount of water consumed in swimming pool management to be 0.42 mil gal. Enter this sum on the sixth line in Table 2-9.

Step 5-2G. 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 in order to obtain the volumes consumed during this work.

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. The practice of shutting off supply at unmetered sites should be compared with the practices at metered sites and compensated for the difference. Establishing bulk water stations to provide water for such use should be considered to assist accountability, efficiency, and positive revenue stream for the water utility (see sidebar on page 37).

The manager for County Water Company estimates the amount of water consumed at construction sites to be 0.56 mil gal. Enter this sum on the seventh line in Table 2-9.

Step 5-2H. 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 manager for County Water Company estimates the amount of water consumed during water quality and other testing to be 1.2 mil gal. Enter this sum on the eighth line in Table 2-9.

Step 5-2I. 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 in the water utility customer billing system. Many municipal water utilities have policies not to bill their own municipal and 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. Estimates can be formulated by comparing buildings to metered locations of similar size and function. 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.

The manager for County Water Company estimates the amount of water consumed at public buildings to be 2.15 mil gal. Enter this sum on the ninth line in Table 2-9.

Step 5-2J. Other. An unmetered but verifiable use may not fit any of the categories previously described. In that case, the best means for estimating the total volume used should be determined and included in the "Other" category.

The manager for County Water Company estimates the amount of water consumed at a variety of miscellaneous uses to be 0.85 mil gal. Enter this sum on the ninth line in Table 2-9.

Step 5-2K. Sum of all components of unbilled authorized consumption: unmetered. Each of the individual estimates obtained under 5-2A through 5-2J as shown in Table 2-9 should be added.

The total estimate of Unbilled Authorized Consumption: Unmetered is 183.82 mil gal. Because this amount is greater than the default calculation of 55.03 mil gal on Line 16 of the worksheet, the manager enters 183.82 mil gal on Line 16A. The worksheet therefore uses the larger of these two values—183.82 mil gal from Line 16A in the further calculations. This water volume is valued at the composite customer retail rate of $3,945 for a total cost impact of $725,170.

The following are several insights regarding Unbilled Authorized Consumption: Unmetered. First, careful policy considerations should be employed regarding water withdrawn from fire hydrants (see sidebar on page 37). Also, how unmetered consumption instances can eventually become metered accounts should be considered. Over time, water utility managers should attempt to establish permanent metering at unmetered sites, particularly if they are permanent structures, such as municipal buildings. Finally, while these types of consumption may not provide revenue to the water utility, they should not be wasteful. There should be consideration for how water efficiency

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

An important question for water utility managers: Are the 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 to use recreationally 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 Authorized Consumption: Unmetered in the water audit and includes street cleaning, filling public swimming pools, providing transient supplies (such as nonpotable supply to a traveling circus), community gardens, and 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

- 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 as fire hydrants are usually configured to face the street. The public (often children) is pushed by water under high pressure into the roadway to compete with 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.

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.

Task 6—Quantify Water Losses

Water losses are made up of apparent and real losses. In the top-down water audit approach, water losses are determined as nonrevenue water minus the sum of Unbilled Authorized Consumption: Metered and Unmetered.

The worksheet in Figure 2-4 calculates the volume of water losses as: water losses (WL) = NRW – (UACM + UACU). For County Water Company, WL = 1,143.96 – (15.42 + 183.82) = 944.72 mil gal. The cost impact of water losses can be calculated by summing the costs of Apparent Losses and Real Losses (Line 24 + Line 25) and equals $978,295.

Task 7—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 distort customer consumption data and cost water utilities revenue when accounts are underbilled. Apparent losses are comprised of

- Customer meter inaccuracy,
- Systematic data handling error, and
- Unauthorized consumption.

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

Step 7-1. Estimate customer meter inaccuracy. In Chapter 3, the Customer Meter Inaccuracy section gives background information on customer metering. For water utilities with unmetered customer consumption, there is no amount of apparent loss caused by customer meter inaccuracy, and 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 consumption. This is good industry practice supported by AWWA. Meters are subject to wear and loss of accuracy with continued use. Another common source of meter inaccuracy occurs when meters are oversized 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. Historically, meter sizing calculations have been based on conservative techniques, which resulted in a significant percentage 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. The degree of inaccuracy in the meter population at any point in time depends on 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 of the meter population by the water utility management. Taking these factors into account, the water auditor can determine an estimate of the amount of water lost to the inaccuracy of customer meters.

Because there are typically many thousands of customer meters in any drinking water utility, it is not practical to inspect and test every one each year. Instead, annual inspections and testing should consider large meters sized 2 in. and larger, along with a random sample of smaller meters. As a minimum, it is important to ensure that

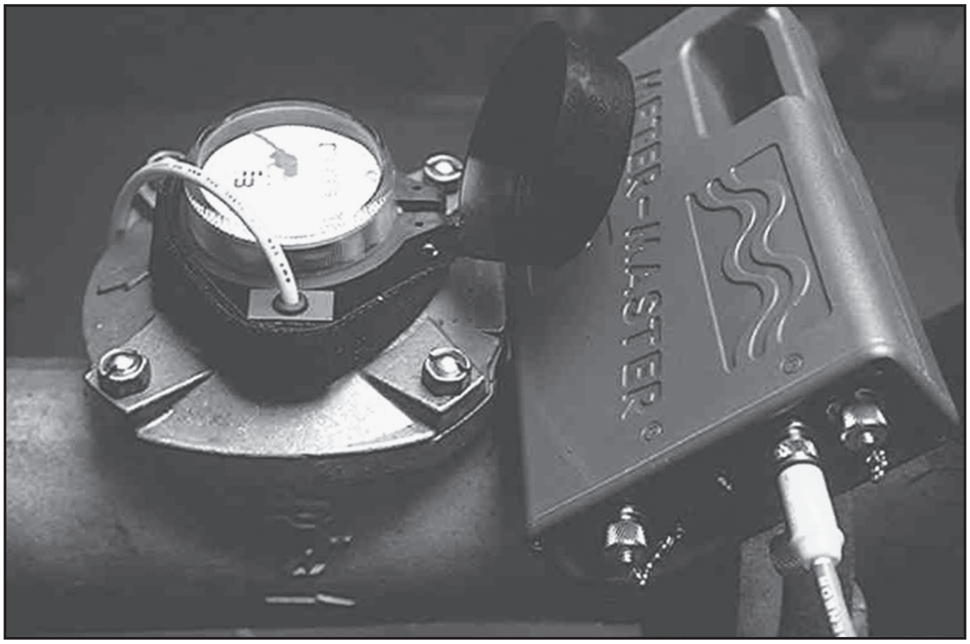


Figure 2-8 Customer meter flow recorder (Courtesy of F.S. Brainard and Co.)

the meters serving the largest users are sized properly and maintained on a regular basis.

Step 7-1A. Check for proper installation. The utility's practices on meter selection, sizing, and installation should be reviewed to determine whether or not present practices permit accurate operation. 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*, and AWWA Manual M22, *Sizing Water Service Lines and Meters*.[3]

Industrial, commercial, and agricultural meters register a much larger portion of consumption and produce a much larger share of revenue per account than do residential meters. Industrial and commercial accounts should be inspected for proper selection, sizing, and installation. In addition, all large meters should be inspected and tested before they are used. Not all new meters are sufficiently accurate.

Meter right-sizing programs. Traditional meter sizing approaches were conducted conservatively 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. Meter right-sizing programs can recoup much of that loss with significant gains in billed consumption. Flow recorders, such as shown Figure 2-8, can provide accurate flow rate data and meter sizing decisions.

Step 7-1B. Test residential meters. A random sample of residential meters should be tested; 50 to 100 is 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 test bench or sent to the factory or a consultant for testing. (For more information see AWWA Manual M6, *Water Meters—Selection, Installation, Testing, and Maintenance.*)

Table 2-11 Weighting factors for flow rates related to volume percentages for ⅝-in. and ¾-in. water meters*

Percent of Time	Range, gpm	Average, gpm	% Volume†
15	Low 0.50–1.0	0.75	2.0
70	Medium 1–10	5.00	63.8
15	High 10–15	12.50	34.2

* Based on information from Tao, Penchin, "Statistical Sampling Technique for Controlling the Accuracy of Small Meters," *Journal AWWA*, 6:296 (1982).

† 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 2.0 percent of the total water consumed occurs at the low-flow range of approximately 0.5–1.0 gpm.

Instead of using the percentage of volumes shown here, the utility may compute its own percentage volume data. Using special dual-meter yokes and recording meters, the utility can determine the actual flow rates for their water meters.

Table 2-12 Meter testing data from a random sample of 50 meters for County Water Company

Test Flow Rates, gpm	Mean Registration, %
Low (0.25)	88.8
Medium (2.0)	95.0
High (15.0)	94.0

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 specific 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 can 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 meter replacement programs offer an excellent opportunity to ensure that older meters are replaced with the correct type and size new meters. Flow recorders 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.

Step 7-1C. Calculate total customer consumption meter error. Total customer consumption meter error includes meter errors from all meter sizes, including residential, industrial, commercial, agricultural, and others. In general, meter error can be assessed for small meters (⅝ and ¾ in.) considered residential use and all other (large) meters, which include industrial, commercial, agricultural, and others.

Calculate residential (small) meter error. Residential meters are tested for 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 2-11 through 2.13 demonstrate how to use existing meter test data to calculate total residential meter error. The data in the tables are based on Table 2-8.

Table 2-13 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 (ME), mil gal
2.0	2,318..8	46.38	88.8	[(46.38/0.888) – 46.38]	5.85
63.8	2,318.8	1,479.39	95.0	[(1,479.39/0.95) – 1,479.39]	77.86
34.2	2,318.8	793.03	94.0	[(793.03/0.94) – 793.03]	50.62
		Total residential meter error (Line 18 of Figure 2-4)			134.33

* Data from Table 2-11.

† Based on residential water sales data in Table 2-8.

‡ Data from Table 2-12.

Table 2-14 Volume percentages for large meters for County Water Company*

Flow Rates	% Volume Delivered
Low	10
Medium	65
High	25

* For this example, assume flow recordings were made for 24 hr in July and February to indicate the percent of volume delivered by large meters at low-, medium-, and high-flow rates.

Enter the resulting residential meter error from Table 2-13 on Line 18 of the worksheet shown in Figure 2-4. For County Water Company, this is 134.33 mil gal with a cost impact at $4,142 per mil gal or a total of $556,395.

Calculate industrial/commercial (large) meter error. Tables 2-14 through 2.16 show how to use existing meter test data to calculate total large meter error. The mean registration data in Table 2-14 are used to calculate the meter error for large meters. One of the benefits of a water audit is the potential increase in revenue resulting from testing, repairing, or right-sizing large meters (performed as part of the water audit). The auditor can estimate the amount of revenue to be gained by improving the function of large meters by applying the appropriate cost factor.

Enter the resulting commercial/industrial meter error from Table 2-16 on Line 19 of the worksheet shown in Figure 2-4. For County Water Company, this is 29.97 mil gal with a cost impact at $3,627 per mil gal or a total of $108,701.

Step 7-2. Estimate systematic data handling error. The reader is directed to Chapter 3, section Systematic Data Handling Errors for background information. For water utilities that meter customer consumption, integrity must exist not just with the accuracy of the meter but also with the processes to 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 error can therefore occur anywhere from the time that the meter reading is registered to the final reporting and use of the consumption data.

Table 2-15 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 percent of registration)		
						Low	Medium	High
XYZ001	3	Turbine	June 1991	Sensus	Oct 2006	89	93	100
X00ZAA	3	Turbine	June 1993	Sensus	Oct 2006	70	95.2	98
NB123	4	Displace	July 1980	Sparling	Oct 2006	95	99	102
NB456	6	Compound	Sept 1977	Sparling	Oct 2006	98	96.5	102
AA002	6	Propeller	May 1966	Hersey	Oct 2006	98	99	103
				Sum of mean registrations		450	482.7	505
			Mean registration for five meters tested			90	96.54	101

Table 2-16 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)[‡], percent	Meter Error (ME) ME = Vf/(0.01R) – Vf, mil gal	Meter Error (ME), 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]	21.86
25	939.2	234.80	101.0	[(234.80/1.01) – 234.80]	–2.32
		Total meter error for large meters (Line 19 of Figure 2-4)			29.97

* Data from Table 2-14.

† Data from Table 2-8 sum of industrial, commercial, and agricultural metered consumption.

‡ Data from Table 2-15.

Step 7-2A. 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 (AMR). Manual meter reading, with meter reading personnel visiting individual meters to collect readings, is the traditional approach and, as of the final draft of this publication, still used by more than 60 percent of water utilities in North America. In many systems, however, manual reading is being supplanted by AMR, which is usually more accurate, less labor intensive, safer, and typically more cost effective than manual meter reading. AMR has a strong history in the gas and electric utility industry, with implementation in the water industry growing in the past 15 years. Many very successful case studies in water utility AMR have occurred; an example of which is given in the sidebar on page 44. AMR has greatly reduced the accessibility and safety problems that have plagued manual meter reading programs. Radio signals transmit the current meter reading to a device 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 hand-held devices, or more economically, via vans patrolling scheduled meter reading routes, in which multiples readings are gathered almost simultaneously. Fixed-network AMR is starting to emerge as the more comprehensive and effective means of data collection. Fixed networks typically include permanently installed data collector units located strategically across the service area. While the traditional AMR systems gather single meter readings every 30 days or more, fixed-network or data logging AMR systems generate detailed customer consumption profiles by obtaining readings as frequently as every 15 minutes. By collecting more granular data in this manner, fixed-network or data logging AMR 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. The metering and meter reading industry are creating greatly expanded capabilities at the customer end point and label this new functionality under the heading *Advanced Metering Infrastructure (AMI)*. In addition to the above capabilities, AMI includes functions such as backflow detection and tamper detection, and more end-point capabilities are likely to be developed in the future.

While AMR is less susceptible to data handling error, 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. With growing numbers of working couples in families, 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 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 attempts can fail due to a malfunction of the automatic meter reading 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 or meter reading equipment.

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 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 revenue collection functions.

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 could occur in unoccupied buildings) or whether AMR failure or tampering has occurred. Other sources of systematic data transfer error can exist in any given water utility. Depending on the time and resources available to the auditor, investigations can be conducted to assess

The Benefits of Automatic Meter Reading 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 out of every seven water bills issued was based upon an actual meter reading; six were based on estimates. With the installation of over 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 error and unauthorized consumption in the City of Philadelphia.

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.

Enter the quantity attributed to data transfer errors on Line 20 of the worksheet shown in Figure 2-4. For County Water Company, the manager analyzes Apparent Losses related to several different meter data collection functions including meter reading error, estimating error, and computer programming error. The manager estimates the total of error identified in these areas to be 12.57 mil gal with a cost impact at $3,945/mil gal for a total of $49,589.

Step 7-2B. Systematic data analysis errors. Typically meter readings are transferred to customer billing systems where they are used to calculate the volume of customer consumption occurring 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 registered consumption data. An important question is: Are billing adjustments triggered by modifying actual consumption volumes? As described in the sidebar on page 72, billing systems designed with good revenue collection intention 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.

Table 2-17 gives an example of a 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 2002, the water utility was unable to obtain a reliable meter reading at this property. This may have been caused by blocked access to the 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 2004. During the period without 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 2003, when the property was vacated and placed for sale. The property was vacant until August 2003 and experienced only minimal water consumption during periodic caretaker visits from April to August 2003. Upon sale to a new owner in August 2003, a regular pattern of water consumption resumed but at a slightly lower rate than the previous owner.

Between April 2003 and August 2004 (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 2004 meter reading (42477) was overstated by a total of 4,132 ft^3 since the last accurate meter reading in September 2002. This resulting cumulative overestimation error was compounded by

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

When an accurate meter reading was obtained in August 2004, an adjustment of negative 4,132 ft^3 cubic feet 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 operational (*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 2004 is *negative* 4,132 ft^3. While a negative consumption number is acceptable for use for billing (financial) reasons as it translates into a monetary credit, a negative consumption number is unacceptable for operational (engineering) purposes because the actual consumption for August 2004 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 2-17 for conservation or loss control purposes would be in error by 3,840 ft^3 (10,620 – 6,780) over the actual consumption in 2003. Conversely, the analysis would be understated for this account by 3,967 ft^3 (8,915 – 4,948) in 2004. 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 multi-year 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,

Table 2-17 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), ft^3	E Cumulative Billed Water Consumption (per year), ft^3	F Actual Meter Reading	G Actual Consumption, ft^3	H Cumulative Actual Consumption, ft^3
2001	Dec	15004			15004		
2002	Jan	15838	834	834	15383	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	23867	860	8,863
	Nov	24777	885	9,773	24722	855	9,718
	Dec	25662	885	10,658	25535	813	10,531
2003	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
2004	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
2005	Jan	41951	721	721	41951	721	721

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 separate fields for customer consumption: one for *registered* consumption and a separate field for *billed* consumption. Using the same data from the example in Table 2-17, the form of the data with separate fields is shown in Table 2-18.

Table 2-18 includes separate columns for billed consumption (Column D) and registered consumption (Column G). When actual meter readings resumed in August 2004, 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 difference between the two most recent actual meter readings (September 2001 and August 2003). This one-time estimate is determined as

$$(38345 - 23007)/23 \text{ months} = 667 \text{ ft}^3 \qquad \text{(Eq. 2-6)}$$

By September 2004, 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 2004 in Column E and Column H, or 4,948 and 9,747 ft^3, respectively. If only a single field is used for consumption, the billed value of 4,948 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 2004.

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. If a significant understating of customer consumption has occurred, an estimate of this difference should be included as an apparent loss and entered onto Line 21 of the worksheet shown in Figure 2-4.

Enter the quantity attributed to systematic data analysis errors on Line 21 of the worksheet shown in Figure 2-4. For County Water Company, the manager estimates this to be 8.72 mil gal with a cost impact of $3,945/mil gal or a total of $34,400.

Step 7-2C. 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 3 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

- Despite company goals to meter all customers, the installation of meters in certain customer classes is ignored; 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.

- Poor customer account management: accounts not initiated, lost, or transferred erroneously.

Table 2-18 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 2-17)

A Year	B Month	C Meter Reading (estimates shown in gray)	D Billed Consumption (current minus previous meter reading, estimated consumption shown in gray), ft^3	E Cumulative Billed Water Consumption (per year), ft^3	F Actual Meter Reading	G Registered (actual) Consumption, ft^3	H Cumulative Registered (actual) Consumption, ft^3
2001	Dec	15004			15004		
2002	Jan	15838	834	834	15383	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
2003	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
2004	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
2005	Jan	41951	721	721	41951	721	721

The degree to which such shortcomings in billing account management exists is largely dependant 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 down to 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.

Enter the quantity attributed to policy and procedure shortcomings on Line 22 of the worksheet shown in Figure 2-4. For County Water Company, the manager estimates this to be 11.63 mil gal with a cost impact of $3,945/mil gal or a total of $45,880.

Step 7-3. 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 and fire-fighting systems (unmetered fire lines);
- Vandalized or bypassed 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; or
- Illegally opening 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 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. Yet, in most cases for systems of all sizes, the total annual volume of water lost to unauthorized consumption is likely to be a small portion of the utility water into supply volume. For expediency during the top-down water audit, the auditor may choose to use the default value of 0.25 percent of WS. This percentage has been found to be representative of this component of loss in water audits compiled worldwide. In this case, *the worksheet in Figure 2-4 calculates the volume of Unauthorized Consumption in Line 23 as 0.25 percent of the WS. For County Water Company, the manager determines that he does not have sufficient time to fully investigate the occurrence of unauthorized consumption, although he knows that a certain amount of such consumption occurs. He therefore uses the default estimate calculation of (WS) (.0025) = (4,402.16) (.0025) = 11.00 mil gal with a cost impact of $3,945/mil gal for a total of $43,395.*

For small systems, the occurrence of unauthorized consumption may be a larger portion of distribution system input flow. 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.

If an actual quantification of unauthorized consumption is obtained, this value can be entered in Line 23A and used in place of the default estimate listed in Line 23.

Step 7-4. Calculate total apparent losses. The total apparent losses are determined by adding all apparent loss components for customer meter inaccuracy, systematic data handling error, and unauthorized consumption.

The worksheet in Figure 2-4 calculates the total volume of apparent losses in Line 24 as AL: Sum of Apparent Losses = ALMUR1 + ALMUR2 + ALDHE1 + ALDHE2 + ALDHE3 + UC. For County Water Company, the total volume of apparent losses calculates to be 208.22 mil gal with a cost impact of $838,360 of lost revenue.

Task 8—Quantify Real Losses

Water losses consist of the apparent losses plus the real losses occurring in the drinking water utility operations and management. While practical methods to quantify leakage in distribution systems exist (see Chapter 5), the top-down water audit approach mathematically calculates real losses simply as water losses minus apparent losses.

The worksheet in Figure 2-4 calculates the volume of Real Losses in Line 25 as Real Losses (RL) = Water Losses (WL) – Apparent Losses (AL), or (944.72 – 208.22) mil gal = 736.50 mil gal; at a cost impact of (736.50 mil gal) ($190/mil gal) = $139,935. Once the value of Real Losses is calculated, the value of Real Losses per day that the system is pressurized (default days = 365) is calculated in Line 26 as (736.50 mil gal)/(365) = 2.02 mgd.

While this straightforward approach 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 leftover after consumption and apparent losses have been quantified. The reliability of the amount of leakage losses is therefore only approximate because

- The accumulated errors from the other components will be associated with 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

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

These methods are discussed in Chapters 4 and 5.

Task 9—Assign Costs 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, 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 worksheet in Figure 2-4 provides for costs for each of the pertinent components in the water audit to be assigned in the column shown on the right side of the worksheet.

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. (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 9-1. Determine cost impact of apparent loss components. Because apparent losses represent water supplied but not paid for, these losses should be valued at the prevailing retail rate charged to customers. Many water utilities, however, have multiple rates in place for different customer classes such as residential, commercial, or industrial. Also, many utilities include wastewater charges based on the volume of water consumption. Various rate structures are also used: increasing block (conservation) structures, decreasing block structures, as well as surcharges, discounts, and waivers. The auditor should review the rate structure to gain familiarity with the cost impact of apparent losses. For practicality, however, various sub-rates should likely be grouped into only two to four categories to avoid having too many cost categories involved in the water audit. Even a single composite rate can be used for simplicity. The water audit shown in Figure 2-4 lists three rates: a small meter (residential) charge, a large meter (industrial/commercial) cost, and a composite cost (between these two values).

Step 9-2. Determine cost impact of real loss components. Assessing costs for real losses can be complex, but the methods included in this publication recommend keeping the evaluation simple. Real losses include water that has been extracted from a water resource 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. Treatment and delivery costs include the variable costs to produce the water, or the costs to produce the next million gallons (or other standard increment) of water. If the water supplied is purchased from a neighboring water utility, the purchase unit cost should be applied. Generally, unit costs for treatment (chemicals, power) and delivery (pumping power costs) can be readily determined, and these costs will suffice for the water audit.

While not recommended for inclusion in the top-down water audit, it is worth noting that other long-term costs also exist for real losses. The cost of wear and tear on treatment and pumping equipment might be taken into account in the supply costs, particularly if real losses are high. 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, they are not included in this manual. Work is underway to devise user-friendly ways to quantify such impacts.

Another situation for consideration is that of a water utility facing constrained water resources with water 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 worksheet in Figure 2-4 provides for entry and summation of costs for all components of the water balance, as shown in the column on the far right. As listed, the cost impact to County Water Company caused by apparent losses is $838,360, and the cost impact caused by real losses is $139,935.

Task 10—Calculate the Performance Indicators

The IWA/AWWA Water Audit Method published in *Performance Indicators for Water Supply Services* (2000)[1] includes a highly useful array of performance indicators, which represent one of the greatest strengths of the method. With this publication, 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 2-19 and are endorsed by the AWWA Water Loss Control Committee. In 2006, the second edition of the IWA/AWWA publication was published with changes to the structure of several of the performance indicators.[4] The Water Loss Control Committee has not undertaken a review of these changes and remains in support of the performance indicators published in the first edition. These performance indicators appear throughout this manual and the AWWA Water Loss Control Committee's 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. A number of flaws existed in this approach, including

- 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 the fact 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 applied in the development of the IWA/AWWA method to specifically define the nonrevenue water by volume indicator. This new indicator has value but only as a high-level financial indicator, and it is not sufficiently detailed to be useful as an operational indicator.

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 detailed indicators (3). The method includes performance indicators at each of these levels as shown in Table 2-19.

The full array of performance indicators can be calculated on completion of the water audit. Individually, these indicators give good insight to the loss standing in particular functional areas. Collectively, they give a very realistic, objective assessment of overall loss standing and are viewed as the current best practice means to assess water loss standing in water utilities.

Step 10-1. Calculate the 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. The first indicator is expressed as a percentage of the volume of nonrevenue water over the system input volume and labeled as Fi36 on Table 2-19. This performance indicator is closest in its definition to

Table 2-19 IWA/AWWA Water Audit Method—Performance indicators

Function	Level*	Code*	Performance Indicator	Comments
Financial: Nonrevenue water by volume	1 Basic	Fi36	Volume of nonrevenue water as a percentage of system input volume	Easily calculated from the water balance, has limited value in high-level financial terms only; it is misleading to use this as a measure of operational efficiency
Financial: Nonrevenue water by cost	3 Detailed	Fi37	Value of non-revenue water as a percentage of the annual cost of running the system	Incorporates different unit costs for nonrevenue components, good financial indicator
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/psi] (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)	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	3 Detailed	UARL	UARL (gal) = (5.41Lm + 0.15Nc + 7.5Lc) × P, (Eq. 2-7) Where: Lm = length of water mains, mi Nc = number of service connections Lc = total length of private service connection pipe, mi = Nc × average distance from curb stop to customer meter, Lp (see Figures 2-9 through 2-11 to determine L_p) 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 is not valid for systems with less than 3,000 service connections.
Operational: Real Losses	3 Detailed	Op25	ILI (dimensionless) = CARL/UARL	Ratio of Current Annual Real Losses (CARL) to Unavoidable Annual Real Losses (UARL); best indicator for comparisons between systems

* Descriptors assigned to the performance indicators are from the IWA publication *Performance Indicators for Water Supply Services*, 2000.

the conceptual unaccounted-for water percentage used inconsistently in the past. However, by employing the specifically defined *nonrevenue* water in the numerator, this performance indicator avoids the inconsistencies that have crippled the interpretation of unaccounted-for water. 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, it is not useful as an operational performance indicator.

As shown in Figure 2-4, the Fi36 financial performance indicator for County Water Company is calculated to be 25.9 percent.

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 nonrevenue water over the total annual cost of running the water supply system (Fi37). These 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. These costs should not include any costs to operate wastewater, biosolids, or other systems outside of drinking water. This 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 used when issuing bonds, setting water rates, or employing other financial functions typically undertaken by water utilities.

For County Water Company, the Fi37 financial performance indicator is calculated to be 18.3 percent. Because the Fi37 (Level 3) indicator is a more detailed indicator than Fi36 (Level 1), its value of 18.3 percent is a better reflection of the financial impact of losses occurring in County Water Company. On its own, the Fi36 indicator appears to overstate the impact of losses on this utility.

Step 10-2. Calculate the operational performance indicators. The method also includes five operational performance indicators, the greatest number of indicators in any of the three functional areas. These indicators range in levels of detail from 1 (high level) to 3 (detailed). As shown in Table 2-19, one performance indicator exists for apparent losses and four indicators exist for real losses.

Step 10-2A. Apparent losses normalized. This performance indicator (Op23) measured in gallons of apparent loss per service connection per day is effective is assessing apparent loss standing and is useful to monitor 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 to be recovered, a portion of which can often occur with very modest recovery effort.

For County Water Company, the Op23 performance indicator is calculated to be 46.8 gallons per service connection per day. The cost impact of apparent losses for 2006 is $838,360.

Step 10-2B. Real losses normalized. Two normalized performance indicators exist for real losses; a basic indicator and an intermediate indicator. The basic indicator (Op24) is measured in gallons of real loss per service connection per day. However, for water utilities with a low density of service connections (such as rural systems), the indicator is measured in gallons per mile of main per day. Those systems that have a system-wide average density of less than 32 service connections per mile of main should apply the latter indicator.

For County Water Company, the Op24 performance indicator is calculated to be 165.4 gallons per service connection per day. The cost impact of real losses for 2006 is $139,935.

The intermediate version of the Op24 performance indicator for real losses is expressed in gallons per service connection per day per psi. For low density of connections, the units are gallons of real loss per miles of main per day per psi. The value for pressure is the average distribution system pressure across the system boundaries from in the water audit. The sidebar on pages 56–58 offers guidance on calculating the average system pressure. The same delineation of 32 service connections per mile of main distinguishes low-density systems.

For County Water Company, the intermediate version of the Op24 performance indicator is calculated to be 2.54 gallons per service connection per day per psi of average system pressure.

These performance indicators are 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 these measures should be observed.

Step 10-2C. Infrastructure leakage index (ILI). The infrastructure leakage index (ILI) is a performance indicator designed for benchmarking of leakage standing among water utilities. The ILI is the ratio of the level of current annual real losses (CARL), from the water audit, to the unavoidable annual real losses (UARL). The UARL is a reference 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 if all of the current best leakage management efforts could be exerted. Equation 2-7 calculates the UARL and is shown in Table 2-19. The data needed to calculate the UARL are typically available to water utility staff and include

- The total length of water main piping in the distribution system, mi
- The total number of fire hydrants and average hydrant lead length (from water main to hydrant barrel), ft
- The average pressure across the distribution system, psi (The sidebar on pages 56–58 offers guidance on calculating average system pressure)
- The number of customer service connections
- The miles of service connection piping maintained by the water utility (taken as the average length of a service connection piping under utility responsibility multiplied by the total number of service connections and converted from feet to miles). 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. As shown in Figure 2-4, this parameter is calculated by multiplying the value of Lp by the number of service connections, Nc. Figures 2-9 through 2-11 show the definition of the Lp value in various customer service connection piping and metering configurations.

It can be seen that the structure of the UARL calculation is specific to the individual water utility. Hence, the UARL for a relatively large system with high pressure will be higher than a small system with moderate or relatively low pressure. This system-specific approach portrays the utility's real loss standing in an objective manner, rather than a "one level fits all" approach.

The derivation of the UARL calculation is given in Tables 2-20 and 2-21. The UARL calculation was devised by the IWA Water Loss Task Force during its development of the water audit methodology. In conducting work to develop a reliable benchmarking performance indicator (the ILI), the task force determined to devise a means to evaluate the technical low limit of leakage that could be achieved in a given water distribution system. It is recognized that leakage in any water

DETERMINING AVERAGE SYSTEM PRESSURE IN A WATER UTILITY DISTRIBUTION SYSTEM

Water utility managers need to understand the variation of water pressure across their distribution systems in order to assess the potential for improved pressure management, and to calculate their level of UARL using Equation 2-7 in Table 2-19.

The UARL is typically calculated for the entire water distribution system, and the average pressure across the network is one of the inputs into Equation 2-7. It is recognized that, while 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 4 and 5 discuss pressure management.

Calculating Average Pressure Across a Water Distribution System

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

- The use of a calibrated hydraulic model, which can provide pressures at nodes across the water distribution system under various water demand conditions. The average of pressures across the system can easily be calculated by the data from this model. If a hydraulic model does not exist for the water distribution system, one of the following methods should 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 averaged to obtain the average pressure across the entire distribution system.

An example calculation from the last of the method methods is shown on page 57. The example focuses on one region of County Water Company's service area: the downtown region. The water piping grid for this region is shown on page 58. Fire hydrant locations are shown as well as ground-elevation contours, at 10-ft contour intervals. The ground elevation of this region varies from 850 ft above sea level to more than 910 ft above sea level.

DETERMINING AVERAGE SYSTEM PRESSURE IN A WATER UTILITY DISTRIBUTION SYSTEM (continued)

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

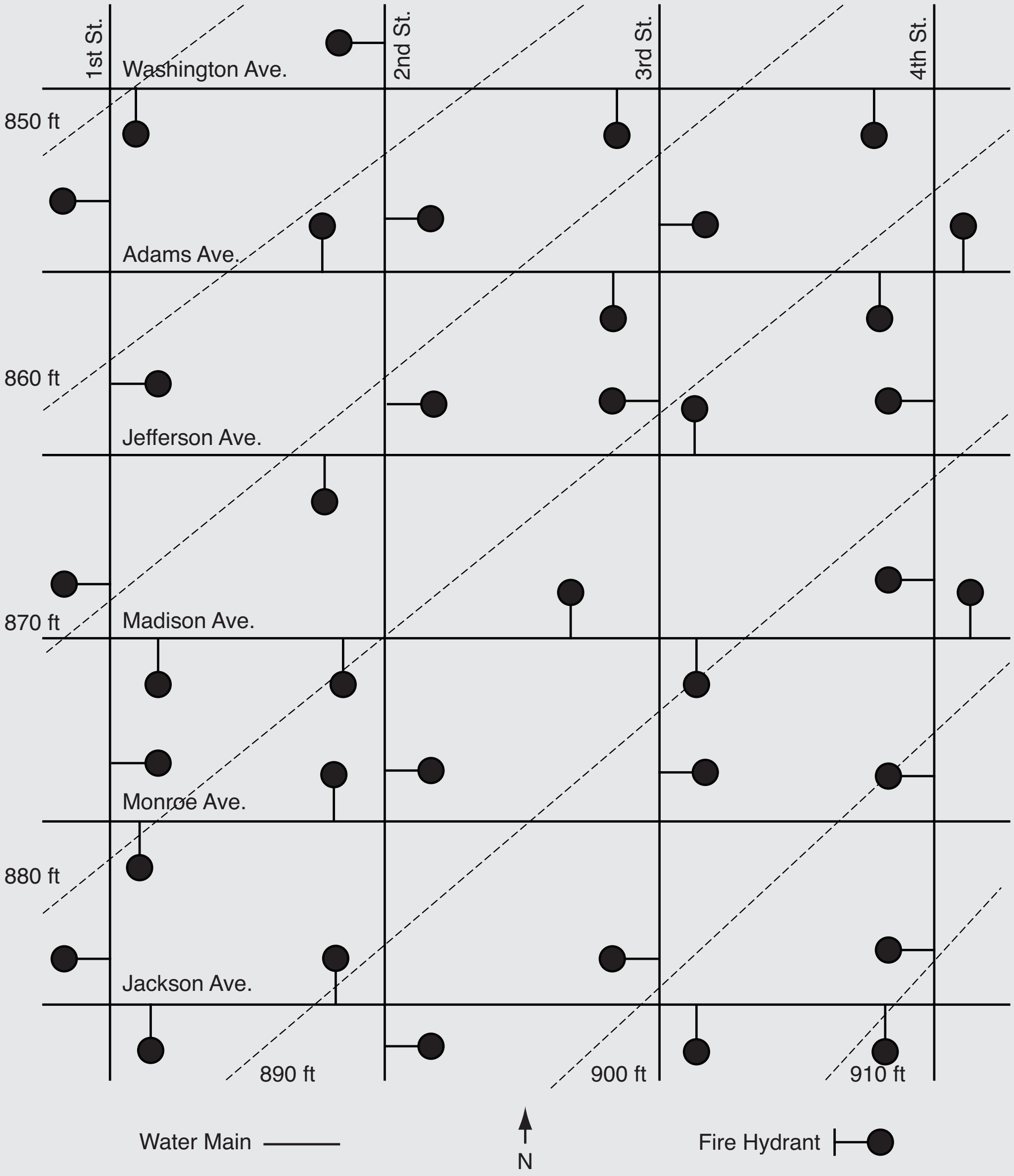
Street	Cross Street	Elevation	Street	Cross Street	Elevation
Washington	1st	850	Washington	W. of 3rd	865
1st	N. of Adams	854	3rd	N. of Adams	872.5
1st	N. of Jefferson	861.5	Adams	W. of 3rd	873
1st	N. of Madison	869	3rd	N. of Jefferson	879.5
Madison	1st	872.5	Jefferson	E. of 3rd	882
1st	N. of Monroe	877.5	Madison	W. of 3rd	885
Monroe	1st	879.5	Madison	E. of 3rd	888.5
1st	N. of Jackson	883	3rd	N. of Monroe	892.5
Jackson	1st	886	3rd	N. of Jackson	899
2nd	N. of Washington	854.5	Jackson	E. of 3rd	902
2nd	N. of Adams	863	Washington	W. of 4th	874.5
Adams	W. of 2nd	862	Adams	E. of 4th	883
2nd	N. of Jefferson	871	Adams	W. of 4th	882
Jefferson	W. of 2nd	871	4th	N. of Jefferson	887
Madison	W. of 2nd	879	4th	N. of Madison	893
2nd	N. of Monroe	885	Madison	E. of 4th	898
Monroe	W. of 2nd	884.5	4th	N. of Monroe	902
Jackson	W. of 2nd	890.5	4th	N. of Jackson	909.5
2nd	S. of Jackson	893.5	Jackson	W. of 4th	910

Weighted Average Calculations

<table>
<tr><th>Lower Limit</th><th>Upper Limit</th><th>Mid-point</th><th>Count</th><th>Count times Mid-Point</th><td rowspan="2">Weighted Average Ground Elevation
= 33,480/38 = 881.0 ft</td></tr>
<tr><td>850</td><td>860</td><td>855</td><td>3</td><td>2,565</td></tr>
<tr><td>860</td><td>870</td><td>865</td><td>5</td><td>4,325</td><td rowspan="3">Nearest location of Average Zone Point = 881.0 ft
Adams, W. of 4th = 882.0 ft
Measured pressure at this fire hydrant = 58 psi; for underground piping, take as 57 psi</td></tr>
<tr><td>870</td><td>880</td><td>875</td><td>10</td><td>8,750</td></tr>
<tr><td>880</td><td>890</td><td>885</td><td>10</td><td>8,850</td></tr>
<tr><td>890</td><td>900</td><td>895</td><td>6</td><td>5,370</td><td rowspan="3">Nearest location of zone Critical Point = 910 ft
Jackson, W. of 4th = 910 ft
Measured pressure at this fire hydrant = 45 psi; for underground piping, take as 44 psi</td></tr>
<tr><td>900</td><td>910</td><td>905</td><td>4</td><td>3,620</td></tr>
<tr><td></td><td></td><td>Total</td><td>38</td><td>33,480</td></tr>
</table>

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. 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.

DETERMINING AVERAGE SYSTEM PRESSURE IN A WATER UTILITY DISTRIBUTION SYSTEM (continued)



distribution system can never be totally eliminated; and there is no reasonable expectation that such is possible. However, a number of water utilities have been successful in driving leakage down to extremely low levels and maintaining low-loss operations.

The Water Loss Task Force obtained data from dozens of world class systems and observed the rate at which new leaks arise despite having comprehensive leakage controls in place. From this, 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 in Chapters 4 and 5. 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.

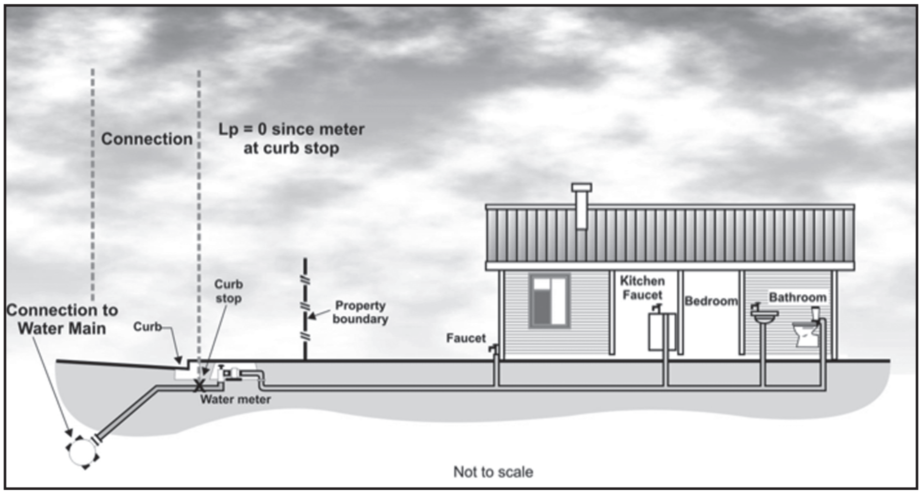


Figure 2-9 Determining the Lp distance for customer meter located at the curb stop[5] (Courtesy of Ronnie McKenzie, WRP Pty Ltd.)

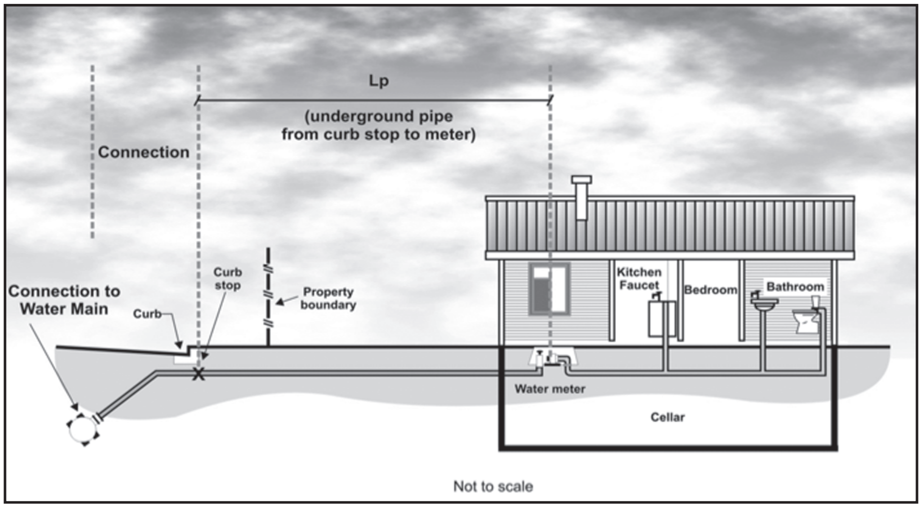


Figure 2-10 Determining the Lp distance for customer meter located inside customer premises[5] (Courtesy of Ronnie McKenzie, WRP Pty Ltd.)

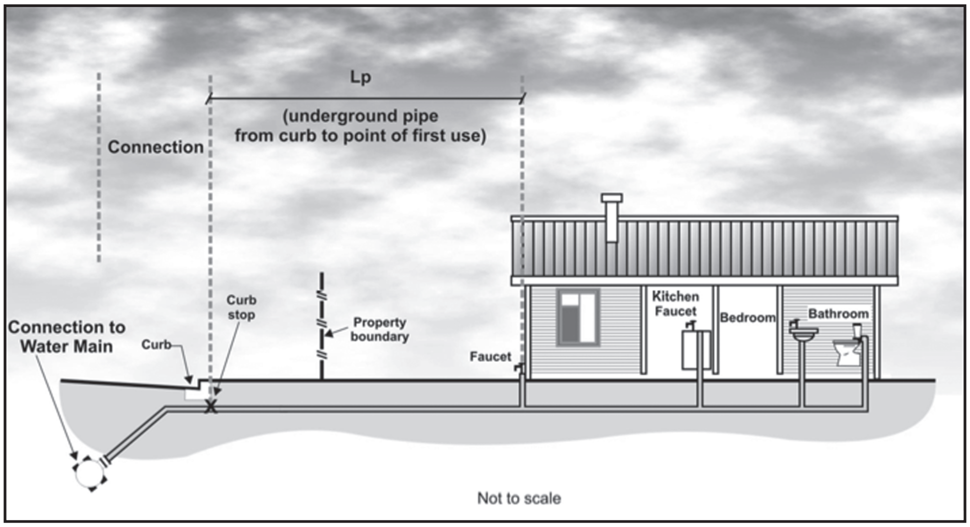


Figure 2-11 Determining the Lp distance for unmetered customer properties[5] (Courtesy of Ronnie McKenzie, WRP Pty Ltd.)

Table 2-20 Component values of the UARL calculation[6]

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/yr at 50 gpm for 3 days' duration	0.01 breaks/mi/yr 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.

Leakage events serving as the basis for these allowances are shown in Table 2-20. The equivalent leakage rates that occur under the conditions in Table 2-20 are shown in Table 2-21. As shown in Figure 2-4, the system specific data for County Water Company (miles of water main, average pressure, Lp value, and number of customer service connections) are used to calculate the UARL value.

Note: The UARL calculation has not yet been sufficiently proven valid for small systems with less than 3,000 service connections or a service connection density of less than 16 connections per mile of pipeline. Systems at or below these levels can rely on the real losses Op24 (gallons per mile of main per day) performance indicator as a measure of real loss standing.

The ILI is the ratio of CARL over UARL. The ILI is structured as a benchmarking performance indicator, allowing reliable comparisons of real loss standing among water utilities. 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 5). Setting

Table 2-21 Standard unit values used for the UARL calculation[6]

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/mile of service connection/d/psi	4.78	0.57	2.12	7.5	Gal/mil of service connection/d/psi

* The UARL values give the following equation:

$$\text{UARL (gal)} = (5.4L_m + 0.15Nc + 7.5Lc) \times P$$

Where:

Lm = length of water mains, mi (including hydrant lead length)
Lc = Nc × Lp (average length of private pipe)
Nc = number of service connections
P = average pressure in the system, psi

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, the ILI should serve only as a benchmarking indicator. Real loss reduction can then be tracked via the Op24 performance indicator.

For County Water Company, the CARL is 736.50 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.

During the first several years since the publication of the IWA/AWWA method, the ILI has become the most recognizable performance indicator quoted by water utilities applying this method. Perhaps one of the most important features for water utilities in performing a water audit is the ability to compare their water loss standing with peer utilities in the industry. The ILI is designed to effectively serve this purpose. Water audit data and findings are reported for several water utilities in case study accounts included in Appendix D. The ILI allows for a reliable method of comparison among these utilities.

Task 11—Compile The Water Balance

Once the worksheet shown in Figure 2-4 has been completed, quantities from the key consumption and loss components can be shown on the water balance. The completed water balance for County Water Company is shown in Figure 2-2. It can be seen that the summation of the component volumes in each column moving left to right is 4,402.16 million gallons, 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 a “catch-all” volume by subtracting authorized consumption and apparent losses from water supplied, the data is forced to balance. The discussion under Task 8 notes that this does necessarily represent a wholly accurate quantification of the real losses because errors in the water supplied, authorized consumption, or apparent losses could induce a degree of error in the real loss value. Statistical methods have been devised to assign values representing the likely degree of error in each of the categories, thereby identifying those components of the water audit that are less reliable than others. These methods are beyond the scope of this manual but are offered as services by various consultants. Ultimately, the reliability of the top-down water audit is improved by incrementally incorporating bottom-up approaches as described in Chapters 3 and 5.

An Important Final Word About Data Validation

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 downside to the top-down approach is that, for many first-time auditors, the quality and completeness of readily available data may be questionable. While the audit can be completed and the performance indicators calculated, 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 validation. The IWA/AWWA Water Audit Method now exists to give water utilities a highly robust and reliable structure for water auditing. However, as with computer systems, the quality of the output of the water audit (performance indicators) is only as reliable as the quality of the data entered into the water audit.

No water utility has perfect data, and all data are subject to some degree of error. 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 incrementally utilize bottom-up activities to improve the completeness and quality of the data.

Many methods currently exist to display the quality of data in water audits. Many consultants use auditing 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 Water Loss Control Committee’s free Water Audit Software, described in Appendix C, includes a data grading capability to weigh the validity of the water audit data. Rather than applying statistics, it uses a process-based approach to assign a validity score for the audit and provides specific guidance for water utilities. Regardless of the data validity assessment method used, it is important that water utilities assess both the output data and the degree of confidence of the data. The higher the level of confidence or validity of the data in a water audit, the greater is the level of confidence in devising the particular loss reduction strategies.

As water auditing becomes incorporated into the water industry, and perhaps the regulatory environment, the greater will be the need to 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 perform regular water auditing and consistently improve their data via the bottom-up approaches detailed in Chapters 3 and 5.

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 production 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 apparent losses (described in Chapter 3) and real losses (described in Chapter 5).

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Chapter 3

Identifying and Controlling Apparent Losses

As shown in the water balance in Figure 2.1, water losses represent the water volumes that do not reach beneficial use or cost utilities a portion of the revenue to which they are entitled. This chapter addresses in part the question: What kinds of losses exist in drinking water utilities? Water losses in drinking water utilities occur as two distinct types. *Real losses* are the physical losses from distribution systems, most often leakage and tank overflows. *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; thereby inducing a degree of error in the amount of customer consumption. When such errors occur systematically in an appreciable number of customer accounts, the aggregate measure of water consumption can be greatly distorted and appreciable revenue loss can occur.

This chapter explains the causes of apparent losses and describes the significant impacts that they exert on consumption data integrity and revenue recovery in systems with metered customers. Options to control these losses are also discussed.

Apparent losses may be viewed as the nonphysical or “paper” losses in that no water is physically lost from the water supply process. However, these inefficiencies in the accounting and information handling practices of the water utility can have a significant impact. They are caused by faulty, improperly sized, or badly read meters; corruption of water consumption data in billing systems; and water that is taken from the distribution system without authorization. Apparent losses consist of three primary components:

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

Certain occurrences of apparent losses are easily identified; and assumptions can be made to approximate the more subtle or complex components of apparent losses. The latter components can be verified as bottom-up work is conducted and the water loss control strategy develops. Strategies to control apparent losses are discussed in the section Controlling Apparent Losses.

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 oversized customer meters; poor meter reading, billing, and accounting practices; or weak policies. Apparent losses also occur from unauthorized consumption, which is caused by individual customers or others tampering with their metering or meter reading devices, and other causes. 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 the problems of apparent losses and the need to control them.

The specific ways in which apparent losses occur are many and varied and, particularly with unauthorized consumption, always changing. Those intent on stealing water do so for many reasons. Some believe water should be free; others do not believe that they have the financial resources to pay for the service; while others take water maliciously, 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 and maintain accurate measures of the water that it supplies.

A note regarding collections: As water utility financial managers know, not all of their customers pay their water bill as required, or pay their bill on time. 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-day, 60-day, 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 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

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* This component was established by the AWWA Water Loss Control Committee and does not explicitly exist in the definition 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*, 2000.

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.

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. While most North American drinking water utilities meter their customer consumption, a notable number do not. When auditing such systems, meter accuracy cannot by evaluated as an apparent loss, and these utilities must employ other methods to quantify the amount of customer consumption and separate it from components of authorized consumption and water losses.

AWWA's policy statement on metering and accountability is given in the sidebar on page 68. This manual supports AWWA's recommendation to meter water supplied to distribution systems as well as all customer consumption. 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, automatic meter reading (AMR) systems and data-logging technologies now widely available, customer consumption information has become a critical resource to better manage 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 manuals 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.[1] 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.[2]

In general, meter accuracy is influenced in three 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, and the appropriate type of meter to best record the variations in flow.

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 wear and lose accuracy, some more quickly than others. Therefore, meters must be tested, repaired, or replaced with new or refurbished meters (meter rotation). 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). Fire connections should be metered separately. Many meter types exist to measure flows in this variety of settings. Displacement type meters are most common for smaller, residential service. Compound, turbine, or propeller meters are employed to serve large commercial or industrial connections of greater than 1-in. Technology is always advancing, with single-jet meters as an example of a more recent innovation.

AWWA POLICY STATEMENT

Metering and Accountability

The American Water Works Association (AWWA) recommends that every water utility meter all water taken into its system and all water distributed from its system at its customer's point of service. AWWA also recommends that utilities conduct regular water audits to ensure accountability. Customers reselling utility water—such as apartment complexes, wholesalers, agencies, associations, or businesses—should be guided by principles that encourage accurate metering, consumer protection, and financial equity.

Metering and water auditing provide an effective means of managing water system operations and essential data for system performance studies, facility planning, and the evaluation of conservation measures. Water audits evaluate the effectiveness of metering and meter reading systems, as well as billing, accounting, and loss control programs. Metering consumption of all water services provides a basis for assessing users equitably and encourages the efficient use of water.

An effective metering program relies on periodic performance testing, repair, and maintenance of all meters. Accurate metering and water auditing ensure an equitable recovery of revenue based on level of service and wise use of available water resources.

Appropriate sizing of meters to customers' consumption patterns. 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 in the low end of their design range. Many meter types are less accurate in 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.[3]

Selecting the appropriate type of meter for the customer application. Particularly for large meters, certain types are designed for specific flow patterns. Turbine meters are designed to capture continuous moderate and high flows, but if the user has periodic lower flows, apparent loss results. Variations in flow can be measured reliably by compound meters. Water utilities can use customer profiles to determine the consumption variation and select the appropriate type of meter.

Data-logging technology provides the means to obtain detailed customer consumption profiles in increments of minutes or hours for periods of days, weeks, or months. AMR systems that provide data-logging capabilities also exist on the commercial market. Using such detailed data, astute individual meter sizing can be conducted. Applying this user-specific approach can promote superior meter accuracy, particularly in large water utilities with widely varying user classes. As described in AWWA Manual M22, accurate data-logging for meter sizing is dependent on the resolution of the data. Data resolution is a function of the water volume per pulse logged and the data storage interval. Both should be as small as possible so that actual flow rates are recorded, as opposed to just a collection of average flow rates, which may not accurately reflect the consumption profile. Examples of customer consumption profile graphs derived from data-logging are given in Figures 3.1 and 3.2.

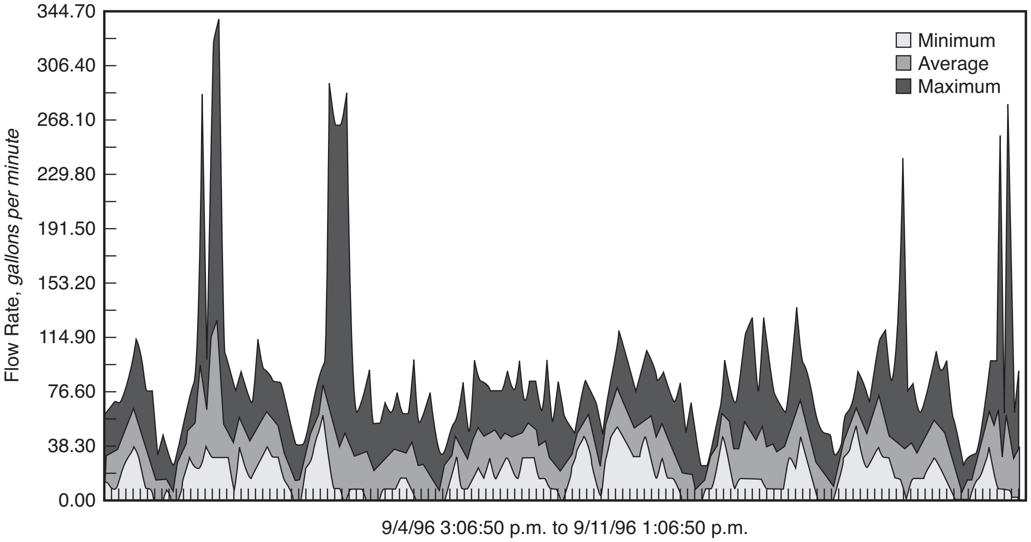


Figure 3-1 Graph produced from customer consumption meter data-logging showing minimum/average/maximum flow rates (Courtesy of F.S. Brainard and Co.)

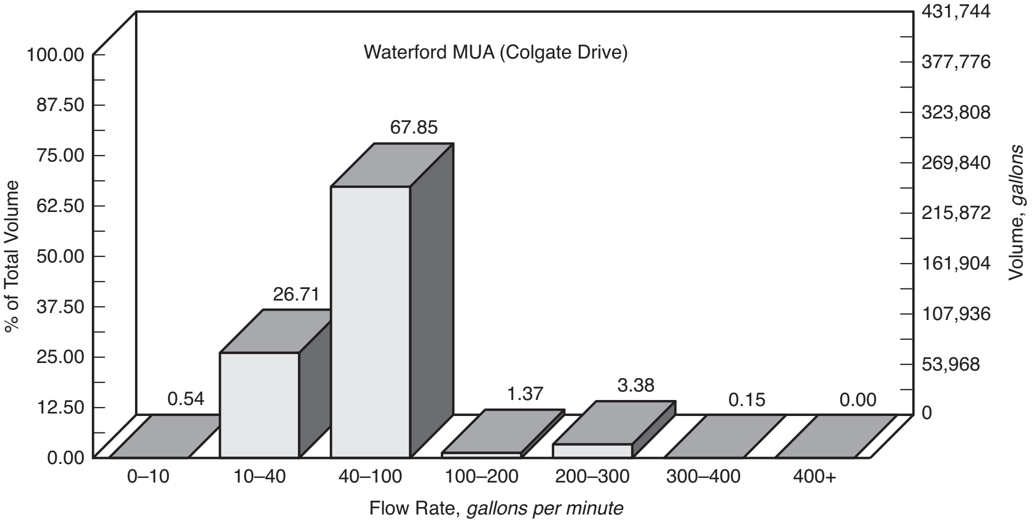


Figure 3-2 Graph produced from customer consumption meter data-logging showing percentage of time in given flow ranges (Courtesy of F.S. Brainard and Co.)

For many water utilities, more than 50 percent of revenue is received from less than 20 percent of customer accounts classified as commercial, multi-family, or industrial that utilize 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.

Current thought also now targets meter testing and rotation criteria based on the cumulative flows passing through the meter rather than a fixed time interval. Traditionally, water utilities set meter rotation schedules based on years of service and meter size. Targeting rotations 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 3,000-mile odometer reading is reached. This approach can be more efficient because heavily used meters will rotate on a timely basis that will ensure accuracy is maintained, while lightly used meters will not waste resources by rotating the meters too soon. Decisions regarding meter rotation based on cumulative consumption should be formulated in conjunction with crew deployment and scheduling realities, because it may be advantageous to have crews rotate multiple meters in a given area at the same time; even if some of the meters have not yet reached their cumulative target.

Managing a large population of customer meters requires knowledge of meter 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 conservation programs, loss control methods, and economic efficiency.

A word of caution about data handling. Meter accuracy is only the first step in obtaining customer consumption data. While the meter must provide an accurate measure, the subsequent processes—including meter readings (gathered manually or automatically), data transfer to billing systems, and archival operations—must also be handled accurately, or the actual customer consumption will be distorted, or lost entirely. In many water utilities, it is not uncommon to find accurate meter data transposed erroneously, adjusted improperly, or incorrectly archived. If any part of the entire 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.

Systematic Data Handling Errors

The customer water meter is only the beginning of 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 shear volume of the bulk data. Figure 3-3 gives an overview of the typical steps existing in the data trail from meter to historical archive.

Errors in the data transfer, billing, or archival processes can result in distortions in the summary data that is ultimately documented as customer consumption. Some of the ways in which the integrity of customer consumption data may be compromised are

- Data transfer errors
    - Manual meter reading errors
    - AMR equipment failure
    - Procedural/data entry errors during meter change-outs
- Data analysis errors
    - Use of poorly estimated volumes in lieu of meter readings

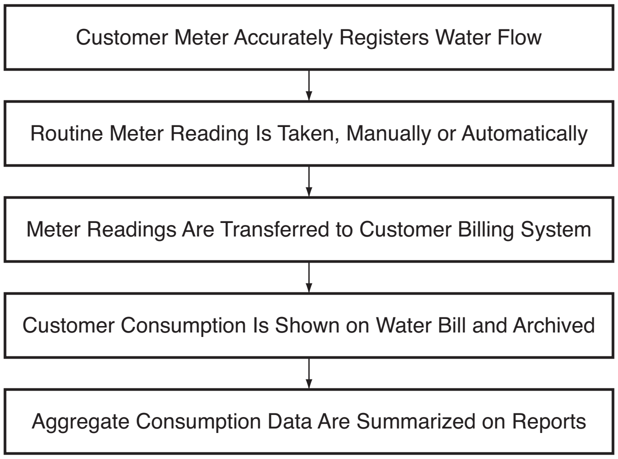


Figure 3-3 Metered consumption data archival path

  - Customer billing adjustments granted by manipulating actual metered consumption data
  - Poor customer account management: accounts not activated, lost, or transferred erroneously
- Policy and procedure shortcomings
  - Despite policies for universal customer metering, certain customers intentionally left unmeasured or unread—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 unmonitored as a result of poor management
  - Adjustment policies that do not take into account preservation of actual customer consumption
  - Bureaucratic regulations or performance lapses that cause delays in permitting, metering, or billing operations
  - Organizational divisions or tensions within the utility that do not recognize the importance or "big picture" of water loss control

This 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 their organization. Any action that unduly modifies the actual amount of customer consumption can be considered an apparent loss. The IWA Water Loss Task Force did not specifically identify data handling error as a source of apparent loss during the initial work published by Alegre, et al. (2000)[4]; however subsequent articles published by IWA and AWWA clearly define this category. The AWWA Water Loss Control Committee considers such manipulations of data as apparent losses.

The sidebar on page 72 discusses the workings of the customer billing system that should be flowcharted and confirmed by the utility to determine the potential for apparent losses from data handling error. While data handling error can be subtle and require considerable investigative time to detect, corrections are often quick and

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 for water consumption, typically on a monthly 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 needed 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 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—while 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—while 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 systems 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 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 is implemented, an estimate of the impact of such adjustment activity should be included as a component of the apparent losses. See the discussion under Step 7-2B, Systematic Data Analysis Errors in Chapter 2, for an example of registered and billed consumption.

inexpensive, sometimes requiring only minor procedural or programming changes. A fast and effective payback can often be attained in pursuing these types of apparent loss recoveries. Addressing data handling flaws early in the water loss control program also creates a foundation of data integrity that is essential as the loss control program matures.

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 paying for it. 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 strength and consistency of the enforcement policies and practices existing in the water utility
- 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;
- Buried or otherwise obscured meters;
- Misuse of fire hydrants and fire-fighting systems (unmetered fire lines);
- Vandalized or bypassed 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.

The water audit should quantify the component of unauthorized consumption occurring in the utility. For initial water audits, or where unauthorized consumption is not believed to be excessive, the auditor should use the default value of 0.25 percent of water supplied. This percentage has been found to be representative of this component of loss in water audits compiled worldwide. 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 specifically identified, as well as policies and practices that may, unwittingly, create opportunities to manipulate metering equipment to reduce or avoid payment. 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.

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 aggressive unauthorized consumption enforcement is the best policy. It is never justified to take water service in an unauthorized manner based on the purely subjective statement of a customer as to economic hardship. However, it is appropriate that water utilities recognize the limitations of certain customers in justifiable need and offer them an avenue to legitimately purchase water service at affordable rates.

PROBLEMS THAT APPARENT LOSSES CREATE

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

- 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.
- Apparent losses cause water utilities to miss the collection of a portion of the revenue to which they are entitled.

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 mil gal/d). If routine water auditing found apparent losses equal to 1 mil gal/d (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. Apparent losses cost utilities revenue and can account for 0.5 percent to 5.0 percent of a utility's annual billing for water and wastewater service rendered to individual customers. With increasing pressures from a variety of forces and limited funding, most water utilities stand to make great gains from the revenue recovery of apparent 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. 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. When water resources are greatly limited, real losses can also be valued at the retail rate based on the theory 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 to provide the water to cover fixed and administrative costs, infrastructure improvement, and debt repayment. Therefore, apparent losses can have a dramatic financial impact on the water utility's revenue stream.

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 understated. 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 cost. This is key 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.

In 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.

CONTROLLING APPARENT LOSSES

There is a tendency for many in the drinking water industry to assume that their system's apparent losses are solely caused by customer meter inaccuracy and that replacement of the entire customer meter population is the appropriate remedy. The water auditing process detailed in Chapter 2 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 changeout if the bulk of the apparent losses are actually caused by billing system data error or unauthorized consumption. Yet, many water utilities have done just this and are perplexed when, after spending up to millions of dollars on new meters, their apparent loss standing remains unchanged. Conversely, certain apparent losses, such as 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.

The Bottom-up Validation of the Water Audit

Chapter 2 details the top-down or preliminary water audit approach. Once this work is completed, the utility operator has a good initial sense of the quantities of apparent loss components. Before a definitive strategy is set, however, the auditor should begin to perform more detailed investigations of the source data or functions to validate the preliminary data and obtain a more accurate picture of the apparent losses. The bottom-up process involves detailed investigation or auditing work, similar to detailed financial audits that accountants perform. Bottom-up water auditing functions should consider the following activities:

- 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.
- 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.

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 is evaluated in the other steps.

Systematic data handling error. For most drinking water utilities, the customer billing system serves as the source of all customer data, including water consumption. As recommended in the sidebar on page 72, the water utility operator should develop a detailed understanding of the ways in which consumption data is managed in the 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 can create apparent losses.

Figures 3.4 to 3.7 represent several customer billing system flowcharts for the City of Philadelphia. The Philadelphia Water Department and Water Revenue Bureau, an office of the city's Revenue Department, together manage the customer billing process. Figure 3-4 is a flowchart that represents an overview of the entire billing process. While it displays the major billing functions at a glance, it lacks sufficient detail to identify likely occurrences of apparent loss. Additional flowcharts that display individual subprocesses of the customer billing system are given in Figures 3.5–3.7. In these flowcharts, the meter reading sequence for both automatic and manually read customer meters are shown, as well as the meter rotation (replacement) process. Although Philadelphia installed the largest water utility AMR system in the United States from 1997–1999, approximately 2 percent of its customer accounts await AMR as a result of access issues or the need to address large meter constraints. Therefore, Philadelphia utilizes both AMR and, to a much smaller degree, manual meter reading. Using flowcharts to assess various subprocesses of billing operations allows

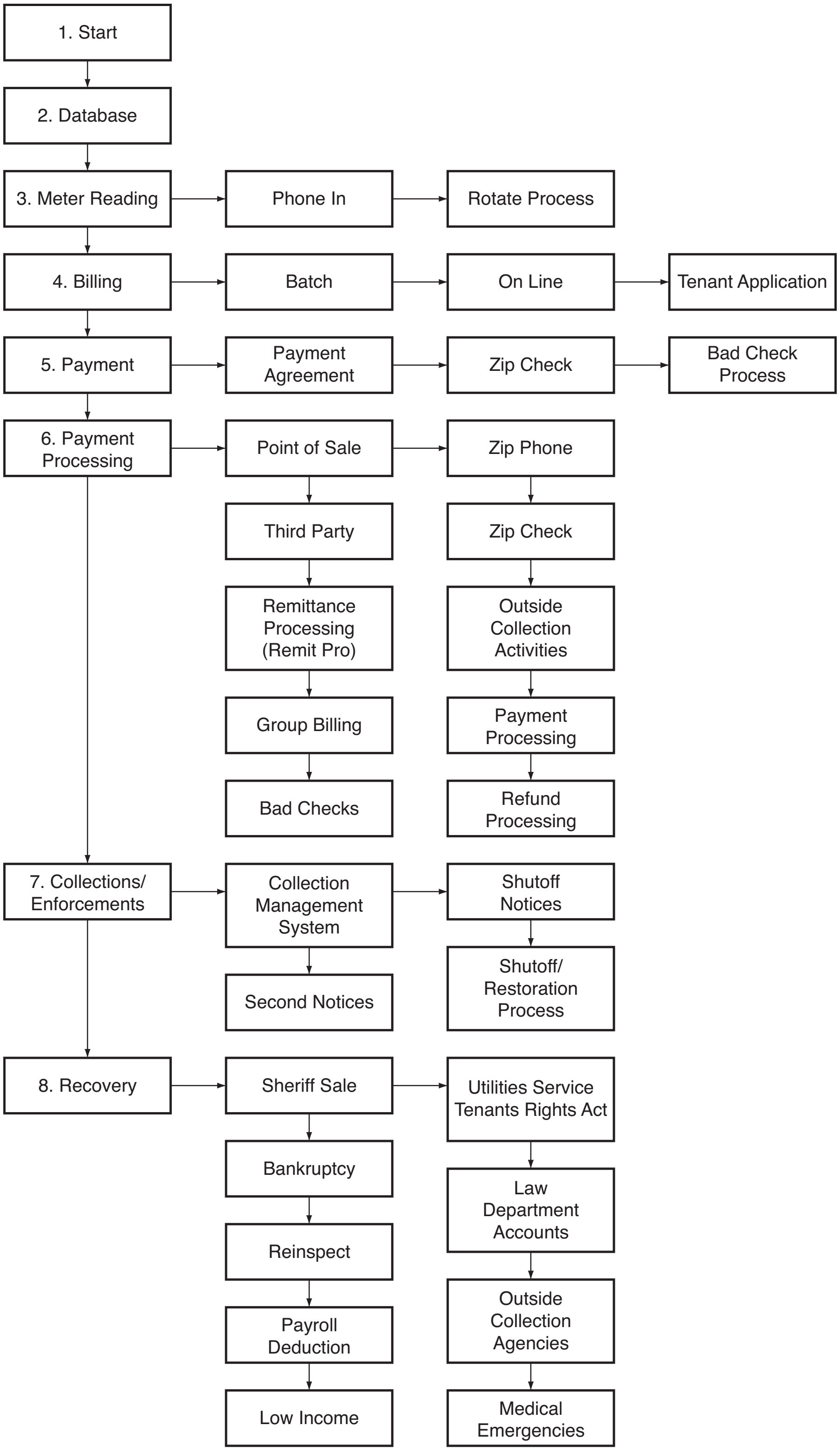


Figure 3-4 Customer billing system overview flowchart for the City of Philadelphia (Courtesy of Philadelphia Water Department)

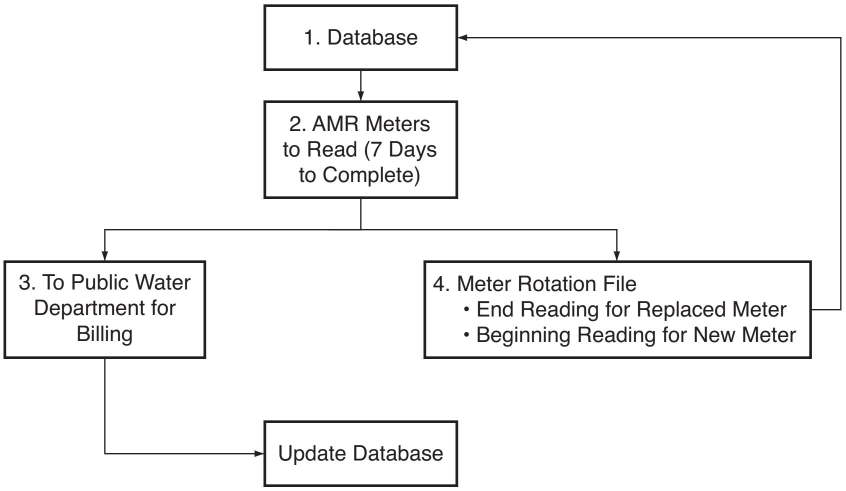


Figure 3-5 Automatic meter reading flowchart for the City of Philadelphia (Courtesy of Philadelphia Water Department)

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 lose revenue.

The billing system flowcharts shown in Figures 3.4–3.7 are given for illustrative purposes only. While they are valid for the process used in Philadelphia, each water utility has a customer billing 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 error. A small sample of several dozen to several hundred customer accounts in various categories should be analyzed to determine if any loss impacts are found to 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, the auditor might consider

- Policy—Are policies regarding customer metering, billing, water rates, customer service connection piping responsibilities, etc., 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 in transferring water consumption data, and ensure that policies and procedures are being followed?

Additionally:

- 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?

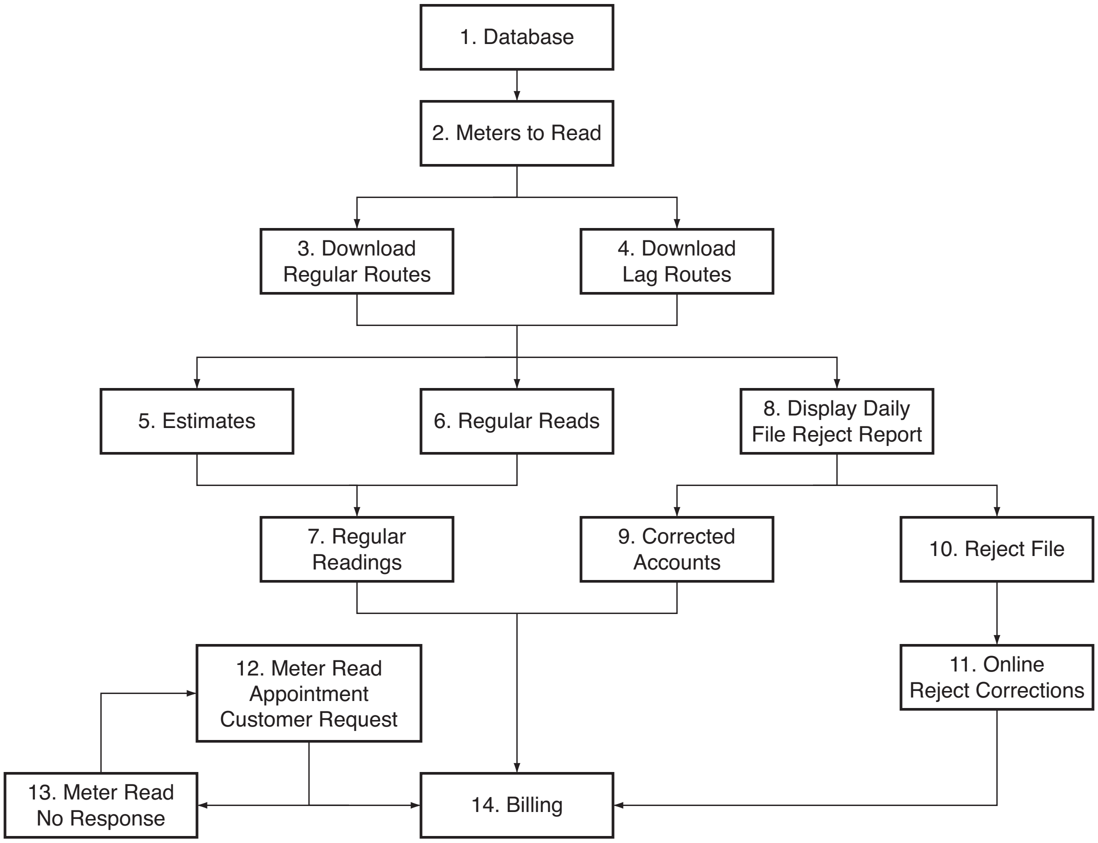
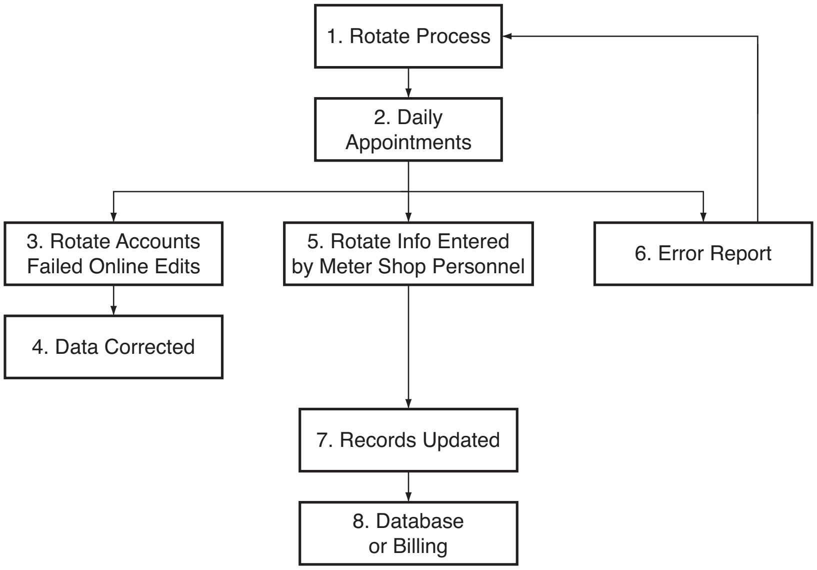


Figure 3-6 Manual meter reading (non-AMR) flowchart for the City of Philadelphia (Courtesy of Philadelphia Water Department)

- Can customers enter a nonbilled status for conditions such as property vacancy, delinquent or shutoff accounts, etc? If so, are these accounts routinely monitored to detect any unbilled water consumption?
- 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 unduly modify actual metered consumption data, such as shown in Tables 2-17 and 2-18?
- 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?
- 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 conservation, loss control programs, or demographic trends such as growth in the industrial sector?



NOTE: New meters replace old meters—need new-start reading.

Figure 3-7 Customer meter rotation process flowchart for the City of Philadelphia (Courtesy of Philadelphia Water Department)

These are just some of the questions that might be posed during the bottom-up audit of the data handling process. For every water utility, certain unique processes can exist and should be scrutinized by the auditor.

Customer meter accuracy. See Chapter 2, Task 7, Step 7-1 for information on estimating apparent losses caused by customer meter inaccuracy. 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 three components: first, the physical capability to reliably register a volume of water passed in a given period of time, and secondly, the appropriate sizing of meters to accurately register customers' consumption patterns. Finally, the proper type of meter must be used in a given application. Customer meters must both work properly and be appropriately sized for the customer demand pattern if they are to avoid under-registering flows, causing understated consumption and revenue loss. 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, are not current with the status of their meter population. 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, rotation, or right-sizing. 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. Table 3-1 is an expanded version of Table 2.7 for the fictitious County Water Company (CWC), which serves as the illustrative example throughout this manual. Table 3-1 summarizes the basic demographics of the CWC customer meter population.

Table 3-1 Customer meter poulation demographics and metered consumption for County Water Company: January 1, 2006–December 31, 2006

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 (11,480)	13	71.2
¾	10	0.08	PD (10)	Rockwell (10)	26	0.1
1	338	2.8	PD (338)	Badger (250)	18	2.8
				Neptune (88)	11	
1½	124	1.0	PD (124)	Badger (18)	18	2.8
				Neptune (106)	9	
2	216	1.8	PD (216)	Rockwell (54)	28	11.7
				Badger (146)	22	
				Neptune (16)	20	
3	15	0.12	Turbine (15)	Sensus (15)	15	6.6
4	7	0.05	PD (2)	Sparling (2)	26	2.2
			Turbine (5)	Sensus (5)	15	
6	6	0.05	Turbine (2)	Sensus (2)	15	2.6
			Compound (2)	Sparling (2)	29	
			Propeller (2)	Hersey (2)	40	
Total	12,196	100.00				100.0

* PD = Positive displacement.

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 in order to establish a sound meter testing, right-sizing, and rotation strategy.

To determine the *physical accuracy* of the meter population, many water utilities operate their own test facility and equipment, and perform ongoing accuracy testing of meters that have been rotated out of service. For these operations, testing of targeted groups of meters can be readily accommodated. Water utilities that do not have their own facilities need to outsource their testing to specialty companies.

AWWA's guidance manuals on meters give excellent instruction on meter accuracy testing. Generally, accuracy tests should be conducted at low, medium, and high flow rates. For small residential meters, sample groups of meters can be tested. A randomly selected sample of several dozen to several hundred meters (depending on the size of the meter population) can be selected and tested. A separate sample of meters with high cumulative consumption should also be tested. Results of the latter testing can help to develop a long-term meter change-out strategy based on the level of cumulative consumption when accuracy begins to decline. Selected large meters should also be identified for testing and/or rotation, including 1-in., 1½ in., and 2-in. meters, a mid-range that sometimes is 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.

For determining whether or not meters are properly sized for existing customers, a representative sample of large meter accounts can be identified for data-logging to confirm the customer water consumption profile. If large meters have been in service

Table 3-2 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 percent of registration)		
						Low	Medium	High
XYZ001	3	Turbine	June 1991	Sensus	Oct 2006	89	93	100
X00ZAA	3	Turbine	June 1993	Sensus	Oct 2006	70	95.2	98
NB123	4	Displace	July 1980	Sparling	Oct 2006	95	99	102
NB456	6	Compound	Sept 1977	Sparling	Oct 2006	98	96.5	102
AA002	6	Propeller	May 1966	Hersey	Oct 2006	98	99	103
				Sum of mean registrations		450	482.7	505
			Mean registration for five meters tested			90	96.54	101

for many years, current customer flows may not match the demands at the time the meter was installed. Low flows may not be registered by some large, old meters and data-logging may prove the need to downsize the existing meter to an appropriate size. Table 3-2 gives example large meter test results for CWC as described in Chapter 2.

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 rotation of customer meters. Implementing a program that routinely tests groups of customer meters incrementally can be an efficient and economical way to keep a meter population current; and the program would provide essential data to develop a rational long-term meter change-out plan for the customer meter population.

Unauthorized consumption. No water utility is immune to the occurrence of unauthorized consumption, only to the extent that the occurrence varies.[5] Unauthorized consumption occurs as a result of weak policies, practices, and oversight by the water utility and deliberate actions by a segment of the customer population set on avoiding paying for water service. Water utilities can exert control over unauthorized consumption via

- Detection—the ability to become aware of unauthorized consumption in its various manners.
- Enforcement—the means to halt such consumption and invoke appropriate penalties.

Water utilities should have mechanisms in place to detect trends of unauthorized consumption. As described in the sidebar on page 37, the auditor should review opportunities for the unauthorized use of fire hydrants and ensure that a rational policy regarding fire hydrants exists. Flowcharting the processes of the customer billing system as illustrated in Figures 3.4–3.7 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, realizing a quick return of additional revenue. Billing data should be reviewed for suspicious trends that might reflect unauthorized consumption. For instance, active accounts registering unchanged meter readings (zero consumption) for consecutive billing cycles might be an indication of meter tampering. Household inspections can be conducted on select zero consumption accounts to determine whether actual consumption is occurring. Boundary valves to neighboring water systems should be inspected periodically to ensure that they are in the proper position. If utility policy allows customer service to be terminated because of payment delinquency, followup random inspections should be conducted to ensure that customers have not reactivated their service illegally. Customer meter tampering can be cost-effectively controlled by locking devices that are commercially available at competitive prices for all sizes and configurations of customer meters. All of these actions are typical of the bottom-up procedures utilities can undertake to control unauthorized consumption.

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, and the creation of new ones. Implementing such changes in these instruments can be politically sensitive and requires skilled effort over potentially long periods of time; however, a strong legal framework will ultimately allow the water utility to operate with enforcement powers to keep unauthorized consumption to an economic minimum.

Developing the Apparent Loss Control Strategy

Figure 3-8 is a graphic that represents a conceptual approach to loss control applied to apparent losses. The center boxes represent three levels of apparent losses, as defined in the following list:

- The outer box represents the current volume of apparent losses listed in the water audit.
- 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 inner box is the unavoidable annual apparent losses (UAAL). 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 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 continues.[6]
- The four wide arrows represent how 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 3-9 provides a cost curve for meter replacement, with points plotted at replacement frequency (years) and average cumulative consumption passed through the meters (mil gal). 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 meter inaccuracy is shown graphically in Figure 3-10. In this graph, the meter replacement cost curve is

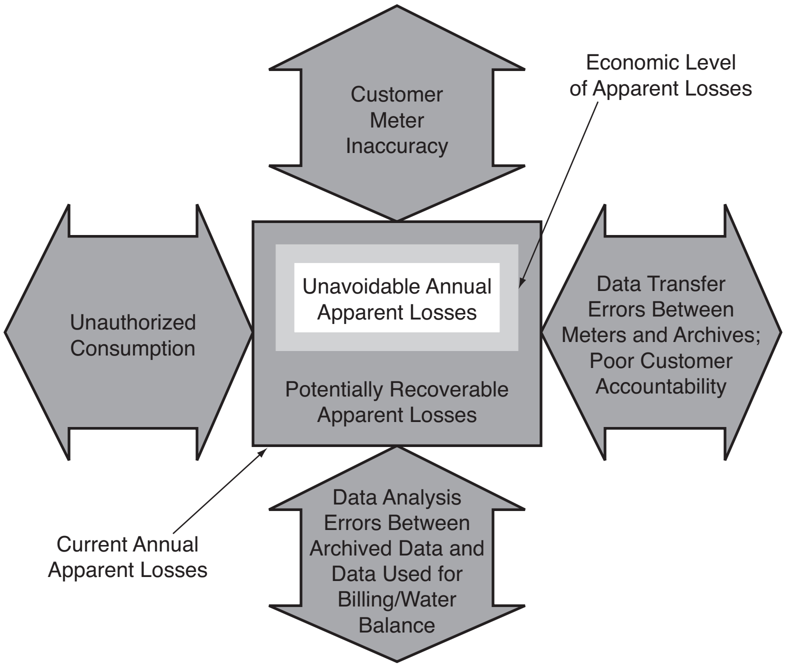


Figure 3-8 The four-pillar approach to the control of apparent losses[6]

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 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 3-10. 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 meter inaccuracy, 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 cost–benefit analysis for reducing meter errors should be sure to recognize significant costs where they exist, including administrator and billing personnel expenses to manage errors, refunds, and the cost to verify readings.

In setting out to generate 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 implementation or a new 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 hand-held meter reading computers to the implementation of a complete AMR 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 cost–benefit. Only those solutions with a sufficiently attractive cost–benefit ratio or payback period should be

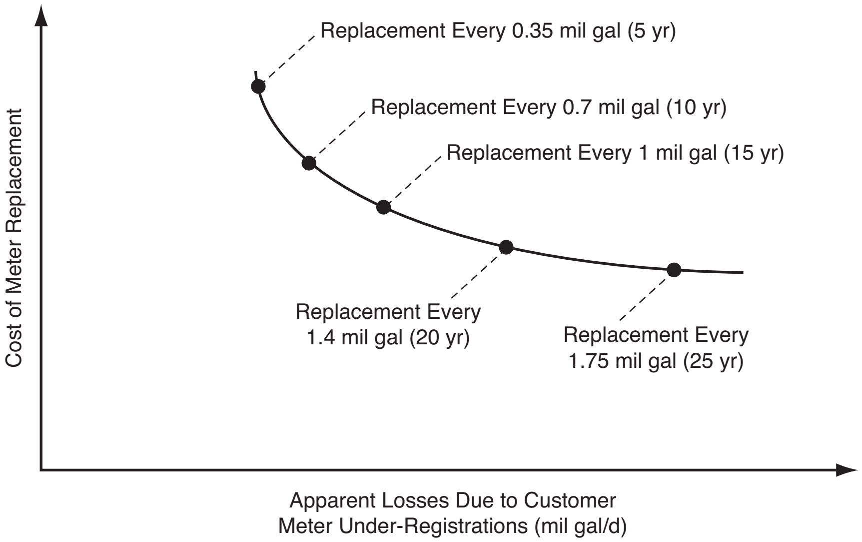


Figure 3-9 Cost curve for meter replacement programs[7]

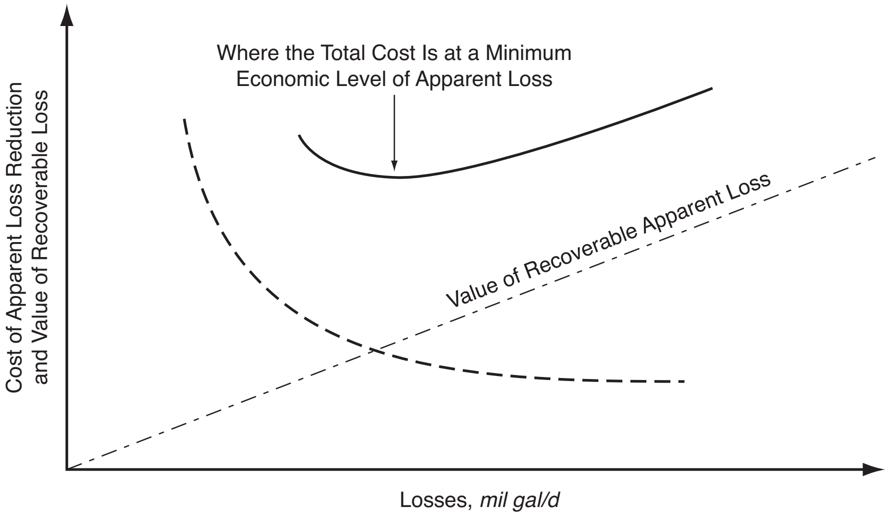


Figure 3-10 Economic balance for an apparent loss reduction solution

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, it is up to each water 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 lives 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 meter inaccuracy, 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, work is underway by the IWA Water Loss Task Force to develop a simpler, straightforward method of obtaining the ELAL.

Clearly, the current approach to identify the overall ELAL is resource intensive and time-consuming. While work is undertaken to develop a simpler method to calculate the ELAL, water utilities can still 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 their 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 offered as standard starting points for water utilities in apparent loss control:

- 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 may identify a number of loss components that are quickly and inexpensively corrected by policy, procedural, or computer programming changes.
- Unless the customer meter population is very young and well documented, 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.

The previous 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 3-11 identifies a sequence of steps to take to develop and implement the apparent loss control strategy after the initial top-down water audit has been compiled. These steps, starting with the bottom-up auditing procedure, should be followed in sequence to ensure that intervention actions are economically justified and well planned.

Developing a Revenue Protection Plan to Control Apparent Losses in County Water Company

The most significant impact of apparent losses for water utility managers is uncaptured revenue. Therefore, 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

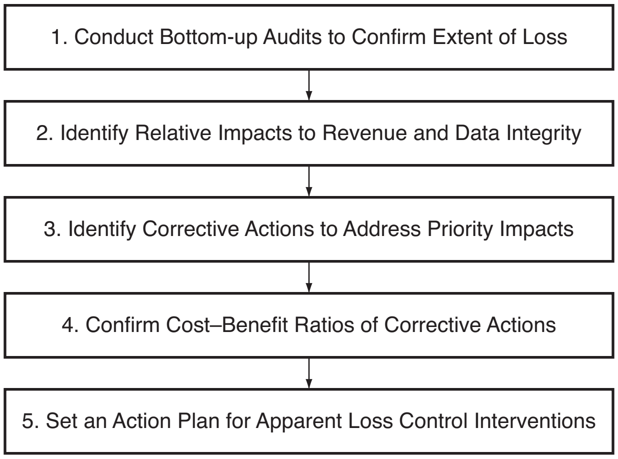


Figure 3-11 Establishing an apparent loss control strategy

program must be tailored to the individual needs of the water utility. The following 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: customer meter inaccuracy, systematic data handling error, 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 example in the sidebar, CWC estimates that very little unauthorized consumption occurs in its system, so this component is not included in its initial revenue protection program.

As shown in the sidebar on pages 88–90, the cost impact in lost revenue to CWC caused by apparent losses is $838,360, which is 8.7 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 to continue testing a sample 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 800 ft^3/month of water (71,808 gal/yr), 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 and costly improvements to control apparent losses. Such efforts can include wholesale meter change-out, installation of AMR systems, or implementation of a new computerized billing system and process. Chapter 6 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.

Apparent Loss Control: A 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 almost always 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.

SAMPLE REVENUE PROTECTION PLAN

Name of Water Utility: *County Water Company* Date: *07/10/2007*

I. Revenue Protection Plan

After completing County Water Company's (CWC) first annual water audit (See Figure 2-4), 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

• Residential meter under-registration	134.33 mil gal @ $556,395
• Industrial/commercial/agricultural meter under-registration	29.97 mil gal @ $108,701
• 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)	11.0 mil gal @ $43,395
Total Apparent Losses	208.22 mil gal @ $838,360

SAMPLE REVENUE PROTECTION PLAN (continued)

From this summary the cost impact of customer meter inaccuracy is $556,395 + $108,701 = $665,096. This is equal to 6.9 percent of the total cost of running the system ($665,096/$9,600,000). The three subcomponents of systematic data handling error 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 meter inaccuracy, with a secondary focus on systematic data handling error. 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 error.

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 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
		Total, $/hr 108.50	$/d 868.00

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	39.00	11.00	50.00	24,024.00

III. Customer Meter Accuracy Testing

III-a. The water audit for CWC estimates that customer meter inaccuracy caused under-registered consumption worth $665,096 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 2.11–2.16. 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 meter inaccuracy. Based on the value of this

SAMPLE REVENUE PROTECTION PLAN (continued)

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, they utilize 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 & 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
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
Meter Testing Services Cost, $/small meter 250.00 Cost for 5 meter tests, $1,250
Meter Testing Service Cost, $3,000

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 are

Customer Billing Process Analysis,	$24,024.00
Annual Meter Testing Program,	$7,140.00
Total Revenue Protection Program Cost,	$31,164.00

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 2-4) of $3,945/mil gal of customer consumption, an equivalent volume of consumption can be determined.

$$\text{breakeven recovery volume} = \frac{\$31{,}164.00}{\$3{,}945/\text{mil gal}} = 7.90 \text{ mil gal}$$

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 2-4. 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.

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Chapter 4

Understanding Real Losses: The Occurrence and Impacts of Leakage

This chapter addresses the second part of the question: What kinds of losses exist in drinking water utilities? It is known from the water balance in Figure 2-1 that water losses represent the water volumes that do not reach 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, energized 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 reservoir walls; 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 5.

For most water utilities, leakage is the greatest portion of real losses. While tank overflows (Figure 4-1) are included in the definition of real losses, these events are typically less frequent and often visible; therefore, they are less likely to run unattended for extended periods of time. Given this, the content of this chapter focuses on leakage as the primary component of real losses.

Figure 4-1 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 is common to all utilities—only the volume varies. The volume of leakage losses over a reference period of time is the difference between the volume of water entering as distribution system input and the volume reaching authorized consumption, minus any overflows and water drawn directly from the distribution system from fire hydrants or other system appurtenances.

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[1]

- Inferior or defective materials, whether of the pipes and jointing or in bedding or support;
- Pipe breaks resulting from poor workership or materials handling in pipe laying—unsupported lengths of pipe, stones in contact with pipes, nonadherence 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 too rapidly, 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, thermal effects during extreme temperatures;
- 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; and
- Accidental or deliberate damage to water mains, hydrants, or other appurtenances, heavy traffic loadings, or careless construction activity over shallow water mains.

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 sound rehabilitation and renewal programs.

The extent of the occurrence of leakage within a water utility depends on

- The characteristics of the water distribution system;
- The importance attached to loss control by the water utility;
- The way in which the distribution system is operated and maintained; and
- The 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 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 can be gained in the second area, the 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, *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.

Figure 4-2 Large main break

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 4-2) wreak havoc and garner much attention, these events typically contribute measurable, but small, volumes of nonrevenue water. 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 4-3) account for the greatest overall volume of leakage losses in a distribution system over the course of the year. In well-run systems worldwide, 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.[2] Although their leakage rates are low, small leaks often run undetected for long periods of time. The influence of run time, as shown in Figure 4-4, is the primary factor in the volume of water lost to leakage over the course of a year. In systems with no active leak detection programs, the run time of hidden leaks is continuous until they are detected by the water utility or an external party such as a customer, usually after the leak becomes evident through some form of damage that it is causing.

As depicted in Figure 4-4, the run time of leaks comprises three elements:

1. Awareness time. This is the time needed for the 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.

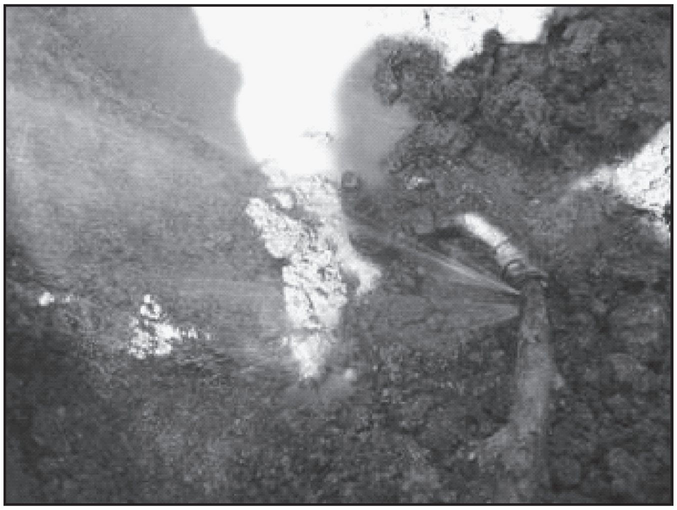


Figure 4-3 Small leak on customer service connection piping

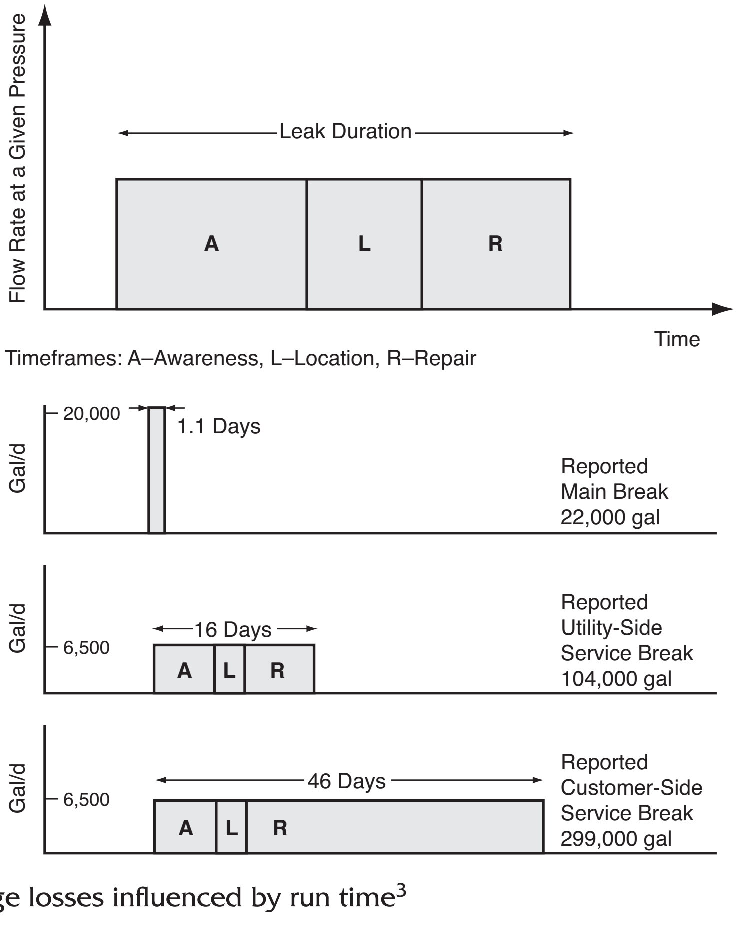


Figure 4-4 Leakage losses influenced by run time[3]

3. Repair time. This is the time to affect a repair that halts the leakage flow, once the leak position has been identified. This is not just the time of the shutoff or repair action, but all time needed to route the repair work order, schedule the repair, notify customers, and other activities, which can take days or weeks depending on the polices of the water utility.

In many water systems worldwide, small leaks and breaks can run for periods of weeks, months, or even years before they are discovered and repaired. Consequently, although the flow rate from such leaks may be relatively small, the 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 Figure 4-4 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 4-5 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 4-5, nonetheless, further suggests the value that can be gained in minimizing leak run time to optimize water loss reduction.

CHARACTERIZING LEAKAGE EVENTS

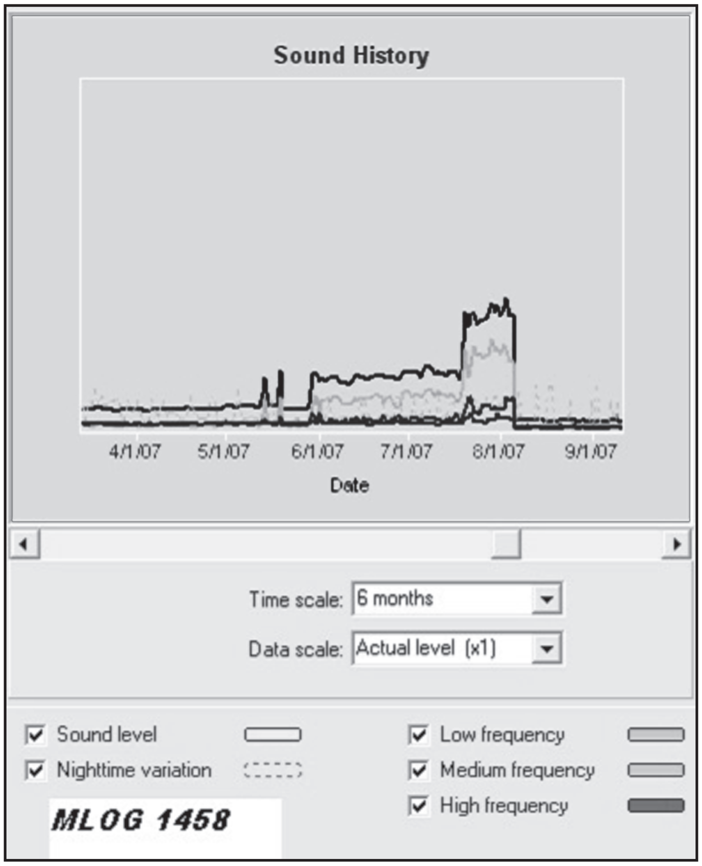
Because leak run time is such a prominent factor in the occurrence of leakage losses, developing a strategy to minimize leakage run time is key to a successful leakage management program. The first phase of the response to a leak is the awareness time. Leaks can be segregated into two primary categories that are determined by the manner in which the utility operator becomes aware of them. These are

- 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 supervisory control and data acquisition systems can be categorized as reported leaks.
- 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 is the most common means currently used in North America to identify unreported leaks. Unfortunately, many water utilities do not regularly perform leak detection work.

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 are operating a *proactive* leakage management program. For many utilities, most leakage losses over the course of a year occur from unreported leaks. 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.

A third type of leakage also exists with unique characteristics. Background leakage involves the tiny weeps and seeps at joints and fittings that defy detection through conventional acoustic means. Such tiny leaks 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. The use of pressure management has



Time scale: 6 months

Data scale: Actual level (x1)

☑ Sound level

☑ Nighttime variation

☑ Low frequency

☑ Medium frequency

☑ High frequency

Figure 4-5 Leak noise signature of a leak showing increasing flow rate over time (Courtesy of American Water)

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 *component analysis* of leakage types. Reported and unreported leaks have different ALR times. Some examples are

- Visible water main breaks typically have very short ALR times (see Figure 4-4), because the disruptive nature of such events prompts 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).
- 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 leaks once they are aware of them.
- Hidden leaks on customer service connections may also have variable awareness times for the same reasons as 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 repairs on sections of,

or all of, their service connection piping. Such policies have been found to be 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 repair time 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.

Efficient computer spreadsheet models have been developed by various consultants to model the leakage components occurring in water utilities and provide data to the water audit. Information can be input regarding 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 refined ALR policies. Component analysis, discussed in greater detail in Chapter 5, is one of the powerful innovations developed to assist leakage management planning.

A FURTHER WORD ON CUSTOMER SERVICE CONNECTION PIPING LEAKAGE

Worldwide, the majority of leakage events and the majority of leakage volume losses occur on customer service connection piping, not on the water main piping of the distribution system. Several reasons exist for this. 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, which 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. The quality of materials and caliber of workership can become suspect in such arrangements as it is difficult to oversee the activities of a large number of independent contractors. 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 for 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 conduct 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. 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

Worldwide many drinking water utilities operate with pressures greatly exceeding that necessary to meet their service obligations to customers and communities. This has a cost in terms of lost water from elevated leakage rates, as well as higher energy demands to pump water to higher pressures. Moreover, water pressure levels often are not monitored closely by water utilities across the extent of their distribution systems.

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 flow of water out of the leak. Yet, until relatively recently, pressure was not commonly analyzed for its effect on leakage in water distribution systems. The list of operational causes of leakage—excessive pressure, filling pipelines too rapidly, closing valves too rapidly, water hammer—are all associated with operating pressure, either directly or indirectly.[4]

Operating pressures not only have a major effect on the amount of water escaping from active leaks but also a surprisingly large influence on the rate of generation of new leaks. Water main break and service leak frequency increases rapidly when high pressure is encountered, either as pressure surges or when operated at continuous high pressure. 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. A study by the International Water Association's Water Loss Task Force of 110 water systems from 10 countries showed significant reductions in numbers of leaks and breaks, as have two of the case studies detailed in Appendix D[5]. Reducing pressure also will result in less damage caused by the main break to adjacent property and infrastructure.

The FAVAD theory of *fixed and variable area discharge paths* was developed in 1994 and has greatly advanced the understanding of pressure–leakage relationships for water distribution systems.[6] 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. 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. Numerous field tests using the FAVAD theory since the mid-1990s have confirmed that the influence of pressure on the volume of leakage and frequency of new leaks is far greater than estimated previously. The exponent variable is referred to as the *N1 exponent*.

In recognizing this relationship and by developing a means to calculate it for individual distribution systems, *advanced pressure management* has become a distinct tool in the control of leakage losses. 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 what was previously viewed as unavoidable leakage. Strategies have been employed in many water utilities worldwide with high pressure to reduce excessive pressures (pressure shaving) to reduce leakage from widespread background leaks. Pressure reducing valves with versatile controllers can be installed to safely inhibit pressure spikes and reduce pressure during periods of low water demand, while still allowing for an adequate level of water service to customers for consumptive and fire-fighting needs. Establishing pressure management as a strategy in the leakage management tool box is one of the most effective innovations of recent years; it is discussed in detail in Chapter 5.

LOCATING AND QUANTIFYING LEAKAGE

It has become essential for the utility operator to know *where water loss is occurring 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:

- 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.

- 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. 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 4-6, a leak correlator pinpoints the exact leak location by comparing leak noises from two sites that encompass the leak. In a relatively short time, the leak correlator has become 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

Figure 4-6 Leak correlators have become a standard pinpointing tool of the leak detection squad in many water utilities (Courtesy of Fluid Conservation Systems)

either permanently in fixed locations or rotated from site to site. The loggers are usually programmed to *awaken* during the minimum consumption night hours and record leak noises. The recorded sounds can then be downloaded and compared with 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 4-7 gives a typical configuration of leak noise loggers deployed in permanent locations. Leak noise loggers properly stationed throughout an area can find leaks at fairly low flow rates. There is evidence that early detection not only reduces leakage significantly, but early repair reduces the cost of repair, restoration, and damage.

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.

While 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 in order 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 leaks worsen. 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.

Figure 4-7 Leak noise loggers help to automate the leak survey process and provide consistent sounding capabilities for effective leak detection (Courtesy of Fluid Conservation Systems)

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 distinct district metered areas (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 night hours; therefore, high night flows can infer the existence of leakage. However, in areas with continuous industrial consumption or dry regions with considerable night-time 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 sprinklers 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 4-8 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 ("step test") exercise; 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 5.

Employing sectoring methods such as DMAs in conjunction with geographical information systems (GISs) and making use of hydraulic models can allow for advanced analysis of 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.

Generally, an acoustic leak survey and repair program forms part of a short- to medium-term loss reduction program. Flow monitoring, DMA control, and pressure management form part of a medium- to long-term intervention. Infrastructure replacement completes the long-term program.

THE IMPACT OF LEAKAGE

While leakage from water distribution systems is labeled a *loss*, it should be recognized that the water is indestructible and 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. The negative effects that leakage imparts on society, however, are numerous.

Some of these impacts are

- 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.

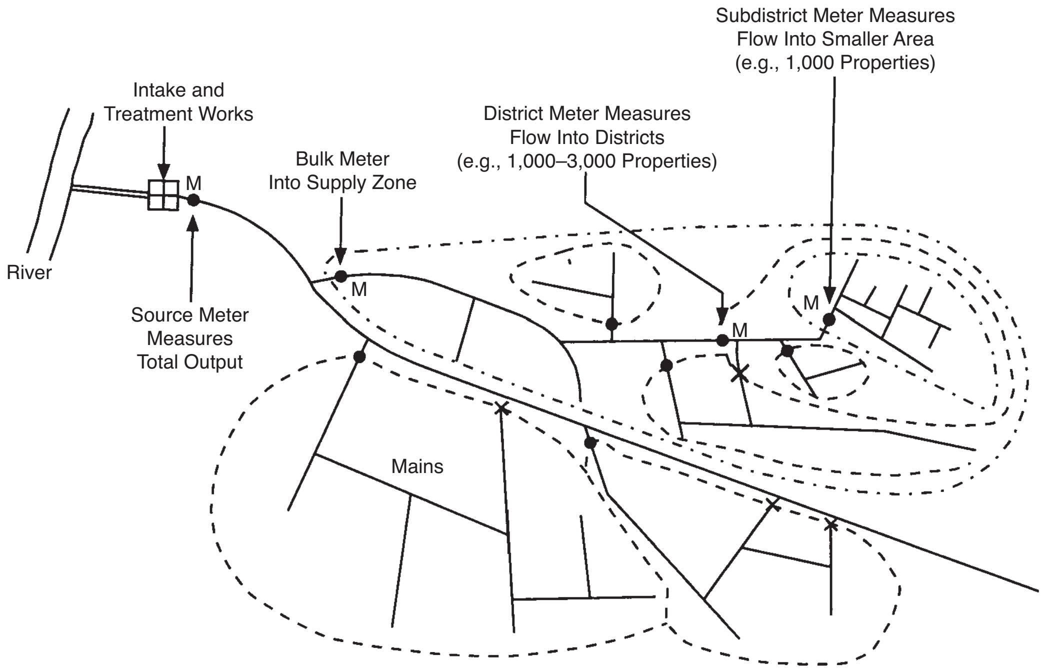


Figure 4-8 Distribution system flow metering and DMA design options[7]

- High leakage losses require larger infrastructure than needed to meet customer demand, a compelling factor because infrastructure rehabilitation and renewal is of great concern in North America. Assessments of infrastructure condition and needs should include an evaluation of leakage losses to distinguish that portion of infrastructure capacity that currently 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 discussion in the sidebar on page 107.)
- Leaks and breaks often cause considerable damage and increase liability for water suppliers.
- 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.[8]
- 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 utility. Associated with these issues are financial impacts. Any negative

THE ENERGY IMPACTS OF WATER LOSS

Throughout North America, 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 taxes energy generating infrastructure, which interestingly relies on large quantities of water in the generation process. It is estimated that water utilities consume from 2–10 percent of all power use in any country, and power can consume up to 65 percent of a water utility's operating budget.[9,10] 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.[11] It is possible that between 5–10 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 of the state's electricity and 32 percent of the state's natural gas. One large-scale water supply project alone utilizes 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 recently 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.[12]

Many water utilities have found that reducing water demand by water loss control, water conservation, or reuse also results in significant energy savings. 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. The City of Philadelphia Water Department has witnessed its water demand decline by almost 20 percent over a 12-year period and has realized electricity demands reduce commensurately by 22 percent, dropping to a level of electricity consumption 36 million kilowatt-hours lower than that of 12 years earlier. Philadelphia's annual expenditures for electricity to supply drinking water dropped from almost $10 million to $6 million during this time. Declining population has played a role in the city's water and energy savings, but it is believed that improved leakage management and conservation by customers from low-flow toilets and more accurate monthly billings generated by an automatic meter reading system are also pertinent factors.

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.

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 can even be valued at 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 customers, therefore the retail rate applies.

Leakage represents inefficiency in the process that a water utility uses to deliver water to its customers. While 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.

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Chapter 5

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 answers the question: 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 4 prior to reading this chapter. Chapter 4 explains the nature and impacts of leakage in water distribution systems.

Table 5-1 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 5.

This chapter presumes that the first three steps listed in Table 5-1 have been completed and that the water utility is now poised to develop its leakage management program. Continuing to Step 4 in Table 5-1, 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 5-1 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 pillar activities 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 four primary leakage control methods, which are

Table 5-1 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 6).
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 2).
3. Validate the system input volume of the water audit by testing source meters.
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 component analysis technique and/or minimum hour flow measurements in pilot zones or district metered areas.
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 component analysis based on any new assumptions.
11. Set goals for medium- and long-term reduction, including methods and targets.

1. Active leakage control: identifying and quantifying existing leakage in a distribution system, typically by performing sonic 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 is critical to the success of the leakage management program.

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 identifying the types and volumes of leakage losses within the distribution system, the cost of water in the utility, and the costs of the appropriate techniques to reduce specific components of leakage.

FORMULATING A LEAKAGE REDUCTION TARGET

The center boxes shown in Figure 5-1 represent three levels of real losses.

- The outer box represents the CARL, as quantified in the water audit.
- The middle box represents the *economic level of leakage (real losses), or ELL. This represents the amount of leakage that can be economically avoided through leakage control measures whose costs are balanced against the savings of reducing ELL.*
- The inner box is the unavoidable annual real losses (UARL). This represents the *theoretical* low level of loss that could be attained if all loss control efforts could be exerted to reduce the losses. The derivation of the UARL calculation is given in Table 2.19 and was developed from data from water utilities that have achieved excellent leakage control. The UARL is a *reference level* used to

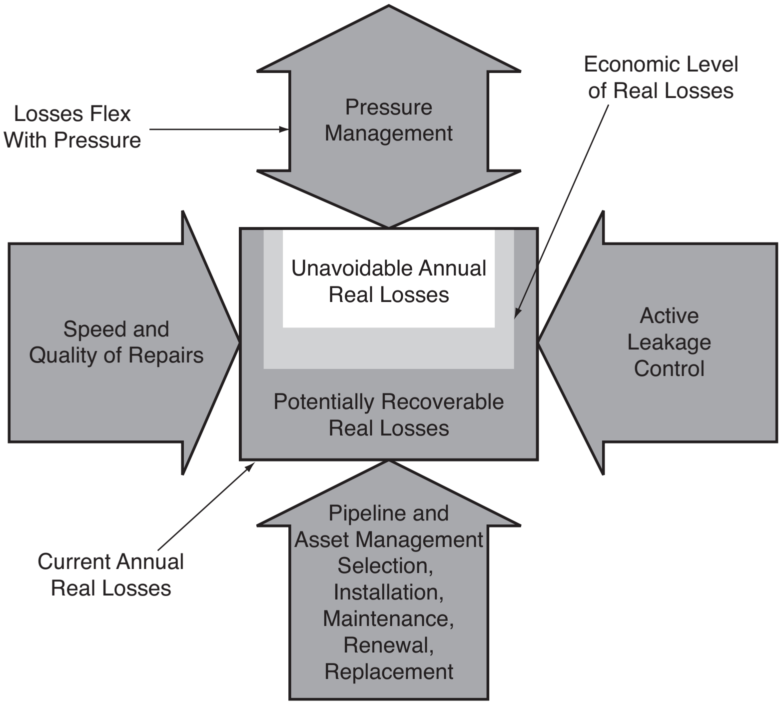


Figure 5-1 The four-pillar approach to the control of real losses

calculate the performance indicator infrastructure leakage index (ILI). Water utilities need not seek the UARL 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, i.e., 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 losses exist, and it is 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.

A number of approaches have been developed to calculate the ELL. The first methods devised for this purpose are complex and require 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 Awwa Research Foundation report *Evaluating Water Loss and Planning Loss Reduction Strategies*[1]. More recent 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. Members of the International Water Association Water Loss Task Force continue to refine the methods of 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 5-2 provides target-setting guidelines. This table, which was developed by the AWWA Water Loss Control Committee,[2] suggests approximate target levels using the ILI and water resources, operational, and financial considerations that utilities typically encounter. While the ILI is a benchmarking indicator, water utilities working in the early phases of a program can use the ILI to set a preliminary leakage target. The target can be refined as the leakage management strategy moves forward, producing more reliable field data on leakage occurrences and the most effective means of control. An example of the preliminary target-setting process is given in the following sidebar.

The ELL is dependent on the cost of water. The higher the cost of leaking water, the lower the ELL. The more prone the system is to have leaks, the more intense the leakage management effort will be.

Table 5-2 AWWA Water Loss Control Committee—leakage management target-setting guidelines[2]

Guidelines for Use of the Level 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. 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 via the bottom-up approach.		

Once an initial target range is set, the auditor has an estimate of the potential cost savings to be recouped by the initial leakage reduction. These potential savings can be weighed against the costs of possible leakage controls to determine the appropriate leakage management plan. Ultimately, target-setting and loss control planning becomes an iterative process. Initial targets are usually revised after initial leak reduction activities are conducted, generating more reliable data on the types and quantities of leakage occurring in the water distribution system. It is therefore acceptable that initial leakage targets are approximate and subject to later refinement.

COUNTY WATER COMPANY—PRELIMINARY LEAKAGE LOSS REDUCTION TARGET-SETTING ANALYSIS

(from data in Chapter 2 – Figure 2-4)

From the water audit data shown in Figure 2-4, County Water Company (CWC) was found to have current annual real losses (CARL) of around 737 mil gal for the 2006 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; and the cost impact of the real losses is 737 × $190/mil gal = $140,000 in production costs for 2006. To develop a preliminary leakage loss reduction target, a three-step process is recommended:

Step 1—Evaluate the current ILI value: Refer to Table 5-2 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 for CWC is 8.8. Table 5-2 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 target ILI range from Table 5-2 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 semi-arid area 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 upon 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

COUNTY WATER COMPANY—PRELIMINARY LEAKAGE LOSS REDUCTION TARGET-SETTING ANALYSIS

(continued)

(from data in Chapter 2 – Figure 2-4)

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 5-2, 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.

ILI	Real Loss Volume (mil gal/yr)	Annual Real Loss Cost	Potential Savings (current costs minus this ILI cost)	ILI	Real Loss Volume (mil gal/yr)	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	$31,800	$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 considerations for the target ILI range from Table 5-2: 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 as shown in Figure 2-4. 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 parantheses 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
Cost savings ≈ $60,500

ILI = 3.0
Real (leakage) loss reduction = (737 – 251) = 486 mil gal
Cost savings ≈ $92,300

COUNTY WATER COMPANY—PRELIMINARY LEAKAGE LOSS REDUCTION TARGET-SETTING ANALYSIS

(continued)

(from data in Chapter 2 – Figure 2-4)

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 around $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 weighted 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 given later on pages 166–167.

Note: A reminder about real (leakage) loss costs. As described in Chapter 2, real losses include water that has been extracted from a water source, treated, energized, and transported some distance before being lost from the distribution system. The examples for CWC in Figures 2-4 and the sidebar on pages 113–115 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. In addition to these *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 instream 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 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.

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 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 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 *sustain* the lower leakage levels to the greatest extent possible. To define 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 6.1 in Chapter 6 also provides instruction in setting these goals.

As discussed in Chapter 2, water auditing occurs at three levels of refinement:

1. **Top-down approach:** the initial desktop process of gathering information from records, procedures, data, and other information systems.

2. **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.

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 allow a 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 component analysis, bottom-up field measurements, or both of these assessments.

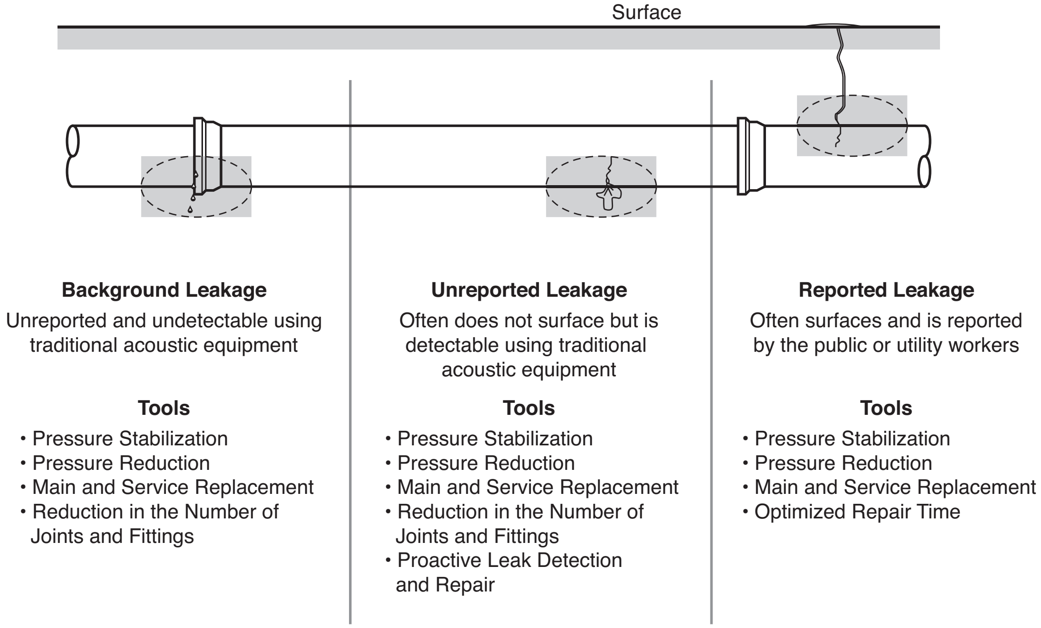


Figure 5-2 Components of leakage and appropriate intervention tools[3]

The three components of leakage loss occur in different manners, and specific tools are needed for the most successful intervention. Figure 5-2 illustrates the three types, or components, of real losses: reported leaks, unreported leaks, and background leakage, and the appropriate activities to control them.

Component Analysis

After the CARL has been estimated from the top-down water audit, it is recommended to attempt to broadly quantify the different components of leakage to understand which components are the greatest portions of the CARL and how these losses occur. Component analysis 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.

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 sonic leak detection methods. If a system incurs high amounts of background leakage, sonic leak detection surveys will not be effective in detecting this leakage. However, pressure management can be an effective tool to reduce background leakage.

Component analysis 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, 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. This type of component analysis is conducted in the following four steps and illustrated in the example for CWC given in the sidebar on pages 122–125.

Step 1. Quantify current reported leakage (CRL). The annual volume of current reported leakage (CRL) can be assessed by summing the product of each leak per year by the flow rate of the leak (adjusted for pressure) by the run time of each leak. This can be simplified by applying the following equation:

$$\text{annual CRL} = \text{sum of } [(\text{NLr})(\text{QLr-ave})(\text{Tave})] \qquad \text{(Eq. 5-1)}$$

Where:

NLr = number of annual reported leaks and break events on water mains and customer services ("reported" leaks/breaks are those events where water surfaces and the event is reported)

QLr-ave = average flow rates for reported leaks/breaks at the current average system pressure. See Tables 5-3 and 5-4 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 4.4 in Chapter 4). Separate calculations should be made for different sizes of mains and for service connections. The average run times can be compared with those used in the UARL formula, (see Table 2.20 in Chapter 2) namely

- 3 days for reported water main breaks
- 8 days for reported leaks on services (main to curb stop)
- 9 days for reported leaks on services (curb stop to meter)

Step 2. Quantify economic unreported leakage (EUL). Figure 5-1 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 detected by continuous flow monitoring in DMAs or leak detection techniques, such as continuous acoustic monitoring. These approaches are detailed in sections "Zone or DMA Flow Measurement and Analysis to Quantify and Manage Leakage Volumes" and "Acoustic Leak Detection," respectively. Many water utilities schedule crews to perform periodic leak soundings (leak surveys) to identify unreported leaks.

The portion of unreported leakage in a water utility that can be cost-justified to identify and repair is referred to as the economic unreported leakage (EUL) level. A preliminary schedule for sonic leak detection surveys or zone measurement, including an appropriate annual budget for active leakage control interventions, can be assessed using only three parameters[4]:

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 ($/mile of mains/year, excluding repair costs).

3. The average rate of rise (RR) of unreported leakage (thous gal/mile of mains/day in a year).

The appropriate level of intervention to control unreported real losses (URL) can be evaluated in terms of how frequent leak surveys are economically effective. This is proportional to the cost of the leak survey (CI) and inversely proportional to the variable cost of real losses (CV)—the higher the cost of water, the shorter the survey frequency. It is also inversely proportional to 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 frequency. It is expressed mathematically as

$$\begin{gathered}\text{economic intervention frequency (EIF) (months)} = \\ [0.789^*(\mathrm{CI}/\mathrm{CV})/\mathrm{RR}]^{0.5}\end{gathered} \qquad \text{(Eq. 5-2)}$$

The percentage of the system to be inspected annually (assuming a continuous program) EP% is the inverse of the EIF:

$$\text{economic percentage of system to be surveyed} = 100\%^*12/\mathrm{EIF} \qquad \text{(Eq. 5-3)}$$

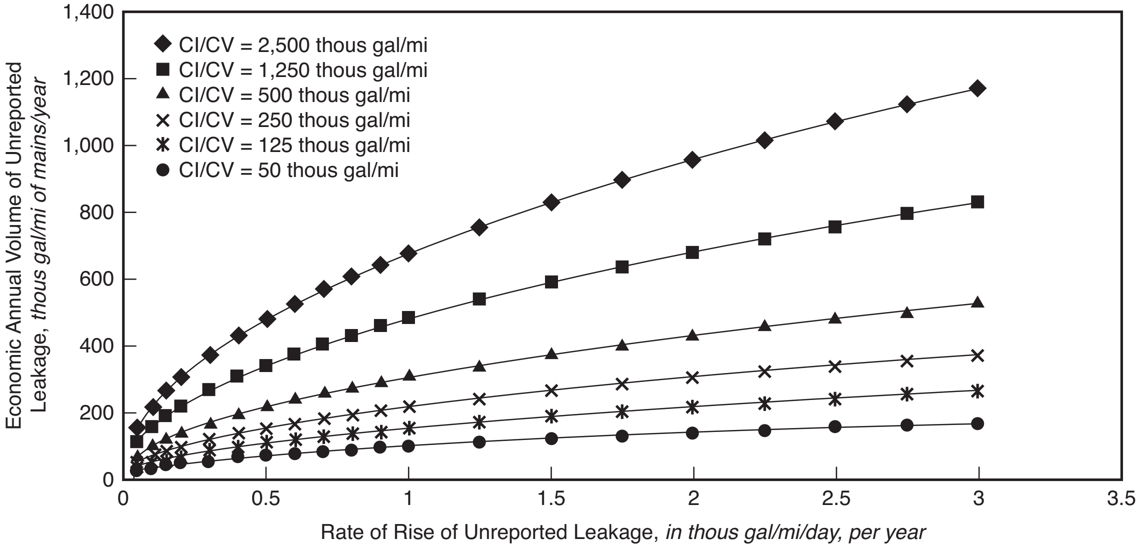
The appropriate annual budget for intervention is then the cost to survey the entire system multiplied by the economic percentage of system to be surveyed:

$$\begin{gathered}\text{average annual budget for intervention} = \\ \text{cost of leak survey (CI)*economic percentage of system to be surveyed}\end{gathered} \qquad \text{(Eq. 5-4)}$$

The calculated EUL expressed in units of thousand gallons is the ratio of the annual budget for intervention to the variable cost in real losses:

$$\mathrm{EUL} = \text{average annual budget for intervention}/\mathrm{CV} \qquad \text{(Eq. 5-5)}$$

Figure 5-3 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 (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:



NOTE: CI/CV = Intervention Cost ($/mile of mains/Variable Cost ($/thous gal)

Figure 5-3 Economic unreported real losses for regular survey (Courtesy of Veritec Consulting Inc. and ILMSS Ltd.)

and the EUL annual volume can be read on the Y-axis. Similar graphs are available to predict economic intervention frequency (EIF), economic percentage of system to be surveyed each year (EP%), and annual budget for intervention (ABI)[4].

If no leak detection and repair activities have previously been conducted, an approximate estimate of 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 equations can be used to give a quick estimate of the four parameters for economic intervention (EIF, EP%, ABI, and EUL). This approach can also be used to identify whether the current annual budget and frequency of leak surveys are appropriate.

Step 3. Estimate the unavoidable background leakage (UBL) and target background leakage (TBL). This is done in two tasks.

- Task 1: Calculate the UBL for the system.

Equation 5-6 calculates the UBL but is appropriate for well-maintained infrastructure, subject to intensive and efficient active leakage control.

$$\text{UBL (thous gal/d)} = [(0.20*\text{Lm}) + (0.008*\text{Nc}) + (0.34 * L_c)] \times (\text{Pav}/70)^{1.5} \qquad \text{(Eq. 5-6)}$$

Where:

Lm = total length of water mains (mi)

Nc = number of service connections (main to curb stop)

L_c = total length of private pipes, curb stop to customer meter (converted to mi) = Nc*Lp (see Figure 2-4)

Pav = average system pressure (psi)

- Task 2: Calculate the TBL by using a multiplier call the infrastructure condition factor.

  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. A multiplier called the *infrastructure condition factor* (ICF) is used and 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. This is similar to the concept of the ILI, where

$$\text{TBL (thous gal/d)} = \text{ICF*UBL} \qquad \text{(Eq. 5-7)}$$

Where:

ILI = current annual real losses/unavoidable annual real losses

ICF = TBL/UBL

that leads to Equation 5-8 (substituting for UBL the previous equation):

$$\text{TBL (thous gal/d)} = \text{ICF*}[(0.20\text{*Lm}) + (0.008\text{*Nc}) + (0.34\text{*}L_c)]\text{*}(\text{Pav}/70)^{1.5} \qquad \text{(Eq. 5-8)}$$

The ICF can be estimated or calculated in several different 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 DMAs representative of the system. Using night flows at carefully selected times of year, compare the measured background leakage immediately after a “find and fix” active leak detection program with that derived from the UBL formula; the ICF will be the ratio of the two values. This method requires the greatest amount of work and is therefore appropriate only for utilities that employ extensive leakage management programs. It is typically used to refine earlier estimates of the ICF.
- **ICF Method B:** 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-min steps by incrementally closing the inlet valve. The inflow data, together with pressures measured at the location representative of the average pressure occurring in the DMA, the average zone pressure (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 component analysis, 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 EUL volumes from the CARL, all of the remaining real losses are attributable to background leakage, and to calculate the ICF accordingly. 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.
- **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.[5]

- **ICF Method E:** Having decided a target ILI—5.0 in the CWC case per the target-setting guidelines shown in the sidebar on pages 122–125—calculate the target real loss (TRL) at the current pressure from the following equation:

$$\text{TRL} = \text{CARL}^{*}(\text{target ILI}/\text{current ILI}) \qquad \text{(Eq. 5-9)}$$

As TRL = CRL + EUL + TBL, then TBL = TRL – CRL – EUC, and TBL = CARL*(target ILI/current ILI) – CRL – EUL and under this approach taking the targe ILI equal to the current ILI, then

$$\text{TBL} = \text{CARL} - \text{CRL} - \text{EUL} \qquad \text{(Eq. 5-10)}$$

The ICF can then be calculated as the ratio of TBL/UBL and should preferably be reasonably close to the target ILI (as in Method D).

Step 4. Estimate the potentially recoverable leakage (PRL). When the three components of the TRL have been assessed, the potentially recoverable leakage (PRL) is the difference between the CARL and TRL, as calculated in Equation 5-10.

$$\text{PRL} = \text{CARL} - \text{CRL} - \text{EUL} - \text{TBL} \qquad \text{(Eq. 5-11)}$$

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 sidebar on page 122 finds that CRL is only 18.9 mil gal/yr, which is just 2.6 percent of the annual real loss. With the current schedule of active leakage control surveys only once every 5 years, the unreported leakage is around 183 mil gal/yr, but the economic frequency of intervention analysis shows this should be reduced to around 112 mil gal/yr, with approximately one third of the system being checked each year. The analysis estimates TBL (assuming an ICF of 3.9) as 204 mil gal or around 28 percent of the current annual real loss; leaving 402 mil gal/yr as the first estimate of PRL, representing 54 percent of current leakage.

The economic intervention analysis shows that more frequent leak surveys are justified. However, provision for flow monitoring in discrete zones or DMAs would improve the targeting of areas for active leakage control interventions (Case Study A in Appendix D demonstrates this). 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 potentially recoverable leakage 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 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, but this option requires the longest timeframe to implement, as well as being the most costly.

COUNTY WATER COMPANY—CONDUCTING A COMPONENT ANALYSIS TO QUANTIFY INDIVIDUAL LEAKAGE TYPES

(from data in Chapter 2—Figure 2-4)

From the water audit data shown in Figure 2-4 CWC was found to have current annual real losses (CARL) of 737 mil gal for the 2006 audit year. Its 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 ILI for CWC is calculated as 737/83.7 = 8.8. Figure 5-1 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 an approximate component analysis as follows.

Step 1—Quantify current reported leakage (CRL): During the 2006 audit year, CWC encountered 148 reported break/leak events. These events are detailed from the following CWC records:

Leakage Occurrence	Pipe Diameter, in.	No. of Events	Daily Flow Rate, thous gal*	Average Run Time, days	Annual Leakage Volume, mil gal†
Customer service connection, utility responsibility	1	66	9.6	3	1.9
Customer service connection, customer responsibility	1	36	9.6	23	7.9
Break, round crack (circ.)	6	22	154	1	3.4
Break, longitudinal/split bell	6	17	193	1	3.3
Break, longitudinal/split bell	8	5	260	1	1.3
Break, longitudinal/split bell	10	1	308	1	0.3
Joint leak	16	1	38.6	21	0.8
Totals		148			18.9

* Reference leakage flow rate from Table 5-3 later in the chapter and multiply by 1,440 (gal/min × 60 min/hr × 24 hr/d) to obtain units of gal/d.

† Total leakage volume = [(no. of events) × (daily flow rate) × (average response time)]/1,000,000 mil gal

Note that the largest volume of leakage loss for the year is for customer service connection piping leaks that fall under customer responsibility and are repaired by contractors or plumbers arranged by customers. CWC has a policy that leaks occurring on customer service connections between the curb stop and the customer water meter are the responsibility of the customer. In CWC's distribution system, customer meters typically exist in a meter pit an average of 18 ft away from the curb stop. Leaks on the piping between the water main and the curb stop are the repair responsibility of CWC. Customer-arranged leak repairs mostly result in longer response times than utility-arranged repairs.

COUNTY WATER COMPANY—CONDUCTING A COMPONENT ANALYSIS TO QUANTIFY INDIVIDUAL LEAKAGE TYPES (continued)

(from data in Chapter 2—Figure 2-4)

Also note that the annual volume of current reported leakage (CRL) of 18.9 mil gal is only a small fraction (2.6 percent) of the CARL of 737 mil gal from the annual water audit data given in Figure 2-4. This illustrates that, while reported leaks can be disruptive and garner much attention, overall they are typically addressed quickly and normally do not account for a major portion of the annual volume of real loss. Hidden unreported leaks that are left to run continuously, and undetectable background leakage, often account for a major portion of the CARL in water distribution systems.

Step 2—Quantify economic unreported leakage (EUL). 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 mil gal/d. The average flow rate of unreported leaks locatable by survey in the five-year period is taken as one half this 5-year finding, which is 0.5 mil gal/d or 183 mil gal/yr. The economic intervention equations can now be used to check if the frequency of the five-year survey and repair interventions is economic and to calculate the economic intervention parameters for this type of survey.

The implied average RR of 0.2 mil gal/d each year is 200,000/256 mi = 0.78 thous gal/mi of mains/d/yr. The variable cost of water CV is $190/mil gal (= 0.19 $/thous gal). The cost for each five-year leakage survey is $64,000 (assume CI of $250 per mile of mains), so the ratio CI/CV = 250/0.19 = 1,315. Applying Equations 5-2 through 5-5 gives:

$$\text{EIF (months)} = [0.789*(\text{CI/CV})/\text{RR}]^{0.5} = [0.789*(1{,}315)/(0.78)]^{0.5} = \textbf{36 months}$$

$$\text{economic percentage of system to be surveyed annually} = 100\%*12/\text{EIF}$$
$$= 100\%*12/36 = \textbf{33.3\%}$$

$$\text{average annual budget for intervention} = \text{economic percentage of}$$
$$\text{system to be surveyed * cost of the leak survey} = (33.3\%)*\$64{,}000 = \textbf{\$21,300}$$

$$\text{EUL} = \text{average annual budget for intervention/CV}$$
$$= (\$21{,}300)/(0.19) = 112{,}000 \text{ (thous gal/yr)} = \textbf{112} \text{ mil gal/yr}$$

These calculations indicate that the economic frequency of leak survey and repair intervention is around three years rather than every five years, so 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 **$21,300** per year, and target around one third of the system to be checked each year. It is preferable to structure leak survey efforts to cover ⅓ of the system each year rather than doing the entire system every 3 years, but each approach is acceptable.

The economic intervention equations clearly demonstrate that, as variable cost of water increases, the EIF and the EUL volume will decrease, indicating that more frequent leak survey and repair interventions are justified. Likewise, the annual budget for intervention and economic percentage both increase, while the average run time of unreported leaks and breaks reduces and the total volume of real losses for the year decreases. The reader may wish to repeat the calculations for CWC assuming a higher CV, or to check the EUL calculation using Figure 5-3.

COUNTY WATER COMPANY—CONDUCTING A COMPONENT ANALYSIS TO QUANTIFY INDIVIDUAL LEAKAGE TYPES (continued)

(from data in Chapter 2—Figure 2-4)

Step 3—Quantify unavoidable background leakage (UBL). The UBL can be estimated by utilizing established values for three distribution system components: leaks on water mains, service connection sections (utility responsibility), and service connection sections (customer responsibility). See Tables 2.20 and 2.21 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 discussion in Chapter 4, pages 101–102, Water Pressure and Leakage, for details.)

$$\text{UBL (thous gal/d)} = [(0.20 * \text{Lm}) + (0.008 * \text{Nc}) + (0.34 * \text{Lc})] * (\text{Pav}/70)^{1.5}$$

$$= [(0.2 * 256) + (0.008 * 12{,}196) + (0.34 * 41.6)] \times (65/70)^{1.5}$$

$$= [51.2 + 97.6 + 14.1] \times (0.93)^{1.5}$$

= 162.9 × 0.893 = 145 (thous gal/d) or **53** mil gal/yr

Note: Lc = [(12,196)(18)]/5,289 ft/mi = 41.6 mi

If the UBL could be achieved and therefore equals the targeted background leakage (TBL), the maximum estimated potentially recoverable leakage (PRL) would be calculated as:

PRL = CARL – CRL – EUL – UBL = 737 – 19 – 112 – 53 = 553 mil gal

A reduction of the 553 mil gal would reduce the ILI from 8.8 (737/83.7) to 2.2 [(737 – 553)/83.7], and this level of reduction appears unrealistic for a system of this age and condition.

The setting of an initial ICF to assess TBL is necessarily a subjective judgment in the first stages of component analysis. CWC does not have sufficient leakage repair data to use the more refined methods of estimating its ICF to quantify background leakage but recognizes the benefits of attempting a systematic approach to setting the ICF. CWC, therefore, uses ICF estimation Method E, subject to checking (based on Method D) that the ICF will approximately equal the ILI when the target leakage levels have been achieved.

If the target ILI is assumed to be **4.0** (midway in the range 3 to 5 in Table 5-2), the current annual real losses (CARL) would be 4.0 * UARL = 4 * 83.7 = **335** mil gal/yr. CRL and EUL are **19** and **112** mil gal/yr, respectively, and **UBL** is **53** mil gal/yr.

So initial TBL = 335 – (19 + 112) = **204** mil gal/yr. Implied target ICF = TBL/UBL = 204/ 53 = **3.9**.

This is close to the target ILI of **4.0** and is consistent with Method D of assessing the ICF, so the target ILI is set at **4.0**, and the TBL as **204** mil gal.

Step 4—Estimate potentially recoverable leakage. For the assumed target ILI of 4, the target for annual real losses at the current average pressure of 65 psi is 4 * UARL = 335 mil gal/yr.

The CARL are 737 mil gal/yr, so the potentially recoverable leakage is 737 – 19 – 112 – 204 = 402 mil gal/yr, at a projected savings of $76,400 per year.

Preliminary leakage components. CWC's leakage components are initially quantified as

COUNTY WATER COMPANY—CONDUCTING A COMPONENT ANALYSIS TO QUANTIFY INDIVIDUAL LEAKAGE TYPES (continued)

(from data in Chapter 2—Figure 2-4)

	Volume, mil gal	% of Total
Current reported leakage, CRL	19	2.6
Economic unreported leakage, EUL	112	15.2
Target backround leakage, TBL (if ICF = 3.9)	204	27.7
Potentially recoverable leakage, PRL	402	54.5
Total	737	100.0

Zone or DMA Flow Measurement and Analysis to Quantify and Manage Leakage Volumes

The most accurate means to quantify the individual components of leakage in a water distribution system is to obtain bottom-up 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 flow meters installed on one or more water mains serving as supply feeds to the DMA. Monitoring flows in discrete areas or zones of the water distribution system offers a number of advantages to the water utility in optimizing their water supply efficiency, however. To best present the principles for design and operation of DMAs, guidelines from the publication *A Manual of DMA Practice*[6] are presented with some changes to take into account distribution system characteristics prevalent in North America.

This method has some potential limitations depending on the design and size of the DMA. For example, smaller leaks are sometimes difficult to detect. Distribution systems laid out in a grid and those with water storage tanks may present challenges when designing an effective DMA. Care also is needed to avoid unintended consequences, such as supply restriction or adverse water quality effects.

Principles of DMA operations. Many water utilities throughout the world 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 villages 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. While 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 crews.

The technique of flow measurement to infer leakage volumes requires metering and tracking flows supplying sections of the water distribution system. The design of such a leakage monitoring system for active leakage control has two goals:

- 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 the presence of unreported leaks can be distinguished from levels of normal consumption by analyzing flow patterns during minimum consumption periods of the day.
- 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 eliminating pressure transients that cause ruptures.

Therefore, it follows that a leakage monitoring system will comprise a number of districts where flow is measured by permanently installed flow meters. 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
- 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 their 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 grid, 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 avoids 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 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 properties.* The DMA size is typically expressed in number of properties or service connections. The size of a typical DMA in urban areas varies between 500 and 3,000 properties[7]. The size of an individual DMA will vary, depending on a number of 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)
  - Previous leakage control technique (e.g., former flow measurement areas)
  - Individual water utility preference (e.g., discrimination of service pipe breaks, 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
  - 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 properties, because of high housing density. The number of DMA connections may vary in rural areas, as rural DMAs may consist of a single village, or may encompass a cluster of villages (small number of properties but large geographical areas). If a DMA is larger than 5,000 properties, it becomes difficult to discriminate small leaks (e.g., service 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:

  - Small: < 1,000 properties
  - Medium: 1,000–3,000 properties
  - Large: 3,000–5,000 properties

Ultimately the configuration of the distribution system will play the largest role in determining the size of the DMA, based on factors including

- Type of consumers (industrial, multi-family, single family, commercial, etc.)
- Variation in ground level
- Targeted final leakage level
- Minimum flow and pressure requirements for fire flow, insurance, meeting standards of service
- Looping and redundancy considerations of the piping grid
- The location of service connections serving large or special-needs customers—buildings such as hospitals, schools, etc.—should be examined for any 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 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 steps. 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 a number of distinct 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 distinct design steps should be considered when designing the DMA, including

- 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. 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 any 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 new 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 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 design phase and provisions assigned to avoid poor service while still meeting the DMA objectives. 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 locations in the new DMA area. Inexpensive 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 available 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 this data can an accurate cost–benefit 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. Fixed network automatic meter reading (AMR) 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 night 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 night hours.

An exact count of customer properties is not necessary at the design stage, as long as the relative size guidelines of 500 to 3,000 properties are 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 geographical information system (GIS), billing records, zip-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 inflow water main. Flow and pressure measurements can be gathered by using instruments installed on a temporary basis. The appropriate inflow main to supply water to the DMA should be identified. Temporary metering can be provided by installing a ferrule for an insertion flow meter; or the inflow main can be exposed to use 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 (1:500 or 1:1250) 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/downstream obstructions, typically quoting the distance in terms of a number of 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 location of the critical point (CP) or the location of lowest pressure in the DMA should be determined, and the average zone point (AZP) 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 and is determined by calculating the average pressure across the DMA and identifying the location in the DMA that most closely incurs pressure at this average value. The sidebar on page 56 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) is needed to anticipate the effects of distribution system capacity for fire-fighting flows and normal service in areas of higher elevation. Pressure data is 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 amount of new valves required, installation of flowmeters, PRVs, chambers, etc. 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, etc. 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 5-4.

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. Any conflicts with other utilities (e.g., electricity, cable, etc.) should be identified and addressed in the design phase.

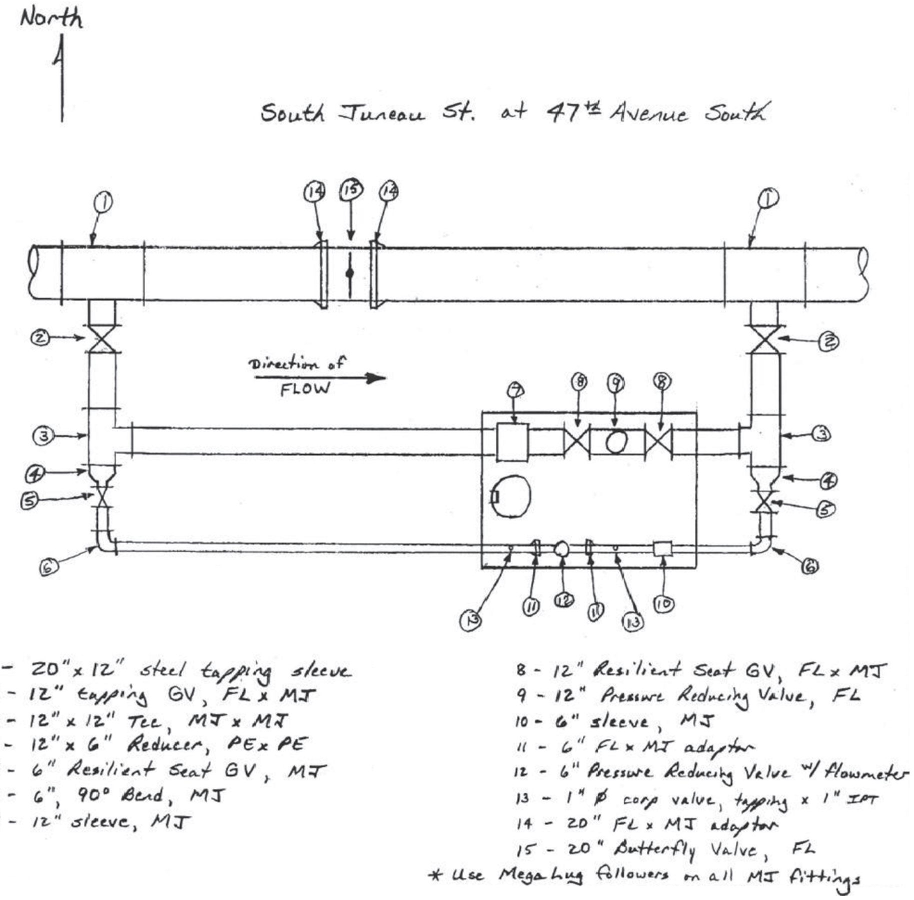


Figure 5-4 Preliminary design sketch for pressure management PRV chamber with bypass (Courtesy of Seattle Public Utilities)

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 critical and average zone pressure points and collect data for several days before closing the boundary valves. Pressure loggers should also be installed near any critical customers in the DMA. Comparing this 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 any 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 future 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 night hours. This period needs to be adjusted to take into account any local differences in demand patterns. The steps in pressure reduction should be in the range of 10–15 psi down to the pressure level where the minimum required pressure at the critical zone pressure point is set. To monitor if the DMA is hydraulically discrete or not, several pressure loggers can be installed outside the DMA boundaries prior to the test. These boundary loggers will record any change in pressure related to pressure drops created within the DMA in case 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 min 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 addressed, 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 critical point and any sensitive customer locations. 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 different type 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 a different purpose 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 in the section Constructing the DMA. Three or four incremental reductions in supply should be conducted with gaps of at least 15 min between step reductions. Pressure should be reduced 10–15 psi for each increment. Flow and pressure levels 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. 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 other low water demand period, because these tests require working pressures to be lowered notably such that customer service may be disrupted for approximately one hour. The pressure step test is a more rigorous version of the pressure drop test described in the section Constructing the DMA.

- 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 size of the reduction, 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, it has an inherent flaw and can give misleading results. DMAs are useful in large part because flow and pressure patterns can be observed for seasonal variations and other supply fluctuations. When a DMA is segmented, the hydraulic conditions—most notably the pressure—can change, and certain leakage rates are very sensitive to pressure changes. Therefore, the amount of leakage in a given portion of the DMA can change as the zone is segmented during the step test. 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, 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, etc.—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 levels 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. In an open system, leak reduction often results in pressures gradually rising, which causes new leaks to form. Hence, an endless cycle of leak developments 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. It is best to have leak detection capabilities 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, 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 by use of permanently installed leak noise loggers that continuously sound for leaks. 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 complimented 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 valves, fire hydrants, or other visible points. Newer techniques have also been developed to sense leaks from probes traveling inside active water piping.

While 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 nearly closed valves that sound very similar to leaks. Acoustic leak detection is complicated when multiple leaks exist within close proximity in a small area of the distribution grid: often, repeat surveys are needed after each leak repair is completed. 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.

A leakage management strategy that relies strictly on acoustic leak detection has limited means to inhibit new leaks, typically only by eliminating those leaks that could undermine the bedding soil support of nearly existing piping. In contrast, pressure management not only reduces background leakage rates, but it inhibits the formation of new leaks by removing excessive pressure and eliminating pressure transients. Because of these limitations of acoustic leak detection, water utilities should employ an active leakage control strategy that includes appropriate combinations of flow measurement (DMAs), acoustic leak detection and pressure management 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 three types of leak sounds. Leak noises in the range of 500 to 800 hertz (Hz) usually originate as orifice-pipe vibration phenomenon and are transmitted along the pipe wall and in the water; in some instances, a considerable distance from the actual leak. Identifying this sound by systematically testing valves, hydrants, and curb-stop valves frequently locates potential leaks. The two other leak sounds emanate in the 20-to-250-Hz range; one of which is caused by the impact of water on soil in the area of the leak, while the remaining sound is caused by water circulation, usually in a cavity in the soil near the leak. This latter sound resembles the sounds of water emanating from a fountain. Unlike the vibration on the pipe wall, the travel distance of the lower frequency sounds is limited to the immediate area of the leak. Because of their limited range, these low-frequency sounds are essential to pinpointing the leak.

Factors affecting leak sounds. The following factors influence leaks sounds:

- Pressure. It is usually necessary to have a water pressure level 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.

- 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 while clay is a poor conductor.

- 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, while asphalt and concrete are good resonators providing a uniform sounding surface.

The 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

- **Detectable leaks on water mains** ranging from a low of 1 gpm to more than 1,000 gpm, but the higher rates frequently become reported leaks as they eventually become disruptive by undermining road paving or causing other disturbances. 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 as 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 connections 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 on visible fire hydrants often become reported leaks but many small leaks remain unreported leaks for long durations. Leaks may also occur in system controls, such as pressure-reducing valves, pressure-sustaining valves, pressure-relief valves, altitude-control valves, blow-offs, and any component 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 metering technology can register flows as low as ⅛ gpm and can be used to identify very small 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 low flow (below detectable limits) leaks may not register on customer meters, and this waste of water may go undetected if not actively monitored.
- **Miscellaneous leaks** occurring as a result of excessive pressure, settlement, overloading, improper installation, improper materials, and improper operation of any other components 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, leak correlators, leak noise loggers, and inline sensors to detect leaks from within active large-diameter transmission piping. 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 sections.

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 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 correlation. This method is accurate in pinpointing many leak locations using an acoustic leak correlator, or microprocessor, to analyze leak sounds (including those 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.

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, and nature of the leak orifice, the 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 linear pipe distance between the contact points, the water pipe material, and size (diameter) of the pipeline. Two electronically amplified microphones, connected to and powered by portable electronic preamplifier outstations, are attached to the selected contact points. The leak sound, picked up by the microphones and amplified by the outstations, is then transmitted to the correlator by a radio housed within the outstation.

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 5-5 where the leak is on a main between two sounding points, **A** and **B**, at a distance **D** apart. In this example, the leak is at a point halfway between **C** and **B**. 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

$$D = 2L + N$$

Substituting velocity **V** multiplied by time difference **Td** for **N**

$$D = 2L + VTd$$

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

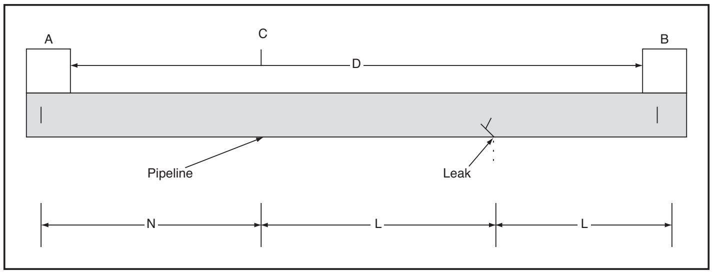


Figure 5-5 Determining the position of a leak using a leak correlator

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.

Modern leak correlator systems are very portable and user friendly in the field. A typical complement of correlator equipment may include

- A laptop microprocessor or personal digital assistant with internal rechargeable 12-VDC power supply, display screen, internal preamplifier, two-channel internal radio receiver, and stereo headphone
- Two electronic amplifier outstations with internal rechargeable **12-VDC** power supply, internal radio transmitters, microphones, and stereo headphones
- Battery charger kit
- Manual and test tape with stereo lead

Commonly available accessories include the following:

- Cases for carrying items and added protection
- Microphone attachment accessory kit
- Portable electronic survey tool that serves as a backup outstation
- Measuring wheel
- Hydrophone sensor package
- Stereo recorder with harness
- Training tapes
- Ground-microphone system
- Printer
- Pipe locator

The leak noise correlator is used to confirm the presence of a leak and pinpoint its location that may not be reliably identified for surfacing and nonsurfacing 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, do not affect the leak correlator. The depth of the main, type of cover, and surface conditions are generally not factors to be considered. However, the leak noise correlator requires an accurate breakdown of the size and types of pipe material between the correlation units. It is not uncommon to use both the leak noise correlator and ground microphone to pinpoint the leak location as precisely as possible. 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.

Leak noise monitors. In recent years, leak detection equipment firms 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 night 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). Leak noise loggers 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 4.7). 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 virtually eliminate 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 of 6–12 units 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. 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 the grid around military bases, government buildings, hospitals, 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. In some cities, thousands of loggers have been purchased and installed.

LNLs can create cost efficiencies by reducing the labor involved in conducting leak surveys. Instead of a crew of 2–4 employees sounding individual appurtenances, 1–2 employees can install LNLs relatively quickly in the same survey area and return the next day to download and analyze data. Leak 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 data transmitters (LNTs). Several AMR firms are making available (with or without connecting water meters) fixed network and mobile AMR 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 mobile AMR 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, 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 of 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, changes little (the rate of rise, RR, of leakage is low), or is expected to consist largely of background leakage or rapidly surfacing large breaks, this would not be an appropriate technology to employ.

District metering (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 (see section Typical Pressure Variations in North American Water Distribution Systems) Nevertheless, there have been documented cases of effectively reducing leakage from such programs. Success is attributed to finding nonsurfacing 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.

In-line leak detection sensor. In cases where external acoustic leak detection techniques are not practical, an in-line 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. In-line surveys are generally appropriate for large-diameter transmission mains, which are often poor at transmitting leak sounds and have limited access points to the pipe. Techniques that use sensors tethered to an umbilical cable have been developed and proven in many utility applications. More recently, tests have been conducted with sensors that are free swimming in the pipeline. In-line methods have been 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 pipelines that run under rivers, major highways, or other inaccessible locations.

Acoustic probes 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. Tethered systems can travel up to 6,000 ft but cannot traverse butterfly valves or other in-line obstructions. Free swimming sensors can travel potentially farther, but these devices cannot be retracted and resent in a single survey as a tethered system, and a free swimming device must be carefully tracked. Any branching mains from the transmission pipeline must be valved closed during the survey. Shorter spacing may be needed in pipelines with many bends. Sensors rely on minimum water pressure of at least 5 psi such that leaks will generate an audible leak noise.

During the survey the operator listens to the audio signal and tracks the location of the sensor. As in-line systems depend on the flow of water for propulsion, steps may need to be taken to adjust the flow. 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 at points around bends, as does drag from the flow of water along the tether. A brief pull-back 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.

In-line 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 for traditional leak detection surveys. While requiring an investment to obtain these services, water utilities have potential to save money in the long run by identifying small leaks on transmission mains and addressing them before they become large, disruptive ruptures. Many water utilities have not surveyed their transmission mains adequately for leaks, and in-line leak detection technology offers an outstanding capability to monitor these important water supply assets.

Innovations in electronic leak detection techniques continue to occur. Free swimming in-line systems hold some promise for the future. Presently, leak correlators, LNLs, LNTs, and in-line tethered 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 by 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 water distribution system in such a manner. The development of leak noise loggers, which can be deployed and programmed to “awaken” at minimum noise hours, 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 levels. 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. 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

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 two miles of pipeline per day at a cost of approximately $200–$300/mi of pipeline. To formulate the work pace, assess the characteristics of the water distribution system, including

    a. Mains and services: types, ages, diameters, joints, installation methods, inspections, leak histories, and operating pressures.

    b. 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 counter clockwise-turning, number of turns to exercise; and how often they are exercised.

    d. 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 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, via the use of leak noise loggers, or a combination of both techniques. This decision will greatly influence the required funding as manual methods require greater labor, while the use of leak noise loggers needs less labor but needs a different form of equipment and training. See the discussion in section Simple Leak Noise Probes.

3. Assemble the leak detection team by selecting motivated employees with a keen sense of hearing, the ability to discern different sounds, familiarity with water meters and the distribution system, 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 provided. Vehicles should be provided with good light 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 noises 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 sidebars on pages 149–153 for sample forms 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, while 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 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 component analysis.

The process for conducting leak surveys can be segregated into four phases.

1. Initial listening survey
2. Relistening to suspect sounds
3. Leak pinpointing
4. Leak repairs and confirmation of pinpointing

These phases are detailed in the following sections.

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 leaks 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. 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. A sample plan is shown in the sidebar beginning on page 149. A blank form is included in Appendix A. The sidebar on page 154 is a sample log used in documenting the findings of the leak detection survey.

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.

A number of 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.

A number of 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.

Relistening 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 (see section Leak Pinpointing). 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 a new alternative to the conventional leak detection survey and may improve the efficiency of the leak detection process.

Automating acoustic leak detection surveys. The section Leak Noise Monitors 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 position using the same communication network that sends the customer meter reading.[8] 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 firms to provide variations to this approach. This is an outstanding example of an application 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 discernable 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 nonsurfacing 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 AMR system, just as the LNTs communicate within the AMR configuration.

Integrating leak detection methodologies. The most effective leakage management approach uses the appropriate combination of leakage control techniques as shown in Figure 5-1. Continuous flow monitoring in DMAs provides detection of rising leakage levels, 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 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 relistening 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 apparatus 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 complex, hospital, 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 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 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 the customer 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 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 relistening 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 section Leak–Noise Correlation. Leak correlators are often used directly but may also be used in conjunction with correlating electronic leak noise loggers.

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 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 for repair.

In-line leak setection sensor (see Figure 5-6). See the description given in section Leak Noise Monitors 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 it 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 section Optimized Leak Repair Functions. Pinpointing should be closely coordinated with repair activities so that confirmation of the pinpointing success or failure

Figure 5-6 Use of inline leak detection technology in a 48-in. water main (Courtesy of Philadelphia Water Department)

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 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.

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 staff or to contract leak detection services can be considerable. Therefore, it is important that the operator defines the proper program capabilities to economically address the types of leakage occurring within the water distribution system. Leak detection economics were previously discussed, with an example calculation shown in the sidebar on pages 122–125. Additional examples illustrating economic methods are shown in the following sidebars.

Nonacoustic Leak Detection

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 also have limitations. These techniques are currently in limited use commercially, although research continues on these and other new methods.

Gas tracer method. Occasionally situations occur where leaks cannot be detected or pinpointed by traditional electrosonic or correlation methods. These types of leaks often occur as hydrostatic test failures on new pipelines during construction. They are usually small and are hard to detect. Tracer gas has proven effective for detecting and pinpointing leaks in these situations, and the technology is being developed to sense leaks on water-filled, pressurized pipelines.

The tracer gas method uses one of two potential gases: helium and hydrogen. For helium detection, the method involves dewatering the section of main or pipe being tested and injecting a gas mixture of 5 to 10 percent helium (with the balance as air) at one end of the section. A relief is kept open at the opposite end to allow the helium to flow through and fill the test section. When helium is detected at the relief end, the relief is closed. The section is then pressurized to a predetermined pressure.

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

SAMPLE LEAKAGE MANAGEMENT PLAN

Name of Water Utility: *County Water Company* Date: *1/18/2007*

I. Leakage Management Approach

After completing CWC's first annual water audit (See Figure 2-4) and component analysis of leakage (See Figure 5-5), the CWC manager determines to create an ongoing leakage management program that (1) reduces the potentially recoverable leakage identified from the water audit and component analysis, and (2) sustains lower leakage conditions once leakage levels are reduced.

The component analysis estimates 402 mil gal of potentially recoverable leakage. The initial economic intervention analysis concludes that, once the target leakage levels have 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 transients and new 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 percent of system to be surveyed each year *34 percent*. Cover the entire system every three years.

List frequency of surveys *every year during spring to cover 34 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: **(.34)(250) = 84 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 two miles of main per day. Factors include distances between services, traffic/safety conditions, and availability of listening contact points. Explain if more than three miles per day are surveyed: *Assume 2.0 mi/ d using 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): **42**

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.*

SAMPLE LEAKAGE MANAGEMENT PLAN (continued)

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 over 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.

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 5-3 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 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	$/hr	38.95	$/d	311.60

SAMPLE LEAKAGE MANAGEMENT PLAN (continued)

C-2. How many consultant staff will be used? **1**

Cost of consultant staff:

Person 1	$/hr	60.00	$/d	480.00
Person 2	$/hr	0	$/d	0
TOTAL	$/hr	60.00	$/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	42	13,088.00
D-2. Consultant crew costs	480.00	16	7,680.00
D-3. Vehicle costs	12.00	42	504.00
D-4. Other	—	—	0
D-5. Total survey costs	—	—	21,272.00

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	$21,272 (Recurring Cost)
E-4. Total leak detection costs	$36,272 (First-Year Cost)
	$21,272 (Year 2 and 3 Costs)

*Eight LNTs and other electronic equipment

F. Leak Survey and Repair Schedule

Indicate realistic, practical dates:

F-1. When will the leak survey begin?	*March 1, 2007*
F-2. When will the leak survey be completed?	*August 6, 2007*
F-3. When will leak repairs begin?	*March 15, 2007*
F-4. When will leak repairs be completed?	*August 27, 2007*

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 mi of pipeline, or 10 percent of CWC's total of 250 mi 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 mi of plastic piping that CWC piloted 25 years ago. As detailed in section Water Pressure and Leakage in Chapter 4, failures on plastic pipe follow a variable path failure mode with high N1 exponents, meaning that leakage rates change rapidly

SAMPLE LEAKAGE MANAGEMENT PLAN (continued)

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 component analysis shown in Figure 5-5 estimates 204 mil gal of background leakage and 402 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 decides to employ pressure management in this area in addition to ongoing leak detection surveys as the key components of the new CWC leakage management plan. The manager also decides to review the break frequencies before and after pressure management to assess to what extent these may have been influenced by the pressure management. 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 manger 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: state park land and a railroad. The Valley District grid is supplied via four distribution mains size 10 in., 8 in., and 6-in. (2), respectively. By closing the two 6-in. supply mains, the Valley District can be configured into a DMA. 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

SAMPLE LEAKAGE MANAGEMENT PLAN (continued)

IV. Leak Management Plan Summary

plan cost = leak survey cost + pressure management cost
= $36,272 + $26,705 = $62,977, use $63,000

As discussed in Figure 5-2, CWC could strive to reduce up to 402 mil gal to lower its ILI from 8.8 to 4.0. The annual savings from this reduction would be $76,400, once the target has been achieved; however, there is no guarantee that CWC can cut 402 mil gal in one year. 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 is determined to move forward with this plan and reevaluate it after the first- and third-year intervals.

Prepared by: *C.M. Biggs, Manager* Date: *January 18, 2007*

to 5 percent hydrogen in nitrogen, or less. Any hydrogen–nitrogen mixture containing less than 5.7 percent hydrogen is nonflammable (ISO 10156).

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 various 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.

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 grounds interior is scanned with radar waves in a manner similar to that of ultrasound to obtain cross-sectional images.[9]

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 differences in the temperature of leaking water and the

LEAK DETECTION SURVEY DAILY LOG

Name of Water Utility: *County Water Company* Date: *April 17, 2007*

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 Cor. Firestone & San Gabriel	U	Y	N	Y	
53	SW Cor. Firestone & San Gabriel	U	Y	N	Y	
54	SW Cor. 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 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.

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 a number of variables, including ambient temperatures of air and soil, relative humidity, seasonal effects, and other variables.[9] It 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 can occur in a water distribution system at any time, 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 CONTROL INTERVENTION METHODS

Active leakage control is a key activity in the four pillars of real loss control as shown in Figure 5-1. 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 where appropriate. The following intervention activities are the remaining three activities of the four pillars of a successful leakage management program, shown in Figure 5-1:

- Optimized repair functions for reported and unreported leaks (short-term actions)
- Pressure management (short-, medium-, and long-term programs)
- Infrastructure rehabilitation and renewal (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.

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 component analysis. 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 5-3
- By calculating losses using modified-orifice and friction-loss formulas; see Tables 5.4 and 5.5. Table 5-4 applies to circular holes in pipelines. Table 5-5 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 5-6. These methods apply to small leaks from valves, meters, pumps, etc.

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 5-3 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 5-3. Leakage rates vary primarily by types of leaks and the level of pressure. A rate of leakage can be easily taken from the various types listed in Table 5-3 and then corrected for the actual level of pressure. The leakage rate at the actual pressure P_a can be determined by applying Equation 5-12:

$$\text{leakage rate at actual pressure } P_a = (\text{leakage rate @ 70 psi})[(P_a/70)^{0.5}] \qquad \text{(Eq. 5-12)}$$

Table 5-3 shows 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 determining the line pressure. A pressure gauge or a hand-held 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 Equation 5-13, which is applied in Table 5-4:

$$Q = \frac{43{,}767}{1{,}440} \times A \times P^{0.5} \qquad \text{(Eq. 5-13)}$$

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 5-3 Leakage flow rates for metallic piping systems[10]

		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 @ 70 psi)[$(65/70)^{0.5}$].

Table 5-4 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	13.593	16.648	19.224	21.493	23.544	25.430	27.186	28.835	30.395
0.4	0.125	17.087	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

*Calculated using Greeley's formula (see Equation 5-13).

Table 5-4 Leakage losses for circular holes under different pressures* (continued)

Diameter of Hole, in.	Area of Hole, in.^{2}	Leak Losses, gpm									
		20	40	60	80	100	120	140	160	180	200
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	180.488	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 Equation 5-13).

Table 5-5 Leak 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.

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 convert time and volume to gallons per minute (see Table 5-6). Time intervals that are convenient for the calculation should be used. The leaking water should be caught for 1 min, the volume collected is the per-minute flow. For other time periods, see Table 5-7.

Table 5-6 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:

$$\begin{gathered}(1 \text{ gal/min})(60 \text{ min/hr})(24 \text{ hr/d})(365 \text{ d/yr})(2 \text{ yr}) \\ \text{a leak of 1.0 gpm for 2 yr} = 1{,}051{,}200 \text{ gal} = 1.051 \text{ mil gal}\end{gathered} \qquad \text{(Eq. 5-14)}$$

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.

Table 5-6 Drips per second and cups per minute converted to gpm

Drips per sec	gpm	8-oz cups per min	gpm
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.

Table 5-7 Multipliers for bucket-and-stopwatch method

Time in sec:	6	10	15	30	
Multiply volume in gal by:	10	6	4	2	To get gpm

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, simply read the meter. 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 connections 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 disconnecting the leaking pipe. 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.)

Sources on % of the Total Expenditures:

	A	B
• Internally generated cash (*)	72%	72%
• Financial deficit	28%	28%
• Covered by:		
• Net stock issues	4%	34%
• Net increase in long term debt	20%	10%
• Net increase in short term debt	4%	4%

(*) Cash flow from operations less cash dividends paid to stockholders

Figure 5-7 Repair clamps are commonly used to repair circumferential ruptures on distribution piping since they are quick to install and are highly durable

- 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 5-7. 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 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 exist, and the potential for water utility personnel to innovate their own repair method always exists. Many unusual pipeline configurations exist, particularly in older systems, so the rule to “expect the unexpected” applies. 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 local requirements.

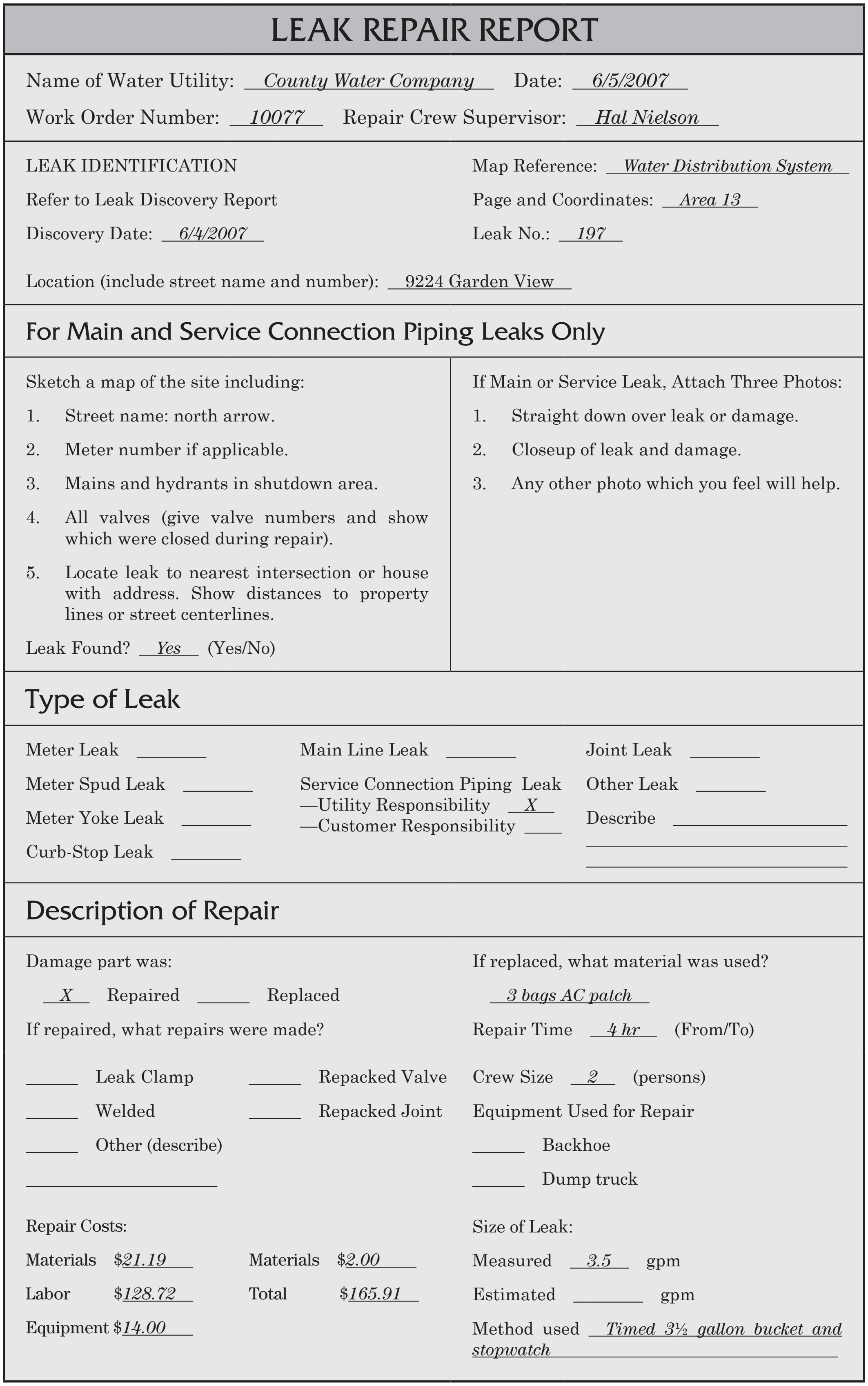
Most small leaks occurring under pressure release water from the pipe or appurtenance with little chance of contamination. These leaks can usually be repaired directly without dewatering the pipeline or appurtenance. Under these circumstances, no additional sanitary steps are needed to complete the repair. 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 the pipeline 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.[11,12]

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 section A Further Word on Customer Service Connection Piping Leakage in Chapter 4, 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. It is important that, during and after leak repairs, information is gathered and documented regarding the nature of the leak or break, the repair method, the underground conditions, street, weather, and costs. Information can be recorded on a leak repair report such as that shown in the sidebar on pages 164–165. This information is needed 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. Data on the annual results of the leakage management activities are also summarized in the sidebar on



LEAK REPAIR REPORT

Name of Water Utility: *County Water Company* Date: *6/5/2007*

Work Order Number: *10077* Repair Crew Supervisor: *Hal Nielson*

LEAK IDENTIFICATION

Refer to Leak Discovery Report

Discovery Date: *6/4/2007*

Map Reference: *Water Distribution System*

Page and Coordinates: *Area 13*

Leak No.: *197*

Location (include street name and number): 9224 Garden View

For Main and Service Connection Piping Leaks Only

Sketch a map of the site including:

1. Street name: north arrow.
2. Meter number if applicable.
3. Mains and hydrants in shutdown area.
4. All valves (give valve numbers and show which were closed during repair).
5. Locate leak to nearest intersection or house with address. Show distances to property lines or street centerlines.

Leak Found? *Yes* (Yes/No)

If Main or Service Leak, Attach Three Photos:

1. Straight down over leak or damage.
2. Closeup of leak and damage.
3. Any other photo which you feel will help.

Type of Leak

Meter Leak ____

Meter Spud Leak ____

Meter Yoke Leak ____

Curb-Stop Leak ____

Main Line Leak ____

Service Connection Piping Leak
—Utility Responsibility *X*
—Customer Responsibility ____

Joint Leak ____

Other Leak ____

Describe ____

Description of Repair

Damage part was:

X Repaired ____ Replaced

If repaired, what repairs were made?

____ Leak Clamp

____ Welded

____ Other (describe)

____

____ Repacked Valve

____ Repacked Joint

If replaced, what material was used?

3 bags AC patch

Repair Time *4 hr* (From/To)

Crew Size *2* (persons)

Equipment Used for Repair

____ Backhoe

____ Dump truck

Repair Costs:

Materials $*21.19*

Labor $*128.72*

Equipment $*14.00*

Materials $*2.00*

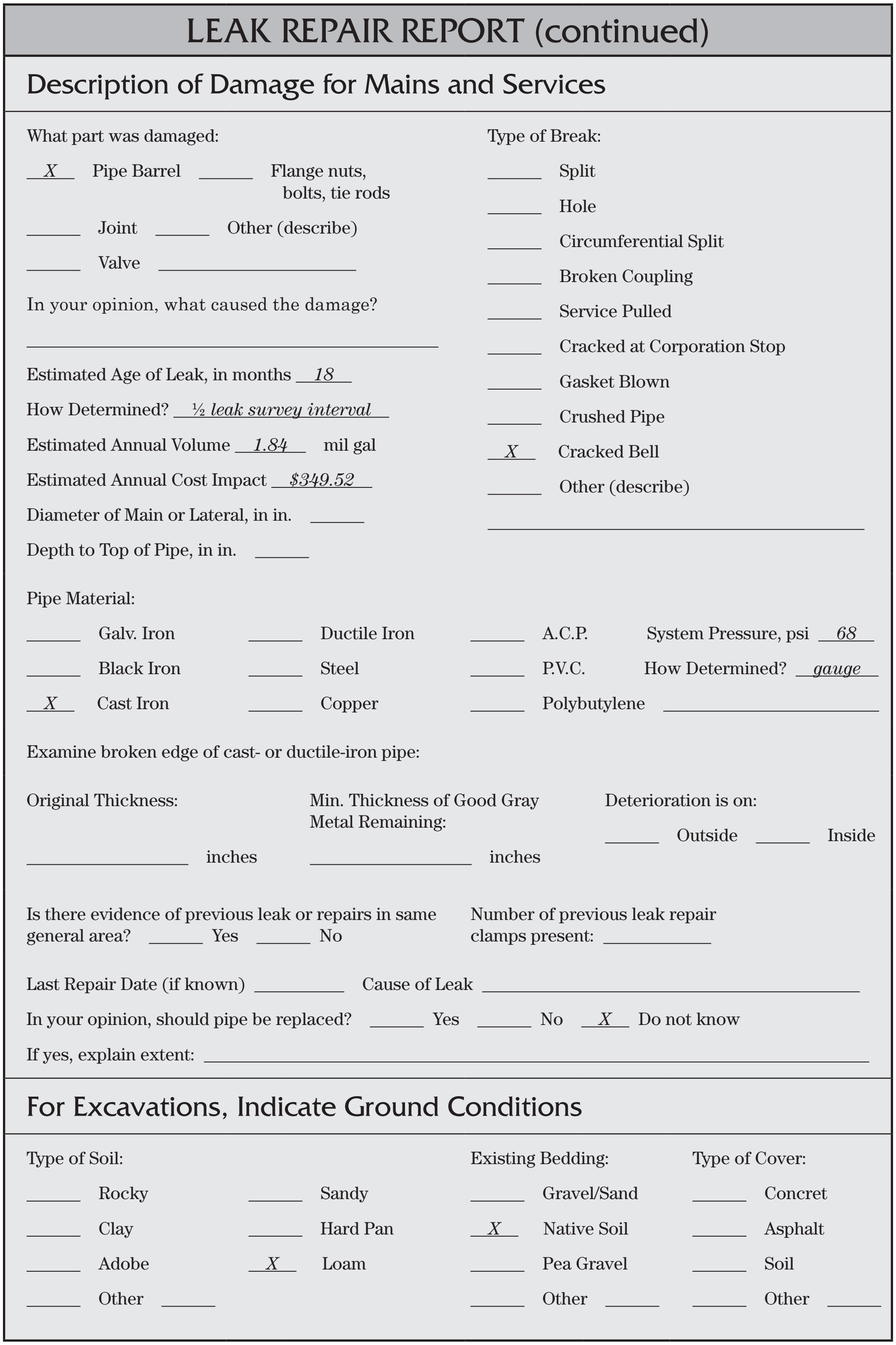
Total $*165.91*

Size of Leak:

Measured *3.5* gpm

Estimated ____ gpm

Method used *Timed 3½ gallon bucket and stopwatch*



LEAK REPAIR REPORT (continued)

Description of Damage for Mains and Services

What part was damaged:

X Pipe Barrel

______ Flange nuts, bolts, tie rods

______ Joint

______ Other (describe)

______ Valve ______________________

In your opinion, what caused the damage?

____

Estimated Age of Leak, in months 18

How Determined? ½ leak survey interval

Estimated Annual Volume 1.84 mil gal

Estimated Annual Cost Impact $349.52

Diameter of Main or Lateral, in in. ______

Depth to Top of Pipe, in in. ______

Type of Break:

______ Split

______ Hole

______ Circumferential Split

______ Broken Coupling

______ Service Pulled

______ Cracked at Corporation Stop

______ Gasket Blown

______ Crushed Pipe

X Cracked Bell

______ Other (describe)

____

Pipe Material:

______ Galv. Iron

______ Black Iron

X Cast Iron

______ Ductile Iron

______ Steel

______ Copper

______ A.C.P.

______ P.V.C.

______ Polybutylene

System Pressure, psi 68

How Determined? gauge

____

Examine broken edge of cast- or ductile-iron pipe:

Original Thickness: __________________ inches

Min. Thickness of Good Gray Metal Remaining: __________________ inches

Deterioration is on: ______ Outside ______ Inside

Is there evidence of previous leak or repairs in same general area? ______ Yes ______ No

Number of previous leak repair clamps present: ____________

Last Repair Date (if known) __________ Cause of Leak ____

In your opinion, should pipe be replaced? ______ Yes ______ No X Do not know

If yes, explain extent: ____

For Excavations, Indicate Ground Conditions

Type of Soil:

______ Rocky

______ Clay

______ Adobe

______ Other ______

______ Sandy

______ Hard Pan

X Loam

Existing Bedding:

______ Gravel/Sand

X Native Soil

______ Pea Gravel

______ Other ______

Type of Cover:

______ Concret

______ Asphalt

______ Soil

______ Other ______

LEAKAGE MANAGEMENT PROGRAM COST-EFFECTIVENESS

Name of Water Utility: *County Water Company*

Name of Report Preparer: *C.M. Biggs*

Date: *9/6/2007*

Leak Detection Survey

Total Number of Days Leak Surveys Were Conducted: *121*

First Survey Date: *3/26/2007* Last Survey Date: *5/23/2007*

	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

$$\text{average survey rate} = \frac{\text{miles of main surveyed} \times 8\ \text{hr/d}}{\text{total survey and pinpointing hr}} = \underline{\ 1.67\ }\ \text{mi/d}$$

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: *3/29/2007* Last Leak Repair Made: *6/28/2007*

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 Nonexcavated Leaks: *78.9* gpm

Total Water Losses: *282.4* gpm

	Excavated Leak Repair Costs	Nonexcavated 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*

LEAKAGE MANAGEMENT PROGRAM COST-EFFECTIVENESS (continued)

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-yr leak survey interval = 547 days

Note: the cost-effectiveness for the 3-yr 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 2-4)

(Vwr) = *282.4* gpm × *1440* min/d × *547* d × $*190*/mil gal × 1 mil gal/1,000,000 = $*42,264*

Step 2. Assemble Leak Survey Program Costs: from page 151, Section E. $*36,272*

Step 3. Divide Vwr (from step 1) by the total costs (calculated in step 2).

$$\text{Benefit/Cost Ratio (B:C)} = \frac{\text{value of water recovered}}{\text{total cost of leak detection survey}} = \frac{\$42{,}264}{\$36{,}272} = \underline{1.16}$$

For planning continuing leak detection efforts, calculate average survey costs per mile

Step 4. Determine average survey costs per mile of main surveyed for 3-yr cycle (C/mi).

$$\text{C/mi} = \frac{\text{3-yr leak survey cost}}{\text{total number of miles surveyed}} = \frac{\$36{,}272 + \$21{,}272 + \$21{,}272}{256 \text{ mi}} = \$\underline{308/mi}$$

At $308/mi the projected results are somewhat more expensive than the assumed value of $250/mi (see page 119). Still, the program has a strong payback of $36,272/$42,264 = 0.86 yr 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 (204 mil gal/yr) and potentially recoverable leakage (402 mil gal/yr) occurs in the Valley District. One half of (204 + 402) = 303 mil gal/yr. Again assume ½ of this volume, or 151.50 mil gal/yr, is recovered.

Average leak duration: because the background leakage reduction occurs all year, the average background leak duration is 365 days.

Vbr = *151.50* mil gal × $*190*/mil gal = $*28,785*

Step 2. Assemble Pressure Management Program Costs: from Figure 5-9, Section III: $*26,705*

Step 3. Divide Vbr (from step 1) by the total costs (calculated in step 2).

$$\text{Benefit/Cost Ratio (B:C)} = \frac{\text{value of water recovered}}{\text{total cost of leak detection survey}} = \frac{\$28{,}785}{\$26{,}705} = \underline{1.08}$$

Step 4. Determine payback period for pressure control equipment $= \frac{\$26{,}705}{\$28{,}785} = \underline{0.93}$

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.

pages 167–168. This manual provides information that assesses the effectiveness of the leakage management strategy. Blank forms are provided in Appendix A.

Information in addition to that shown 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.

Leak data can be collected in the field using either paper or electronic format. In either case, it is highly desirable to insert the leak repair data into a database. This allows for subsequent analysis of the types of pipe that fail, the possible cause, and their location. Location data is extremely useful in making future decisions about pipe renewal priorities.

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.

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 districts (often in conjunction with DMAs)
- 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.

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, or the point that suffers the greatest head loss. In striving to attain at least this minimum level of service to the most sensitive location (critical point), the vast majority of the water

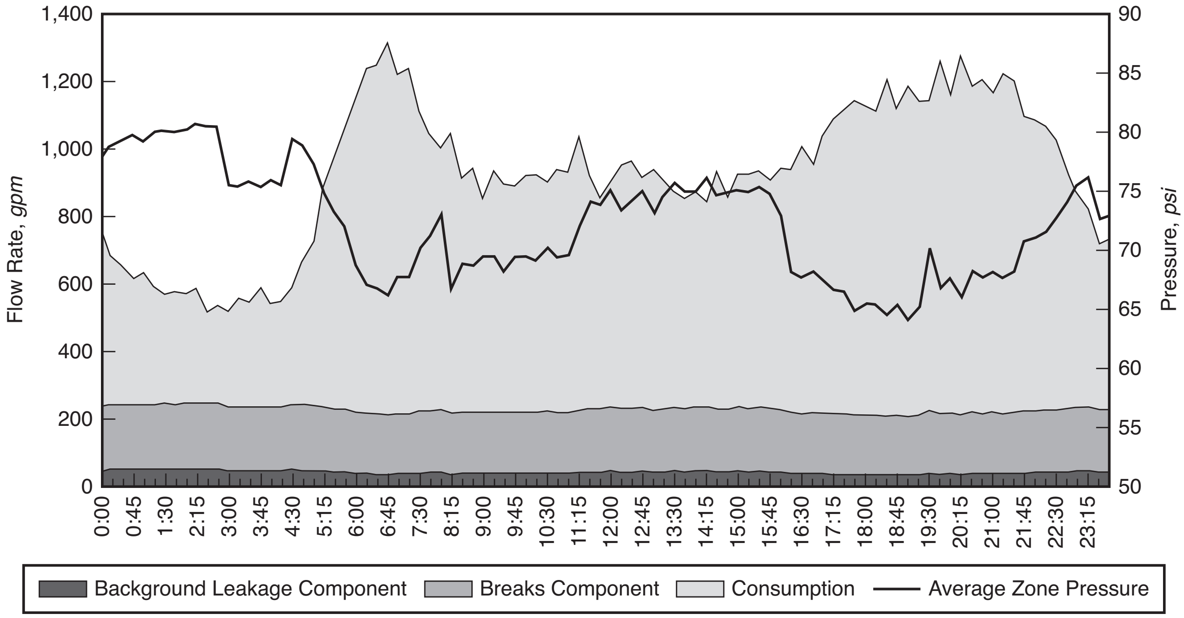


Figure 5-8 Pressure and flow variations in a DMA without specific pressure management controls[13]

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 levels 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, etc. This adds to the effect of excessive pressure across a wide portion of the distribution system.

As shown in Figure 5-8, many water distribution systems experience 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 night 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 pressure levels 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 this design methodology, some water distribution systems may experience excessive pressure during off-season periods—pressure which can 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 systems 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 great additional step for many of these utilities as they already employ basic controls. However, many of the same utilities likely do not have a full understanding of the dramatic leakage control potential that exists for them in employing optimized pressure management.

The benefits of optimized pressure management. The two primary objectives of pressure management for leakage control and infrastructure sustainability are

1. To reduce the frequency of new leaks and breaks occurring within a water distribution system; and

2. To reduce the flow rates of those leaks and breaks and background leakage that cannot be avoided.

Pressure management and infrastructure replacement/rehabilitation are the only real loss control methods that reduce background leakage losses. 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.

Proactive pressure management cannot be applied effectively in all water distribution systems. It cannot be employed where pressure levels are at or near the low service level requirements of the water utility. It may not provide cost-effective improvements where background leakage is low. However, pressure levels should always be assessed in the development of a leakage 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. 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 analyses of *before* and *after* break frequencies in individual systems in which pressure management has been implemented. Members of the International Water Association Water Loss Task Force Pressure Management Team have published case studies where pressure management has produced immediate, significant, and sustained reductions in new break frequencies[14].

One of the most important factors to be investigated is the relationship between pressure and water main break and service connection piping leak frequency. 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 breaks. 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, using very precise data-logging instruments. In developing the leakage management strategy, consideration should be given to launching an evaluation of the 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 factors, rather than any single influence. Figure 5-9 shows, conceptually,

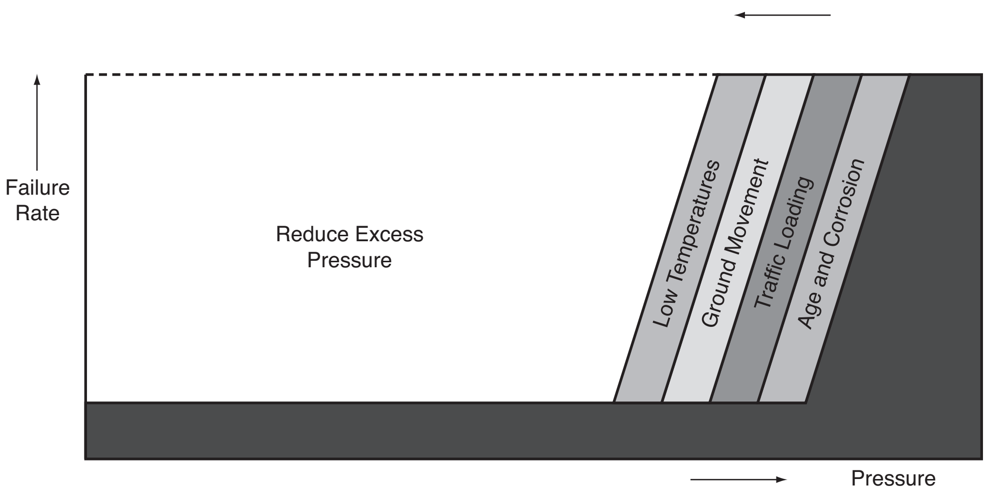


Figure 5-9 Reducing surges and excess pressure prevents the operating pressure range from reaching the point where the failure rate increases rapidly[15]

the relationship between water pressure, main break frequency, and other contributory factors.

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 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 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 as 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 longer service life, with fewer failures, before outright renewal is required.

Influence of pressure on leakage rates and certain consumption components. The section Water Pressure and Leakage in Chapter 4 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 average zone pressure 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 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). The FAVAD concept can be used to predict the effect of pressure management (at different times of day) on different elements of consumption. The higher the N3 value, the greater the potential for impacting some elements of consumption via proactive pressure management.

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 zone or DMA employing pressure management. 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, as 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, etc. 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 cost–benefit analysis*—an initial estimated cost–benefit 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 cost–benefit analysis can be conducted once field data is available. A potential loss in revenue should only be included in the calculation if water conservation is not considered or undertaken.

- *Flow and pressure measurements in the field*—If the desk top 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, the seasonal variations in water demand in the zone or DMA should be captured. Pressure should be recorded at the supply point to the potential district, at the average zone point (AZP), and the point of lowest pressure, the critical point (CP). These measurements provide the data needed to perform the detailed cost–benefit 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.

- *Identify control methods and devices (PRVs, and such)*—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 zone or DMA 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 DMA boundary at an opposite side of the DMA. The second PRV can be configured as a "sleeper" 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 cost–benefit 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 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 valuated 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. 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 different approaches exist to incorporate optimized pressure management into water distribution operations.

- *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 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 5-10 shows the pressure

Figure 5-10 Pressure zones and DMA in the Philadelphia Water Department water service area (Courtesy of Philadelphia Water Department)

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 humanmade 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 5-11, 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 great 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 represent 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. At times of minimal

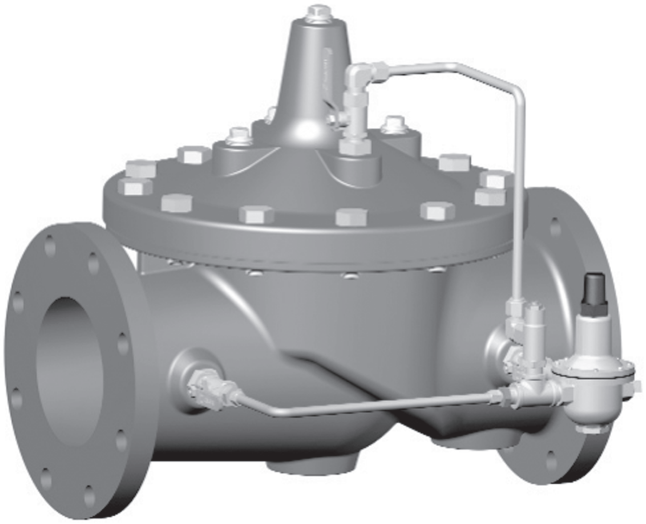


Figure 5-11 Pressure control devices, such as PRVs, provide consistent outlet pressures (Courtesy of Cla-Val Company)

water demand, when a distribution system needs the least pressure, the pressure will be higher, and 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. 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 overpressurized at off-peak times as can be seen in Figure 5-12.

- *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. 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 as 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 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 a zone or DMA. 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,

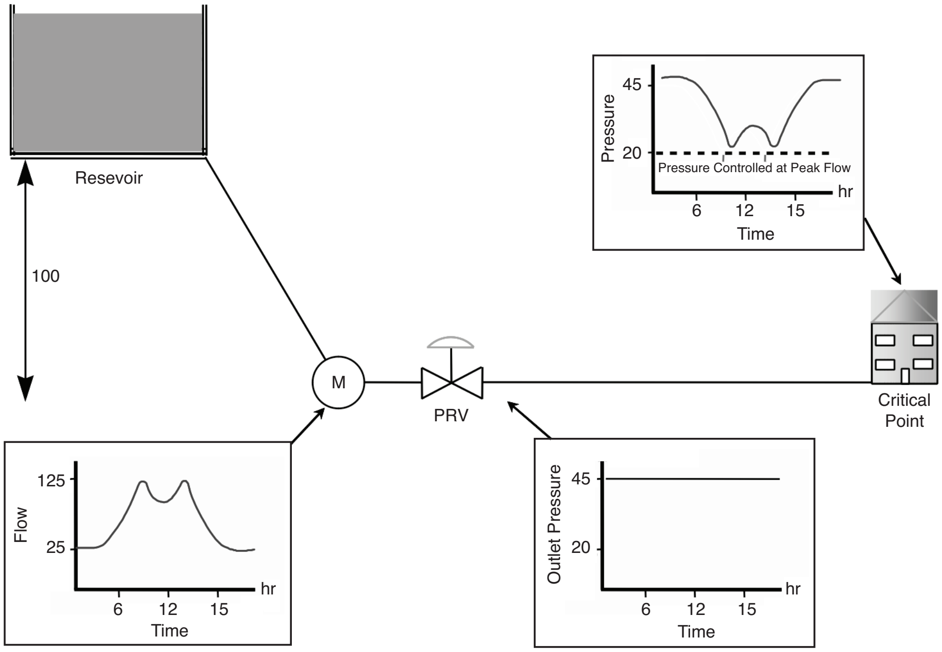


Figure 5-12 Fixed outlet control mode[16]

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 5-13.

- *Remote node control.* This is affected by controlling the outlet pressure of the valve in conjunction with the pressure at a remote location or *node* in the area. The critical point 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 critical point 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 critical point 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 5-14.

Component analysis 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 critical points—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.

Installation of pressure management systems. Pressure-reducing valves have been used for many years to control the hydraulic condition of water systems. With great advances in control technology, PRVs have also become a very efficient means of reducing real losses in water distribution systems. As control options become

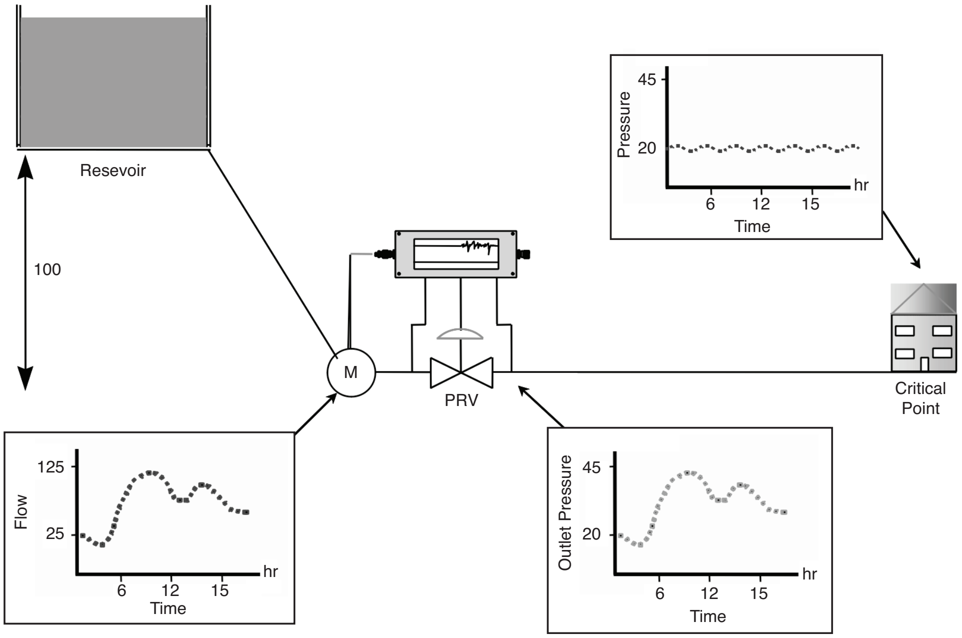


Figure 5-13 Flow-based dynamic modulation mode via a PRV combats high head loss in the distribution system and ensures a smooth pressure profile at the weaker points in the system[16]

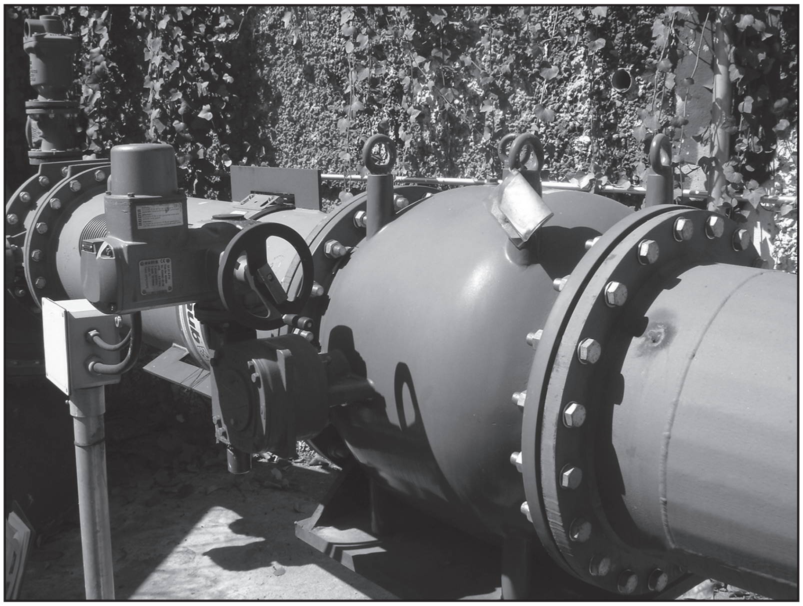


Figure 5-14 Large nonhydraulic valve for remote node-based pressure modulation

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 zone or DMA 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 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

- 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 Figure 5-4 and 5.15 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)
- 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 levels

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 evolving 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 5-15). 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 pressure managed areas, within a DMA configuration or otherwise, is a new concept to most North American water utilities. While the impacts of excessive pressure levels 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."

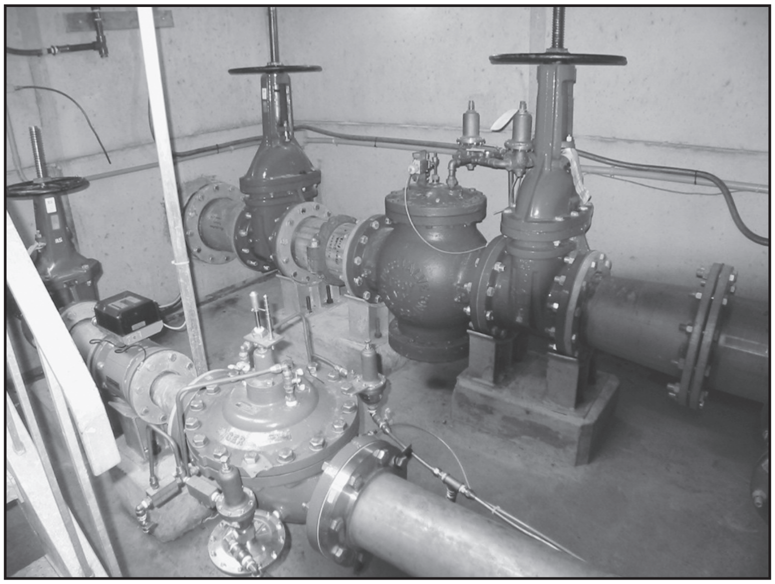


Figure 5-15 Typical pressure management and DMA supply installation (Courtesy of the Halifax Regional Water Commission, Halifax, Nova Scotia, Canada)

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 (138 kPa)," 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.[17]

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 level 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. Some common questions raised by water utility managers when assessing pressure management are

- *Will adequate fire flow capability exist in the pressure managed area?* Providing adequate water to fight fires is of utmost importance. 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 DMA or pressure managed area 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 DMA 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 DMA 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 DMA needing an emergency flow. Fire fighters typically draw pressures down to 20 psi, but 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 in a distant from the primary supply PRV, if head loss is considerable or demands vary widely across the DMA.

From a design perspective, if adequate fire flow capability existed in the water distribution grid prior to the installation of a pressure managed area, 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 pressure managed area. 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 DMA 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 occurs from uses that are volumetric; meaning 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 pressure levels 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 levels 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 does 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 cost–benefit 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 the highest level 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 pressure managed 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 impacted 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, storage tank turnover, the use of flushing programs, and other conditions. A pressure managed area 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 dependant; 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 DMA setting.

  Each DMA 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 pressure managed area. 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 boundary, both inside and outside of the DMA. 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 pressure managed area.

Steps to take to minimize water quality problems might include configuring boundaries so as 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 as 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 section DMA Planning Considerations.

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 unknown 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. While 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 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 of 10–30 miles of pipeline in a single application, which is a typical size range for most DMAs. And 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 water utilities should undertake at least a preliminary evaluation of this potential.

Infrastructure Rehabilitation and Renewal

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

- *Concrete Pressure Pipe* (M9)
- *Steel Water Pipe—A Guide for Design and Installation* (M11)
- *PVC Pipe—Design and Installation* (M23)
- *External Corrosion: Introduction to Chemistry and Control* (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 new pipeline assets. While 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 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, it should be noted that, in many cases, larger annual volumes of real loss are often recovered via customer service connection piping replacement programs than outright main replacement. The component analysis 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.

CONTROLLING REAL LOSSES: A 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 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.

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Chapter 6

Planning and Sustaining the Water Loss Control Program

North American drinking water utilities should perform routine 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 amount of water lost and its economic impact on the utility's operations. Water utilities should employ proactive leakage management activities with appropriate combinations of leak survey, 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, and improve the financial bottom line of the water utility. With a commitment to improve and some reasonable planning, the water utility can quickly begin to improve its accountability practices and get a handle on its losses. This chapter discusses the planning considerations in establishing the water loss control program.

The important first step is for the utility to get started—typically by compiling the water audit. The top-down water audit is straightforward to conduct and gives insight to the areas most needing attention and initiatives offering a quick payback. The AWWA Water Loss Control Committee's Free Water Audit Software is an excellent tool to use for a first time water audit as it can very quickly give a water utility a preliminary sense of their accountability standing. Progressively more sophisticated activities should then be considered as losses are identified and initial success is achieved. All of these activities should be conducted in a manner that can be incorporated into the organizational culture and sustained over the long-term planning horizon of the water utility. The major planning considerations for the water loss control program are detailed as sections of this chapter.

IDENTIFYING THE DESIRED OUTCOMES AND BENEFITS OF THE WATER LOSS CONTROL PROGRAM

Consider how improving the utility's accountability, reducing leakage, and recovering additional revenue can improve the efficiency of the utility operations. Consider also the current or potential regulatory requirements, economic, environmental, or political considerations, as well as specific community needs. Desired benefits might include increased revenues, reduced production costs, restricting withdrawals from water resources, deferred capital expenditures for new water supply infrastructure, less infiltration into wastewater collection systems, avoiding the need to develop new water resources, reduced liability, or improved customer satisfaction by keeping water rates in check and suffering fewer disruptions in service. Benefits realized by external stakeholders can include environmental improvements to watersheds, enhanced economic development opportunities, less stress on street and utility infrastructure, equity and affordability of water rates, and minimized disruption of service. Elevating the value of water in the minds of water utility employees and the community at large is an important outcome that should be considered as a long-term objective for the program.

ESTABLISHING A CROSS-FUNCTIONAL WATER LOSS CONTROL TEAM

Perhaps more than any other aspect of drinking water supply operations, water accountability touches almost every facet of the water utility, including

- Water distribution system operations: production metering, pressure management, supervisory control and data acquisition (SCADA) systems—flow monitoring.
- Water distribution system maintenance: active leak-control activities, distribution system repair, and maintenance management information systems.
- Customer metering: meter sizing, installation, testing, repair, and replacement.
- Customer meter reading: automatic meter reading (AMR) systems provide outstanding capabilities to cost-effectively capture customer consumption data, while manual meter reading is still practiced by many 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 efficiency leads to less disruption to the integrity of the water distribution system conveying potable water.
- 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 with a joint mission to manage water resources efficiently.

- 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 the 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, and promoting economic development.
- External stakeholders: interaction with fire departments is necessary to confirm fire hydrant usage policy and 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: 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 consider forming a team of individuals that represent all or most of the listed functions. The existence 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. Forming a team of responsible individuals from 6–10 of these functional areas also provides an opportunity for groups to learn how other activities are handled 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.

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 often can identify a number of quick, easy refinements, typically in billing system procedure or documentation, that can inexpensively recoup revenue or create cost savings early in the program life. Designing such early funding recovery into the 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 assign them meeting time to compile a top-down water audit and explore potential savings. 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. When available, targeted funding can be employed effectively 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 exist in addition to this manual to provide training resources for operators embarking on a water loss control program.
- Equipment. 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 systems, enhanced billing software, and countless other innovations exist 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 geographic information systems (GIS), hydraulic models, asset management software, and computerized maintenance management systems that have become prevalent in the drinking water industry.

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 not usually specifically defined; instead they are embedded in general operations and maintenance costs. 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 impacting the utility and in the context of how the water loss control program meets the long-term goals of the water utility.

LAUNCHING THE WATER LOSS CONTROL PROGRAM

Table 6-1 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 calibrated, and any gross malfunction corrected, 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 6-1 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 6-1, once launched, a number of the activities of the water loss control program can be conducted concurrently. This allows multiple objectives

Table 6-1 Water loss control program planning matrix

Potential Activities of a Water Loss Control Program
(Not all activities are necessary for every water utility; system-specific needs should be considered.)

Water Auditing		Intervention Activities			
		Apparent Loss Control		Real Loss Control	
Time	Activity	Time	Activity	Time	Activity
S	Top-down water audit	S	Calibrate production flowmeters (*this a very important procedure!*)	S	Review maintenance records, summarize statistics on breaks and leaks.
M	Start bottom-up water audit; outline processes	S	Flowchart the customer billing process: compile general demographics of the customer/meter population.	S	Review policies for customer service connection piping ownership and maintenance, and opportunity to reduce customer service connection piping leakage durations.
Ongoing	Bottom-up water audit: detailed investigations of metering, meter reading, and billing operations. Bottom-up water audit: field measurements and minimum hour leakage analysis; component analysis of leakage.	S	Perform meter accuracy testing on a small sample of customer meters.*	S	Establish a pilot DMA; perform minimum hour leakage analysis.
		S	Audit billing records and visit premises of a small number of customer accounts to determine the potential for missed billings or unauthorized consumption.	S	Compile data on the variation of water pressure throughout the water distribution system.
		M	Investigate the potential costs and savings of instituting an AMR system to reduce missing or erroneous customer meter readings.*	S	Launch a pilot leak detection survey, perhaps via a consultant; consider use of leak noise monitors.
		M	Review/implement policies to thwart unauthorized consumption.	M	Create a leak detection squad, or hire a leak detection contractor, to regularly survey the distribution system for unreported leakage.
		M	Install, upgrade, or replace production flowmeters.	M	Install pressure management areas and/or deploy leak noise monitors.
		L	Install an AMR system and institute monthly billing based on meter readings.*	L	Implement a maintenance management information system.
		L	Install a new customer billing system.*	L	Create additional DMAs.
		L	Conduct wholesale customer meter replacement.*	L	Institute capital replacement program for water main infrastructure.

Timeframe: S – short-term; M – medium-term; L – long-term.
* 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 should be considered as a short- or medium-term initiative of high priority.

to be pursued. 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 this data also provides leakage quantities as the basis for the component analysis of the water audit. This is also true for apparent loss investigations into customer premises to detect instances of unauthorized consumption or metering problems. Once established, many of the activities should be maintained in an ongoing manner. Water auditing should be conducted on a routine basis, just as regular financial auditing is conducted.

Table 6-1 also lists approximate timeframes for the activities of the water loss control program. These are given as short-term (S), medium-term (M), and long-term (L). 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 systems, in 1–2 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 require long timelines 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.

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 2. It is important to also include verification of the production meters in this phase. Descriptions of bottom-up approaches and component analysis for apparent losses are given in Chapter 3. Bottom-up methods and component analysis for real losses are given in Chapter 5. While the water auditing process is not specifically a means to reduce losses, the process can create an important shift in the organization 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 mechanisms 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.

REPORTING THE SUCCESS OF THE WATER LOSS CONTROL PROGRAM

The eminent 19th century British physicist, Lord Kelvin, provided the following quote, which has as much relevance to the field of water loss control as to physics: “If you don’t measure it, you can’t manage it.”

A modern corollary of his statement might read “If we don’t properly define it, measure it, data-warehouse it, and report it, we can’t manage it.”

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 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.

Communicating With Drinking Water Industry Stakeholders

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 hygiene of the water loss control team. The team 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 is 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 the progress to control 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 can be identified, resulting in the need for new documentation and reports. An "owner" of important data should be designated who will be responsible for specifying the how, when, and who concerning the data to be collected.

Philadelphia's Water Accountability Committee created a high-level monthly report shortly after it launched its efforts as a team. As shown in Table 6-2, the report merely lists the system input and billed customer consumption, as well as the difference between these two quantities, or nonrevenue water. For reference, the number of active customer billed accounts is also listed. Because of meter reading lag time inherent in customer billed data, both parameters are reported on a rolling 12-month basis. Philadelphia's committee has been successful in promoting awareness of the importance of water loss control by updating and circulating this report on a monthly basis. This report has been used for over a decade, during which time the nonrevenue water has been reduced by one third. The report is carefully monitored by many employees. It keeps internal stakeholders in touch with the program progress on a frequent basis, while Philadelphia's Water Audit Report provides comprehensive detail on the program on an annual basis.

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 and identify proper 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 External 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 multi-media, 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.

Table 6-2 City of Philadelphia monthly water statistics report for June 2006

Date	Water Delivery (System Input), mgd	Billed Consumption, mgd		Nonrevenue Water, mgd	Number of Customer Billing Accounts	
		City	Exports		Large	Small*
8/04–7/05	260.7	156.9	18.8	85.0	13,355	458,339
9/04–8/05	261.3	159.4	19.1	82.9	13,332	458,251
10/04–9/05	261.5	160.5	18.8	82.2	13,312	458,144
11/04–10/05	261.4	159.9	18.8	82.7	13,292	458,056
12/04–11/05	260.9	159.4	18.9	82.6	13,274	457,966
1/05–12/05	260.3	159.4	19.1	81.8	13,253	457,906
2/05–1/06	258.8	160.6	19.4	78.8	13,237	457,922
3/05–2/06	256.9	159.6	19.3	78.0	13,217	457,949
4/05–3/06	255.6	158.5	19.3	77.8	13,194	457,956
5/05–4/06	254.8	158.0	19.4	77.4	13,176	457,946
6/05–5/06	254.5	157.7	19.5	77.3	13,156	457,972
7/05–6/06	253.8	157.8	19.7	76.3	13,137	458,043

* ⅝ in. and ¾ in.

In undertaking a water loss control program, the water utility should implement communications that will announce program success 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 kinder impact to 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, etc., by better long-term management of existing water resources and infrastructure
- Establishing a reputation of strong reliability from sustainability of water service during periods of drought
- Enhancing customer perceptions by conveying visible accountability and operational efficiency improvements
- 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, etc.

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) departments
- Environmental organizations
- Financial institutions
- Drinking water associations

Improved communication is also part of the drinking water regulatory structure in the United States. The institution 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 operator can build into the program the information or data that needs 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 a top-down water audit. The water audit worksheet in Chapter 2 can serve as a template for this, or the Water Loss Control Committee's Free Water Audit Software, described in Appendix C, can be utilized.

The top-down water audit process will likely identify several initial loss reduction priorities to the team 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.
- 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
- A long-term outlook
- The patience to avoid short-term "quick fixes" that do not provide lasting results
- The ability to implement comprehensive, integrated 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 team leaders and team members. Look for those people who have demonstrated skill and perseverance in their work history. Look for a team leader who will champion the cause and motivate team members and outside stakeholders during the times when progress appears slow.

Sustainability also hinges on the ability to implement long-term interventions to control losses. Water distribution system rehabilitation, AMR 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 team needs to show persistence over a long period of time to implement such improvements. Sustainability is a critical planning consideration because it protects both against relapse 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 7

Considerations for Small Systems

While numerous large water utilities serving populations in the millions provide water service to North America's metropolitan areas, the greatest number of water utilities are those classified as *small systems*, most of which serve only several hundred or several thousand customers in rural areas. In the United States, roughly 93 percent of the 59,000 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 50 million of the 250 million people (20 percent) that are supplied by community water systems[1]. 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 7-1.

Table 7-1 reflects certain notable differences in the characteristics of large and small water systems in the United States. Often small systems 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, distribution, as well as customer metering and billing. In implementing its water quality regulations, the United States Environmental Protection Agency (USEPA) employs a three-tiered approach; requiring the shortest implementation timeframes 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 1996 Amendments to the Safe Drinking Water Act 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 7-1 Characteristics of large and small water systems in the United States[1]

Typical Characteristics	Large Systems	Small Systems
Geography		
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 resevoir, river, or lake network	Most small systems rely on groudwater or a mix of surface water and groundwater from scattered small lakes, streams, and wells.
Proximity	Few large sources usually very proximate to 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 reserves to maintain reliability during short-term droughts.	Many groundwater supplies are shared with 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[1]	Many systems in urban and older suburban areas are aged and require significant upgrades.	Small systems reported to have more than three times the per household infrastructure needs than large systems (in terms of cost to customer).
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 under 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	10 violations per million customers for systems serving more than 10,000 people.	7,164 violations per million customers for systems serving less than 500 people.
Employee Compensation	Compensation and benefits are greater as system size increases.	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.

IMPLEMENTING WATER LOSS CONTROL PROGRAMS IN SMALL SYSTEMS

Often, small water systems may 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 Table 6.1, it may appear that most of these potential 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 their 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 their supplies, this is the recommended first step. By following the worksheet in Chapter 2 or utilizing the AWWA Water Loss Control Committee's free Water Audit Software (Appendix C), any water utility can conduct a basic audit on their water supply operations. By compiling a simple monthly report such as shown in Table 6.2 and compiling the water audit annually, any utility—large or small—can establish a routine, top-down auditing process with a very small investment. Using a water audit 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 as employees intrinsically sense a greater value for water once they realize it is being closely tracked.

Once a top-down water audit has been established, the water utility should progress to the use of bottom-up measurements and investigations to validate the water audit data and better confirm the source 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 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.

Such programs require the consultant to bear the initial risks in launching the program. This approach can be particularly attractive when losses are perceived to be great and recoveries can occur in a relatively brief period. 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. Typically, apparent loss recovery offers a good opportunity for an early payback because many problems offer a relatively expedient solution (such as minor programming or policy changes in customer billing operations) and a surge of additional billings. Performance-based contracts are often most effective in the early stages of a new water loss control program where short-term, low-cost interventions are available. Performance-based contracts can also be cost-effective for long-term interventions, but they may require more complex planning and contractual stipulations. As an example, large-scale capital improvements such as replacement of customer meter populations require considerable funding and contracting, and performance-based contracts may be too complex to use for such initiatives. Still, performance-based contracting may be attractive for water utilities who know that they have significant, feasibly recoverable losses and who desire outside expertise and staffing to launch the program successfully with minimal upfront costs.

Addressing Apparent Losses

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. The following list states several considerations for apparent loss control that are practical for small systems to implement:

- Calibrate production flowmeters from primary water sources at wells, lakes, 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 calibration services are available from a number of providers at reasonable cost.
- Train customer meter readers to detect unauthorized consumption from tampered meters or illegal connections, as well as detect meter malfunctions identified via suspicious data.
- Establish, communicate, and enforce a clear policy for the use of fire hydrants.
- Test the accuracy of meters on several of the largest customer consumers. Often in small systems, a small number of very large customer 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.
- Consider establishing remote meter reading with fixed network or data-logging capability for several of the largest water consumers. 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. Data-logging can reveal customer consumption patterns at short intervals (every hour, 15 minutes, or shorter) that can help utility operations to meet changing water demands. Data-logging and communication systems are now available at very reasonable cost to allow single large customers to be closely monitored. The water utility might even consider entering an agreement to sell this detailed data to the customer on a monthly basis. The data can assist the customer in managing their water demand and creating efficiencies, and can result in additional revenue to the water utility to recoup the cost of the data-logging equipment.
- 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 some customers show long periods of zero consumption? Unless these customer accounts are vacant properties, these readings could reflect tampering with metering or meter reading equipment. 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. Remember the billing system tracks consumption that generates revenue, so a solid understanding of the workings of the billing system is essential to ensure an optimum revenue flow.

Many other approaches to apparent loss control, as described in Chapter 3, 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 often exert a larger proportional impact on small systems than large systems. A crack in a 6-in.-diameter cast-iron pipe leaking at 65 gpm may result in reduced pressures or other service impacts in a very small system where the main is a primary supply feed to an area. 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 well-reinforced grid of distribution mains. Real loss control is just as important in small systems as it is for medium and large sized systems. Often, it is more difficult for small systems to provide ongoing staff resources to active leakage control as many large systems do. While 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 include

- 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 so as to function as an individual district metered area (DMA). 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 any 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 any pressure management objectives that exist for 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 Table 2.6) can be accounted for when quantifying supply flows to the DMA.
- The limited length of small water distribution systems means leak surveys can be conducted faster 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 traffic and noise congestion common in cities. The relative costs of conducting leak survey work in small systems are often less than large systems.

While these leakage management advantages exist for some small systems, many of these systems are challenged to launch the steps needed to implement ongoing active leakage control in their systems. The following list states several considerations for real loss control that are practical for small systems to implement:

- 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.
- Train customer meter readers to identify and report evidence of unreported leakage (leakage sounds, wet spots, damp cellars, etc.) on customer service connection piping or water mains.
- Identify areas of high water pressure that are common in regions of hilly or mountainous terrain. Do opportunities exist to reduce operating pressures?
- Be mindful of the possibility of hidden leaks that may exist on water mains that cross under streams, rivers, railroad lines, or other major utilities. These

are areas where leaking water can escape without notice. Test shutdowns or upstream and downstream pressure measurements may aid in detecting the possibility of leaks at such locations.

- Consider performance-based consulting contracts for leakage reduction. Similar to the water auditing discussion previously in this chapter, performance-based contracting places the initial burden of startup costs on the consultant. Payments are based on the value of the recovered leakage. Again, it is important that the water utility and consultant carefully negotiate the language of the performance-based contract so that the means to define, measure, and value recoveries are clear and explicit to both parties.

Many of the approaches to real loss control, as described in Chapter 5, are viable methods for water utilities of all sizes. Recovering leakage losses and sustaining a low loss system may result in continued economic development in communities that have limited water resources and may avoid the need to develop costly additional 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 Amendments to the Safe Drinking Water Act, and, while stemming from the need to assist small systems in meeting water quality regulations, the program promotes overall capacity development for efficient system operations. In the United States, a number of programs exist to offer small systems technical and infrastructure funding, as well as guidance, training, and assistance[2].Some of the larger programs are offered by the USEPA, United States Department of Agriculture (through the Rural Utilities Service), and United States 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.

Technical guidance and promotion of best practices for small systems is also available from the Small Systems Network of AWWA. The Small Systems Division of AWWA operates this program that provides a wealth of information and assistance to small water utilities on the tools available to them. The National Rural Water Association (www.nrwa.org) also provides a broad array of services to small systems throughout the United States and Puerto Rico. State associations provide training and a variety of assistance services, including the well-known circuit riders, who travel to many locations to offer guidance to rural water utilities.

Tailored programs for specific water auditing and loss control programs are being developed by some of the previously mentioned organizations. Such programs are likely to grow in scope and extent as the value of water resources continues to gain greater recognition. As these programs emerge, small systems can expect to have a wider range of technical and financial assistance to help them establish sound accountability in their operations.

ACCOUNTABILITY IN SMALL SYSTEMS

A good loss control program is 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 often is 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 Water Loss Control Committee's Free Water Audit Software (see Appendix C) was specifically designed to be straightforward and user friendly, 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 our valuable water resources. Various mechanisms exist to assist small systems with funding, training, or expertise from government-sponsored programs. Included in Appendix D are four case study accounts of successful water loss control programs in North American water utilities. One of systems is a small water system. These accounts should give good 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

1. USEPA. 1999. National Characteristics of Drinking Water Systems Serving Populations Under 10,000. EPA 816-R-99-010. Boston, Mass.: The Cadmus Group, Inc.
2. USEPA. 2002. Sources of Technical and Financial Assistance for Small Drinking Water Systems. Washington D.C.: United States Environmental Protection Agency. www.epa.gov/ogwdw/smallsys/pdfs/tfa_sdws.pdf

Appendix A

Blank Forms

This appendix includes blank forms for use in a water audit and leakage management program. Forms include

- Water Audit Worksheet: Top-down Approach
- Water Balance
- Revenue Protection Plan to Control Apparent Losses
- Leakage Management Plan to Control Real Losses
- Leak Detection Survey Daily Log
- Leak Repair Report
- Leakage Management Program Cost-effectiveness Summary

Instructions for completing the water audit worksheet and water balance are given in Chapter 2. Instructions for completing the revenue protection plan are given in Chapter 3. Instructions for completing all other forms are discussed in Chapter 5.

WATER AUDIT WORKSHEET: TOP-DOWN APPROACH

IWA/AWWA WATER AUDIT FOR THE PERIOD		TO	
UTILITY NAME & ADDRESS		POPULATION SERVED	
COMPILED BY		DATE COMPILED	
DATA TO BE ENTERED SHOWN IN WHITE, CALCULATED VALUES SHOWN IN DARK GRAY, SUGGESTED DEFAULT VALUES IN MEDIUM GRAY			

DISTRIBUTION SYSTEM DESCRIPTION INFORMATION

SYSTEM CONFIGURATION TYPE (underline your selection)	Raw Water Transmission	Bulk Treated Transmission	Retail Treated Distribution	Pressure Zone or DMA (specify name)

INFRASTRUCTURE DATA		FINANCIAL DATA	
	Miles of Transmission & Distribution Mains, Lm		Total costs to operate the water supply system
	Number of service connections, residential accounts, Nr		*Customer retail unit rate—residential accounts—applied to Apparent Losses (cost/unit volume)
	Number of service connections, commercial & industrial accounts, Ni		*Customer retail unit rate—industrial, commercial & agricultural accounts—applied to Apparent Losses (cost/unit volume)
	Total number of service connections, Nc = Nr + Ni		*Customer retail unit rate—composite unit rate—applied to Apparent Losses (cost/unit volume)
	Average length of customer service connection from curb stop to customer meter, Lp, ft		Short-term variable cost to produce the next unit of water—applied to Real Losses (cost/unit volume)
	Number of fire hydrants, Nf	OPERATIONAL DATA	
	Average length of fire hydrant leads, Lh, ft	365	Days in water audit period, D
	Average operating pressure, P, psi	100%	Percent of time that system is pressurized

*Calculate the retail customer rates in the volumes units used in the water audit (Ex: dollars/million gallons). This usually requires conversion from hundred cubic feet or thousand gallons to the desired unit (Ex: mil gal).

	WATER BALANCE CALCULATIONS		Water Volume		Costs Rate Applied & Total	
			Unit		Currency	
1.	Volume from Own Sources (raw data)					
1A.	Adjustment: Sources meter error					
1B.	Adjustment: Changes in reservoir and tank storages (+/–)					
1C.	Other Adjustments (specify)					
1D.	Total Adjustments = Lines 1A +1B + 1C					
2.	VOS: Volume from Own Sources (adjusted) = Lines 1 +/– 1D					
3.	VI: Volume of Water Imported (adjusted)					
4.	SIV: System Input Volume = VOS + 1					
5.	BACE: Volume of Water Exported (adjusted)					
6.	WS: Water Supplied = SIV – BACE					
7.	BACM1: Billed Authorized Consumption: Metered (uncorrected) Type 1 (specify)	Residential Accounts				
8.	BACM2: Billed Authorized Consumption: Metered (uncorrected) Type 2 (specify)	Industrial Accounts				
9.	BACM3: Billed Authorized Consumption: Metered (uncorrected) Type 3 (specify)	Commercial Accounts				
10.	BACM4: Billed Authorized Consumption: Metered (uncorrected) Type 4 (specify)	Agricultural Accounts				

WATER BALANCE CALCULATIONS					Water Volume		Costs Rate Applied & Total	
					Unit		Currency	
11.	BACT = (BACM1 + BACM2 + BACM3 + BACM4) (uncorrected)							
11A.	Adjustment due to customer meter reading lag time (+/–)							
12.	BACTAD = BACT +/– Line 11A							
13.	BACU: Billed Authorized Consumption: Unmetered							
14.	NRW: NONREVENUE WATER = WS – (BACTAD + BACU)							
15.	UACM: Unbilled Authorized Consumption: Metered							
16.	UACU: Unbilled Authorized Consumption: Unmetered	Estimated as	1.250%	of WS				
16A.	UACU: Unbilled Authorized Consumption: Unmetered	Use instead of Line 16 if greater than Line 16						
17.	WL: WATER LOSSES = NRW – (UACM + UACU)							
18.	ALMUR1: Apparent Loss – residential meter under-registration:							
19.	ALMUR2: Apparent Loss – industrial/commercial/agricultural meter under-registration:							
20.	ALDHE1: Apparent Loss – systematic data transfer error (specifiy)							
21.	ALDHE2: Apparent Loss – systematic data analysis error (specifiy)							
22.	ALDHE3: Apparent Loss – data policy/procedure impacts							
23.	UC: Unauthorized Consumption	Estimated as	0.250%	of WS				
23A.	UC: Unauthorized Consumption	Use instead of Line 23 if greater than Line 23						
24.	AL: Sum of Apparent Losses = ALMUR1 + ALMUR2 + ALDHE1 + ALDHE2 + ALDHE3 + UC							
25.	CARL: Current Annual Real Losses = WL – AL (In the top-down water audit approach, Real Losses are taken as the losses remaining after Apparent Losses are subtracted from the Total losses)							
26.	Normalized CARL per day							

WATER AUDIT—PERFORMANCE INDICATORS

Category	Description	*IWA Code	Expressed as:	Calculation	Indicator
Financial	Financial: Non-revenue water by volume	Fi36	Volume of Nonrevenue Water as % of System Input Volume		
	Financial: Non-revenue water by cost	Fi37	Value of Nonrevenue Water as % of annual cost to operate the water supply system		
Operational	Water Losses				
	Apparent Losses				
	Current Annual Real Losses				
	Apparent Losses Normalized	Op23	[volume/service connection/d]		
	Real Losses Normalized (1)	Op24	[volume/service connection/d] or [volume/length of mains/d] (only if service connection density is less than 32/mi)		

WATER AUDIT—PERFORMANCE INDICATORS

Category	Description	*IWA Code	Expressed as:	Calculation	Indicator
Operational	Real Losses Normalized (2)		[volume/service connecion/d/unit of pressure] or [volume/length of mains/d/unit of pressure] (only if service connection density is less than 32/mi)		
	Unavoidable Annual Real Losses	UARL	UARL† (gal/d) = (5.41Lm + 0.15Nc + 7.5Lc) × P, Where: Lm = length of water mains, mi (including hydrant lead length) Nc = number of service connections Lc = Nc × Lp, mi Lp = average service connection piping length, ft P = average pressure in the system, psi	Multiply the calculated UARL by 365 to obtain the UARL in volume per year	
	Infrastructure Leakage Index (ILI)	Op25	CARL/UARL (dimensionless)		

* Descriptors assigned to the performance indicators are from the IWA publication *Performance Indicators for Water Supply Services*, 2000.

† This version of the UARL equation exists in the form for units recognized throughout much of the United States:
Volume, gal Length, mi Lp distance, ft Pressure, psi

The metric version of the UARL equation is given below:

UARL Equation in Metric Units

UARL (L/d) = (18Lm + 0.8Nc +25Lc) × P

Where:
Lm = length of water mains, km (including hydrant lead length)
Nc = number of service connections
Lc = Nc × Lp, km
Lp = average service connection length, meters
P = average pressure in the system, meters of water

Multiply the UARL calculated by the above equation by 365 to obtain the UARL in volume per year.

<table>
<tr><th colspan="7">WATER BALANCE FOR (UTILITY NAME): ____________________ YEAR: __________</th></tr>
<tr><td rowspan="11">Water From Own Sources (corrected for known errors)
________</td><td rowspan="12">System Input Volume
________</td><td>Water Exported
________</td><td rowspan="5">Authorized Consumption
________</td><td rowspan="3">Billed Authorized Consumption
________</td><td>Billed Water Exported
________</td><td rowspan="3">Revenue Water
________</td></tr>
<tr><td rowspan="11">Water Supplied
________</td><td>Billed Metered Consumption
________</td></tr>
<tr><td>Billed Unmetered Consumption
________</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption
________</td><td>Unbilled Metered Consumption
________</td><td rowspan="9">Non-revenue Water
________</td></tr>
<tr><td>Unbilled Unmetered Consumption
________</td></tr>
<tr><td rowspan="7">Water Losses
________</td><td rowspan="3">Apparent Losses
________</td><td>Unauthorized Consumption
________</td></tr>
<tr><td>Customer Metering Inaccuracies
________</td></tr>
<tr><td>Systematic Data Handling Errors
________</td></tr>
<tr><td rowspan="4">Real Losses
________</td><td>Leakage on Transmission and Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td rowspan="2">Leakage on Service Connections Up to Point of Customer Metering
(Individual Leakage Components Not Quantified)</td></tr>
<tr><td>Water Imported
________</td></tr>
</table>

List the volume units for the period of reference: ____________________ Total volumes should be the same in all columns.

REVENUE PROTECTION PLAN TO CONTROL APPARENT LOSSES

Name of Water Utility: ______________________ Date: __________

I. Revenue Protection Plan Approach

I-a: List below the apparent loss component volumes and costs from the water audit worksheet

	Volume, units	Costs
Residential meter under-registration		
Industrial/commercial/agricultural meter under-registration		
Systematic data transfer error		
Systematic data analysis error		
Data policy/procedure impacts		
Unauthorized Consumption (note 0.25% default value if used)		
TOTAL		

I-b. From the water audit worksheet, list the retail unit rates charged to customers

	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 water utilities should take in the revenue protection program is an analysis of the customer billing system in order to understand its workings and reveal the extent of systematic data handling error that exists 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 be based solely on the cost impact of the loss component. It might instead be based on scheduling logistics (e.g., meter changeout 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)	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 customer billing systems and systematic data handling error occurring in these systems can corrupt data generated by accurate metering and meter reading systems. The water utility should use a 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, any 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, $/hr ______ $/day ______

Number of consultant staff ______ Cost, $/hr ______ $/day ______

Total Cost, $/hr ______ $/day ______

II-b. Duration

Days, per Project Task	Flowcharting/ Analysis	Corrections	Total Days	Total Project Costs, $
Utility	______	______	______	______
Consultant	______	______	______	______
Total	______	______	______	______

II-c. Payback

List water and revenue recoveries gained from corrections conducted as part of the customer billing system analysis.

Recovery Description	Water Volume Recovered, units	Revenue Recovered, $
______	______	______
______	______	______
______	______	______
______	______	______

III. Customer Meter Accuracy Evaluation

III-a. Customer water meters must be appropriately sized and maintained 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 meter inaccuracy is a significant source of apparent loss. Meter inaccuracy can occur from meter wear from high cumulative consumption, inappropriate sizing, 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.

REVENUE PROTECTION PLAN TO CONTROL APPARENT LOSSES (continued)

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

III-c. List utility staffing costs for meter accuracy testing, including wages and benefits

Number of utility staff ___________

Supervisor Cost, $/hr _______ $/day _______ # of days _______ Cost, $_______

Service Worker Cost, $/hr _______ $/day _______ # 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 Error 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 error) 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 because of 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 because of 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.

REVENUE PROTECTION PLAN TO CONTROL APPARENT LOSSES (continued)

List Suspect Apparent Loss Trend (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, $/hr ________ $/day ________ # of days ________ Cost, $________

Service Worker Cost, $/hr ________ $/day ________ # 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, $

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			
Systematic data transfer error			
Systematic data analysis error			
Data policy/procedure impacts			
Unauthorized consumption			
TOTAL			

REVENUE PROTECTION PLAN TO CONTROL APPARENT LOSSES (continued)

The findings of the activities in Sections I through IV will reveal sources of apparent loss. Corrections to accounts that are incurring loss include meter replacement of inaccurate meters, procedural, programming, or billing process corrections for data handling error 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: ______________________________ Date: ______________

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 percent 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 two miles of main per day. Factors include distances between services, traffic and safety conditions, and number of listening contact points. Explain if more than three miles per day are surveyed: ____

A-4. Number of working days needed to complete survey (divide line 2 by line 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 the plan for detecting leaks.

____

B-4. Describe the procedures and equipment you will use to pinpoint the exact location of detected leaks.

____

____

B-5. Describe how the leak detection team and the repair crew will work together. How will they resolve the problem of dry holes?

____

____

LEAKAGE MANAGEMENT PLAN TO CONTROL REAL LOSSES
(continued)

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 utility staff will be used? __________

Staffing costs including wages and benefits:

Person 1 $/hr __________ $/day __________

Person 2 $/hr __________ $/day __________

TOTAL $/hr __________ $/day __________

C-2. How many consultant staff will be used? __________

Cost of consultant staff:

Person 1 $/hr __________ $/day __________

Person 2 $/hr __________ $/day __________

TOTAL $/hr __________ $/day __________

D. Leak Detection Survey Costs

Leak detection surveys	$/day	# 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 leak repairs begin? __________________

F-4. When will 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.

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 75 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, etc.). 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, etc.).

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:	______________	______________	______________	______________
Misc. Piping & Hardware: List	____			______________
Construction: Labor – ____ workers, ____ days ____ × ____ workers × ____ hr/d × ____ days				______________
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 and 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

____

____

____

LEAK REPAIR REPORT

Name of Water Utility: ______________________________ Date: __________

Work Order Number: __________ Repair Crew Supervisor: ____________________

LEAK IDENTIFICATION

Refer to Leak Discovery Report

Discovery Date: __________

Location (include street name and number): ______________________________

Map Reference: ____________________

Page and Coordinates: ____________________

Leak No.: ______

For Main and Service Connection Piping Leaks Only

Sketch a map of the site including:

1. Street name.
2. Meter number if applicable.
3. Mains and hydrants in shutdown area.
4. All valves (give valve numbers and show which were closed during repair).
5. Locate leak to nearest intersection or house with address. Show distances to property lines or street centerlines.

Leak Found? _____ (Yes/No)

If Main or Service Leak, Attach Three Photos:

1. Straight down over leak or damage.
2. Close-up of leak and damage.
3. Any other photo which you feel will help.

Type of Leak

Meter Leak ______

Meter Spud Leak ______

Meter Yoke Leak ______

Curb Stop Leak ______

Main Line Leak ______

Service Connection Piping Leak
—Utility Responsibility _____
—Customer Responsibility _____

Joint Leak ______

Other Leak ______

Describe ______________
____
____

Description of Repair

Damaged part was:

_____ Repaired _____ Replaced

If repaired, what repairs were made?

_____ Leak Clamp _____ Repacked Valve

_____ Welded _____ Repacked Joint

_____ Other (describe)

____

If replaced, what material was used?

____

Repair Time ______ (from/to)

Crew Size _____ (persons)

Equipment Used for Repair

_____ Backhoe

_____ Dump truck

Repair Costs:

Materials $________ Other $________

Labor $________ Total $________

Equipment $________

Size of Leak:

Measured ______ gpm

Estimated ______ gpm

Method used ____________________
____

LEAK REPAIR REPORT (continued)

Description of Damage for Mains and Services

What part was damaged:

______ Pipe Barrel ______ Flange nuts, bolts, tie rods

______ Joint ______ Other (describe)

______ Valve ____________________

In your opinion, what caused the damage?

____

Estimated Age of Leak, in months ______

How Determined? ____________________

Estimated Annual Volume _________ mil gal

Estimated Annual Cost Impact $___________

Diameter of Main or Lateral, in in. ______

Depth to Top of Pipe, in in. ______

Type of Break:

______ Split

______ Hole

______ Circumferential Split

______ Broken Coupling

______ Service Pulled

______ Cracked at Corporation Stop

______ Gasket Blown

______ Crushed Pipe

______ Cracked Bell

______ Other (describe) ________________

____

Pipe Material:

______ Galv. Iron	______ Ductile Iron	______ A.C.P.	System Pressure, psi ______
______ Black Iron	______ Steel	______ P.V.C.	How Determined? ________
______ Cast Iron	______ Copper	______ Polybutylene	______________________

Examine broken edge of cast- or ductile-iron pipe:

Original Thickness:	Min. Thickness of Good Gray Metal Remaining:	Deterioration is on:
________________ inches	________________ inches	______ Outside ______ Inside

Is there evidence of previous leak or repairs in same general area? ______ Yes ______ No

Number of previous leak repair clamps present: ___________

Last Repair Date (if known) _________ Cause of Leak ______________________________________

In your opinion, should pipe be replaced? ______ Yes ______ No ______ Do not know

If yes, explain extent: ____

For Excavations, Indicate Ground Conditions

Type of Soil:		Existing Bedding:	Type of Cover:
______ Rocky	______ Sandy	______ Gravel/Sand	______ Concret
______ Clay	______ Hard Pan	______ Native Soil	______ Asphalt
______ Adobe	______ Loam	______ Pea Gravel	______ Soil
______ Other _______________		______ Other ______	______ Other ______

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: _____

Number of Listening Points:	Meters	Hydrants	Valves	Test Rods	Other
	_______	_______	_______	_______	_______

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 Survey

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 Nonexcavated Leaks: _______ gpm

Total Water Losses: _______ gpm

	Excavated Leak Repair Costs	Nonexcavated Leak Repair Costs	Total Repair Costs
Materials	$ _______________	$ ____________	$ _________________
Labor	$ _______________	$ ____________	$ _________________
Equipment	$ _______________	$ ____________	$ _________________
Other	$ _______________	$ ____________	$ _________________
Subtotal	$ _______________	$ ____________	$ _________________

LEAKAGE MANAGEMENT PROGRAM COST-EFFECTIVENESS SUMMARY (continued)

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)

Leak duration = ½ of leak survey interval, days

(Wc) = Short-term variable cost of water

(Vwr) = ____ gpm × 1440 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 cossts 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 in 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 × 1440 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).

$$\text{Benefit/Cost Ratio (B:C)} = \frac{\text{value of water recovered}}{\text{total cost of pressure management}} = \_\_\_\_\_\_\_\_$$

Step 4. Payback period for pressure contol equipment = $\frac{\text{Program Costs}}{\text{Vbr}}$ = ________, yr

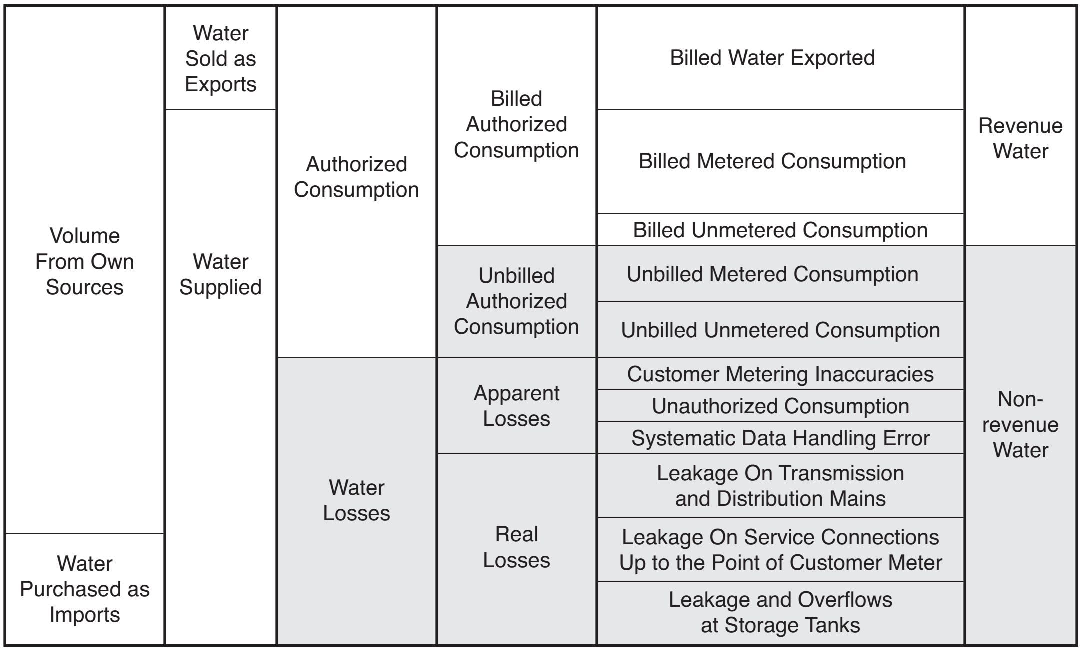
Appendix B

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 storm 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. 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 publication 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 where the customer utilizes the water. Many water audits are conducted on only 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 tracking water from the source to the customer's end use, after the water meter. In this way accountability and losses can be assessed on both raw water upstream of the treatment plant and leakage losses within customer premises, downstream of the customer water meter. General considerations are discussed here; however, the reader is referred to the following AWWA manuals for more detailed information:

- *Water Resources Planning* (M50)[1]
- *Water Conservation Programs—A Planning Manual* (M52)[2]



<table>
<tr><td rowspan="9">Volume From Own Sources</td><td>Water Sold as Exports</td><td rowspan="5">Authorized Consumption</td><td rowspan="3">Billed Authorized Consumption</td><td>Billed Water Exported</td><td rowspan="3">Revenue Water</td></tr>
<tr><td rowspan="10">Water Supplied</td><td>Billed Metered Consumption</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 Error</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage On Transmission and Distribution Mains</td></tr>
<tr><td rowspan="2">Water Purchased as Imports</td><td>Leakage On Service Connections Up to the Point of Customer Meter</td></tr>
<tr><td>Leakage and Overflows at Storage Tanks</td></tr>
</table>

Figure B-1 Standard IWA/AWWA water balance

Manual M50 provides strong insight to the value of water resources, resource development, water reuse, and recycling. Manual M52 gives outstanding guidance on managing water demand at the end user. These publications are valuable supplements to the information presented in this publication.

RAW WATER LOSSES

Figure B-1 is the standard water balance utilized throughout this manual. While its left column starts with the measured volume of 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 metered in the raw water transmission system conveying water from source to treatment. A number of large water supply networks feature aqueducts or transmission pipelines conveying untreated water for long distances—hundreds of miles—with losses of untreated water occurring in these systems. Depending on the specific system configuration and distances, the water auditor has the option to either (1) perform an audit on the raw water process separately from the treated water system, 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 B-2. In either approach, apparent losses, particularly from source meter error should be considered, as well as real (leakage) losses. 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 B-2 closely matches the water balance incorporated in the Annual Primary Facility Report created by the Pennsylvania Department of Environmental Protection in 2006. All community water suppliers in the Commonwealth of Pennsylvania are required to complete and submit a brief report based on this water balance on an annual basis.

<table>
<tr><td rowspan="10">Volume From Own Sources</td><td colspan="4">Raw Water Consumption and Losses
(Consumption Includes In-Treatment Plant Use;
Losses Include Raw Water Meter Inaccuracies and Pipeline Leakage)</td><td>Non-revenue Water</td></tr>
<tr><td>Water Sold as Exports</td><td rowspan="5">Authorized Consumption</td><td rowspan="3">Billed Authorized Consumption</td><td>Billed Water Exported</td><td rowspan="3">Revenue Water</td></tr>
<tr><td rowspan="10">Water Supplied</td><td>Billed Metered Consumption</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>
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<tr><td>Systematic Data Handling Error</td></tr>
<tr><td>Unauthorized Consumption</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage On Transmission and/or Distribution Mains</td></tr>
<tr><td rowspan="2">Volume Purchased as Imports</td><td>Leakage and Overflows at Utility Storage Tanks</td></tr>
<tr><td>Leakage On Service Connections Up to the Point of Metering</td></tr>
</table>

Figure B-2 Modified IWA/AWWA water balance showing raw water withdrawal, utilization, and losses

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? This depends largely on the configuration of the water supply system and the relative scarcity or value of the water. In terms of configuration, consider how extensive the raw water transmission network is. Closed systems (zero discharge facilities) do not need to consider this approach unless the potential for wasting energy 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 distribution system. If raw water is purchased, efficient use of this supply increases in importance. 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 limited resources, expanding economic development, or other demands.

A specific audit of raw water is typically not necessary where the raw water is extracted from a source approximate 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 not likely needed. However, consumption during plant operations and recycling of any 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 raw water, it may be considered as its own separate water audit. Volumes of the raw water supplied and raw water losses, both apparent and real losses, should be displayed. The cost of the raw water—if the water utility must purchase this water—should be included, as well as the costs 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 5.)

Figure B-3 presents perhaps the most holistic water balance that can be applied for drinking water utilities. The balance expands on the balance in Figure B-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. A right-most column is included to depict the water that is used by the utilities' water customers. While the volume passed through the customer meter is measured and billed as *consumption*, a portion of this water is beneficial use by the customer and a portion may go to *waste*, typically because of plumbing leaks or inefficient use by the customer.

The auditor may consider assessing additional parameters to evaluate the utility's overall water resource standing. Because many fast-growing communities are reaching the limits of their water allocations, the following is a measure of this standing:

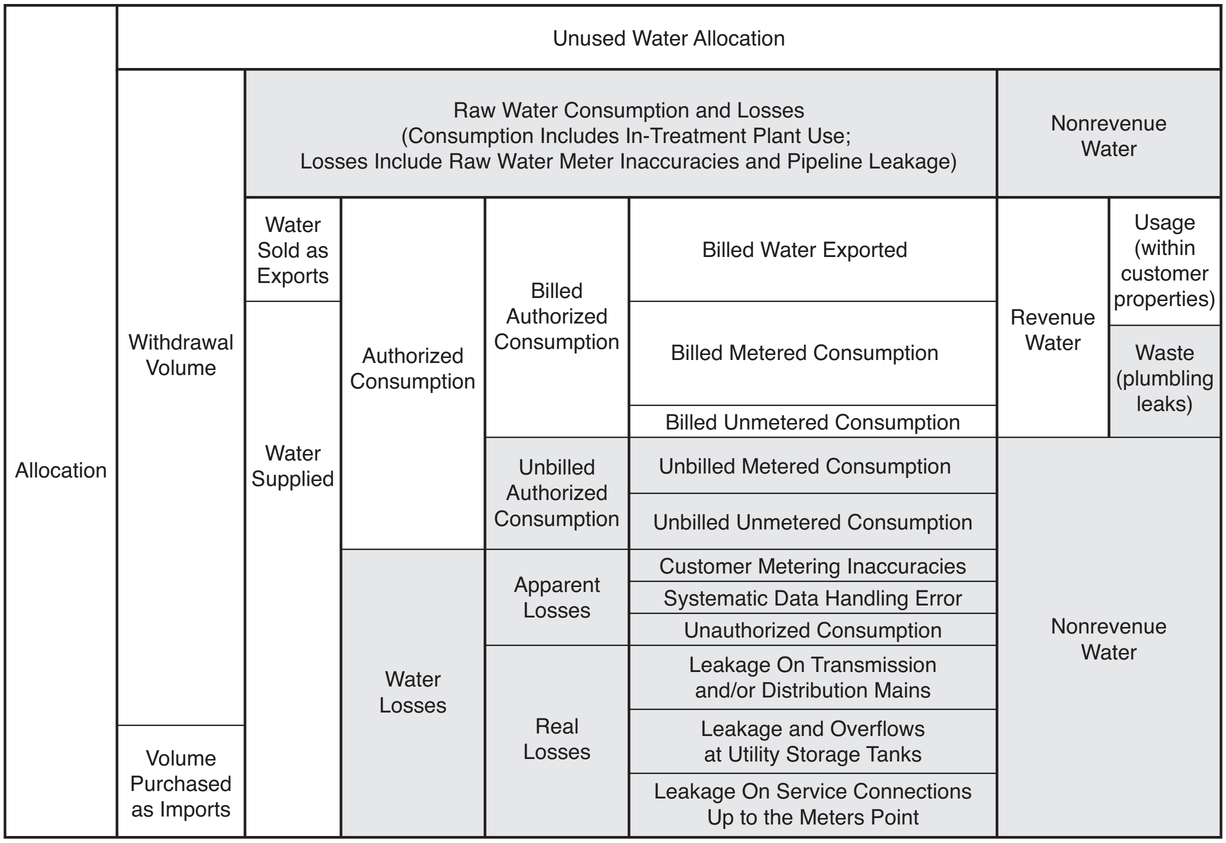
$$\text{remaining allocation} = \text{allocation} - \text{withdrawal}, \textit{vol} \qquad \text{(Eq. B-1)}$$

$$\text{percent remaining allocation} = \frac{\text{allocation} - \text{withdrawal}, \%}{\text{withdrawal}} \qquad \text{(Eq. B-2)}$$

Other aspects of the supply/demand balance to consider in fast-growing, resource-limited regions might include population and water demand growth rates, 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

The water audit detailed in Chapter 2 assigns water volumes measured at the customer meters as the terminal volumes in the water audit. As shown in Figure B-3, a portion of the water consumed by customers may actually go to waste, most typically



Allocation	Unused Water Allocation						
	Withdrawal Volume	Raw Water Consumption and Losses (Consumption Includes In-Treatment Plant Use; Losses Include Raw Water Meter Inaccuracies and Pipeline Leakage)				Nonrevenue Water	
		Water Sold as Exports	Authorized Consumption	Billed Authorized Consumption	Billed Water Exported	Revenue Water	Usage (within customer properties)
		Water Supplied			Billed Metered Consumption		Waste (plumbling leaks)
					Billed Unmetered Consumption		
				Unbilled Authorized Consumption	Unbilled Metered Consumption	Nonrevenue Water	
					Unbilled Unmetered Consumption		
			Water Losses	Apparent Losses	Customer Metering Inaccuracies		
					Systematic Data Handling Error		
					Unauthorized Consumption		
				Real Losses	Leakage On Transmission and/or Distribution Mains		
					Leakage and Overflows at Utility Storage Tanks		
	Volume Purchased as Imports				Leakage On Service Connections Up to the Meters Point		

Figure B-3 Modified IWA/AWWA water balance showing water allocation, raw water withdrawal, and customer usage and waste

via household plumbing leaks, with the common toilet being the most frequent culprit. The 1999 Awwa Research Foundation project *Residential End Uses of Water* found that leaks were responsible for 5.5 percent of the total average residential consumption of 171.8 gallons per capita per day, or 9.5 gallons per capita per day.[3] The occurrence of such leakage is not homogeneous, however, as the study found 10 percent of the properties monitored accounted for 58 percent of the discovered leaks.

Correcting plumbing leaks is one of the fundamental recommendations of a good water conservation program. Many such leaks, particularly toilet leaks, run continuously at low flow rates and drain water away unseen and often unregistered by customer water meters, particularly if the water meter has lost its capability to register low flows. In executing the standard water audit (Chapter 2), all water passing through the customer is registered as metered consumption; no distinction is drawn on the amount of consumption reaching beneficial use vs. waste. All low flows passing unregistered through customer meters are considered apparent losses caused by customer meter inaccuracy. In extending the water audit process to evaluate customer losses, or water waste, the auditor can consider the amounts of flow that go to a loss, typically plumbing leaks or outright wasteful practices, such as leaving garden hoses running unattended. In an audit of individual customers, water lost to leakage is considered a real loss.

In regions that are resource limited, reducing water waste by correcting customer leakage can have a significant overall impact. If the leakage occurs at flow rates below the detectable limits of the customer meters, the water utility suffers this loss as uncaptured revenue. Many customer water meters have a low registration limit of 0.25 gallons per minute (gpm). For example, assume a water utility has 50,000 connections. If one in every 20 homes has a dripping faucet or toilet leaking at 0.15 gpm when no other water is being used (at least 12 hours per day), the composite leakage amounts to 270,000 gallons per day, or almost 100 million gallons per year. At a retail cost of $2.00 per 1,000 gallons, this totals roughly $200,000 per year. Devices known as *unmeasured flow reducers* have recently been developed to modify low flow hydraulic regimes to be detectable by most meters. For the stronger leaks that do register on the customer meter, the customer is paying for water that serves no beneficial use. Some utilities are beginning to install metering, automatic meter reading, and leak noise logging systems that are structured to detect this waste and provide the water utility an early warning of this condition. It should also be noted that some utilities may offer the customer a credit for the excess use; some of this water becomes nonrevenue water. Reducing customer waste to controllable limits can save water resources, while saving money for both the water utility and the customer. Water utilities that operate a water conservation program should ensure that effort is taken to control customer leakage.

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 the 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, 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

1. AWWA. 2000. Manual M50. *Water Resources Planning*. Denver, Colo.: American Water Works Association.
2. AWWA. 2005. Manual M52. *Water Conservation Programs—A Planning Manual*. Denver, Colo.: American Water Works Association.
3. AwwaRF. 1999. *Residential End Uses of Water*. Denver, Colo.: Awwa Research Foundation.

Appendix C

AWWA Water Loss Control Committee's Free Water Audit Software

In 2006, AWWA's Water Loss Control Committee launched its Free Water Audit Software package (Version 2.0) to provide the drinking water industry a workable tool to conduct a basic top-down water audit quickly and inexpensively. The software (currently Version 4.0) is available for free download from AWWA's WaterWiser Web site.

The primary objective of the software tool is to promote the use of the standard water audit method as a true *standard* approach. The drinking water industries in many countries can greatly benefit from having a consistent structure for water accountability. It is essential that rational auditing and reporting structures exist to identify the greatest areas of loss and strategically implement effective interventions to minimize losses.

The software was designed with a number of key attributes:

- The software is user friendly, with the ability to easily toggle to and from individual spreadsheets. While the software is written in Microsoft Excel, there is no computer knowledge needed by users, and they need not be familiar with the water audit methods. They only need to have access to the Excel software on their computer.
- 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; terms and definitions are clearly explained.
- Performance indicators and key statistics are automatically calculated for the user, thereby preventing mathematical errors.

- Logical checks and alerts are included in the software to notify the users to questionable data entry or results. 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 is input.
- The software requires that the user "grade" the validity of each input data, from which a composite score (0–100 scale) is calculated, thereby providing a good assessment of the degree of confidence in the data. This is a powerful feature included in the Version 4.0 software.
- Having the ability to compile water audit data in an electronic format allows water audit data from many systems to be easily compiled, transferred, and analyzed electronically.

These features make the 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 hard pressed to dedicate staff time on auditing. The software allows such systems to begin auditing in an expedient, inexpensive way. Because all of the performance indicators are calculated in the software, the water utility has a means to make performance comparisons with other utilities, and a means 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 drive down losses.

The trade-off of the simplicity of the software, however, is that less detail is provided than the Water Audit Worksheet shown in Figure 2-4 in this manual. Also, the software quantifies real losses in a "catch-all" manner, as the remainder of losses after apparent losses are quantified and subtracted. While the 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 software and perform bottom-up auditing investigations—including those that can more directly quantify real losses—so that a more accurate water audit evolves over time. The Free Water Audit Software is an excellent tool that provides water utilities a quick look into the water supply efficiency of their operations.

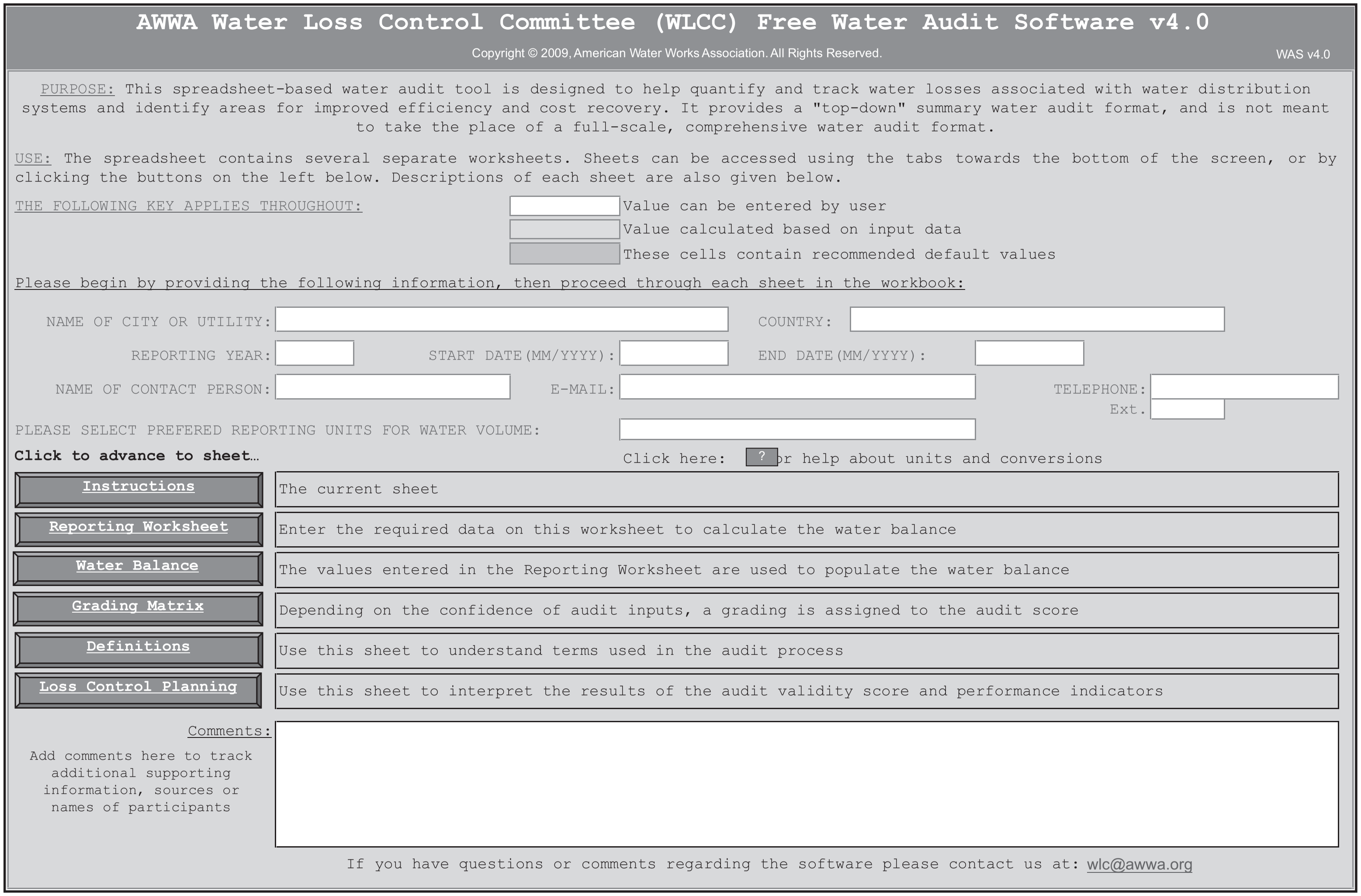
The Free Water Audit Software package exists as a Microsoft Excel workbook that includes five distinct worksheets, as shown in Figures C-1 through C-5, including two example completed water audit worksheets: one in gallons and one in megaliters (one thousand cubic meters). The key worksheet of the package is shown in Figures C-2 and C-3, the Reporting Worksheet for the Philadelphia Water Department and Region of Peel respectively. All of the data input occurs on this worksheet. The other worksheets shown include an instructional worksheet, a data grading guidance worksheet, and a guidance worksheet on data interpretation. Other sheets, not included in this appendix are also included in the software.

What is the best approach to water auditing if a water utility has not previously compiled a water audit? The following two-step recommendation states:

1. Compile a quick top-down water audit using the Free Water Audit Software package. This will quickly and easily provide a preliminary assessment of water loss standing, cost impacts, and serve as a basis for comparisons with other water utilities.

2. Once a preliminary water audit exists in the software, the methods prescribed in this manual can be followed to form a team (Chapter 6), develop a more detailed worksheet (Chapter 2), and start bottom-up activities and interventions to more accurately quantify and control apparent and real losses (Chapters 3 through 5).

The AWWA Water Loss Control Committee maintains the Free Water Audit Software and upgrades and enhances the software based on user feedback and the developing needs of the North American drinking water industry.



AWWA Water Loss Control Committee (WLCC) Free Water Audit Software v4.0

WAS v4.0

PURPOSE: This spreadsheet-based water audit tool is designed to help quantify and track water losses associated with water distribution systems and identify areas for improved efficiency and cost recovery. It provides a "top-down" summary water audit format, and is not meant to take the place of a full-scale, comprehensive water audit format.

USE: The spreadsheet contains several separate worksheets. Sheets can be accessed using the tabs towards the bottom of the screen, or by clicking the buttons on the left below. Descriptions of each sheet are also given below.

THE FOLLOWING KEY APPLIES THROUGHOUT:

- ☐ Value can be entered by user
- ▨ Value calculated based on input data
- ▨ These cells contain recommended default values

Please begin by providing the following information, then proceed through each sheet in the workbook:

NAME OF CITY OR UTILITY: ☐ COUNTRY: ☐

REPORTING YEAR: ☐ START DATE (MM/YYYY): ☐ END DATE (MM/YYYY): ☐

NAME OF CONTACT PERSON: ☐ E-MAIL: ☐ TELEPHONE: ☐ Ext. ☐

PLEASE SELECT PREFERED REPORTING UNITS FOR WATER VOLUME: ☐

Click to advance to sheet…

Click here: ? or help about units and conversions

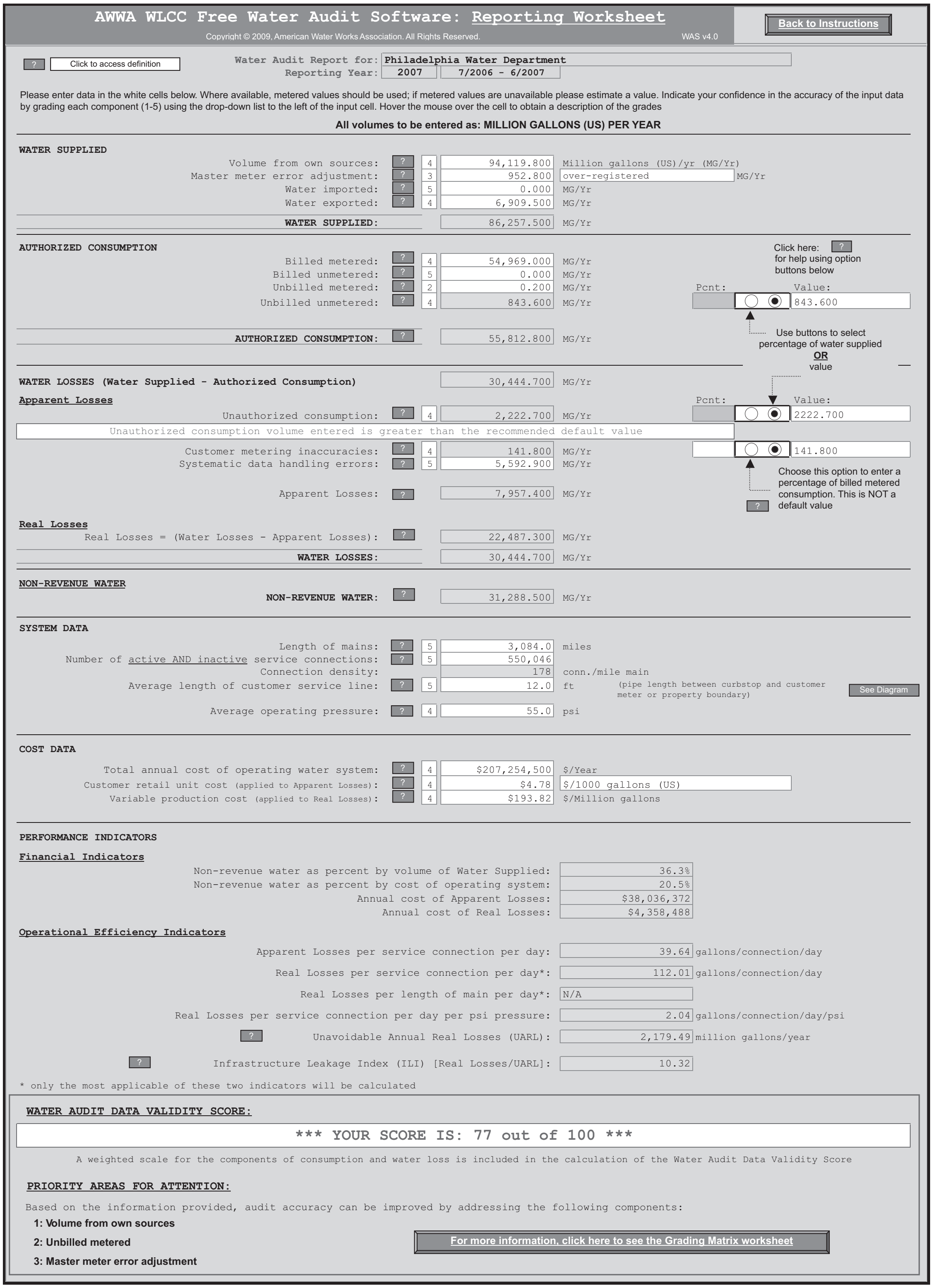
Instructions	The current sheet
Reporting Worksheet	Enter the required data on this worksheet to calculate the water balance
Water Balance	The values entered in the Reporting Worksheet are used to populate the water balance
Grading Matrix	Depending on the confidence of audit inputs, a grading is assigned to the audit score
Definitions	Use this sheet to understand terms used in the audit process
Loss Control Planning	Use this sheet to interpret the results of the audit validity score and performance indicators

Comments:

Add comments here to track additional supporting information, sources or names of participants

If you have questions or comments regarding the software please contact us at: wlc@awwa.org

Figure C-1 AWWA Water Loss Control Committee's Free Water Audit Software—Instructions Worksheet



AWWA WLCC Free Water Audit Software: Reporting Worksheet

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Water Audit Report for: **Philadelphia Water Department**
Reporting Year: **2007** **7/2006 - 6/2007**

Please enter data in the white cells below. Where available, metered values should be used; if metered values are unavailable please estimate a value. Indicate your confidence in the accuracy of the input data by grading each component (1-5) using the drop-down list to the left of the input cell. Hover the mouse over the cell to obtain a description of the grades

All volumes to be entered as: MILLION GALLONS (US) PER YEAR

WATER SUPPLIED

Volume from own sources: 4 94,119.800 Million gallons (US)/yr (MG/Yr)
Master meter error adjustment: 3 952.800 over-registered MG/Yr
Water imported: 5 0.000 MG/Yr
Water exported: 4 6,909.500 MG/Yr

WATER SUPPLIED: 86,257.500 MG/Yr

AUTHORIZED CONSUMPTION

Billed metered: 4 54,969.000 MG/Yr
Billed unmetered: 5 0.000 MG/Yr
Unbilled metered: 2 0.200 MG/Yr
Unbilled unmetered: 4 843.600 MG/Yr Pcnt: ○ ● Value: 843.600

AUTHORIZED CONSUMPTION: 55,812.800 MG/Yr

WATER LOSSES (Water Supplied - Authorized Consumption) 30,444.700 MG/Yr

Apparent Losses

Unauthorized consumption: 4 2,222.700 MG/Yr Pcnt: ○ ● Value: 2222.700
Unauthorized consumption volume entered is greater than the recommended default value
Customer metering inaccuracies: 4 141.800 MG/Yr ○ ● 141.800
Systematic data handling errors: 5 5,592.900 MG/Yr

Apparent Losses: 7,957.400 MG/Yr

Real Losses

Real Losses = (Water Losses - Apparent Losses): 22,487.300 MG/Yr

WATER LOSSES: 30,444.700 MG/Yr

NON-REVENUE WATER

NON-REVENUE WATER: 31,288.500 MG/Yr

SYSTEM DATA

Length of mains: 5 3,084.0 miles
Number of active AND inactive service connections: 5 550,046
Connection density: 178 conn./mile main
Average length of customer service line: 5 12.0 ft (pipe length between curbstop and customer meter or property boundary)
Average operating pressure: 4 55.0 psi

COST DATA

Total annual cost of operating water system: 4 $207,254,500 $/Year
Customer retail unit cost (applied to Apparent Losses): 4 $4.78 $/1000 gallons (US)
Variable production cost (applied to Real Losses): 4 $193.82 $/Million gallons

PERFORMANCE INDICATORS

Financial Indicators

Non-revenue water as percent by volume of Water Supplied: 36.3%
Non-revenue water as percent by cost of operating system: 20.5%
Annual cost of Apparent Losses: $38,036,372
Annual cost of Real Losses: $4,358,488

Operational Efficiency Indicators

Apparent Losses per service connection per day: 39.64 gallons/connection/day
Real Losses per service connection per day*: 112.01 gallons/connection/day
Real Losses per length of main per day*: N/A
Real Losses per service connection per day per psi pressure: 2.04 gallons/connection/day/psi
Unavoidable Annual Real Losses (UARL): 2,179.49 million gallons/year
Infrastructure Leakage Index (ILI) [Real Losses/UARL]: 10.32

* only the most applicable of these two indicators will be calculated

WATER AUDIT DATA VALIDITY SCORE:

*** YOUR SCORE IS: 77 out of 100 ***

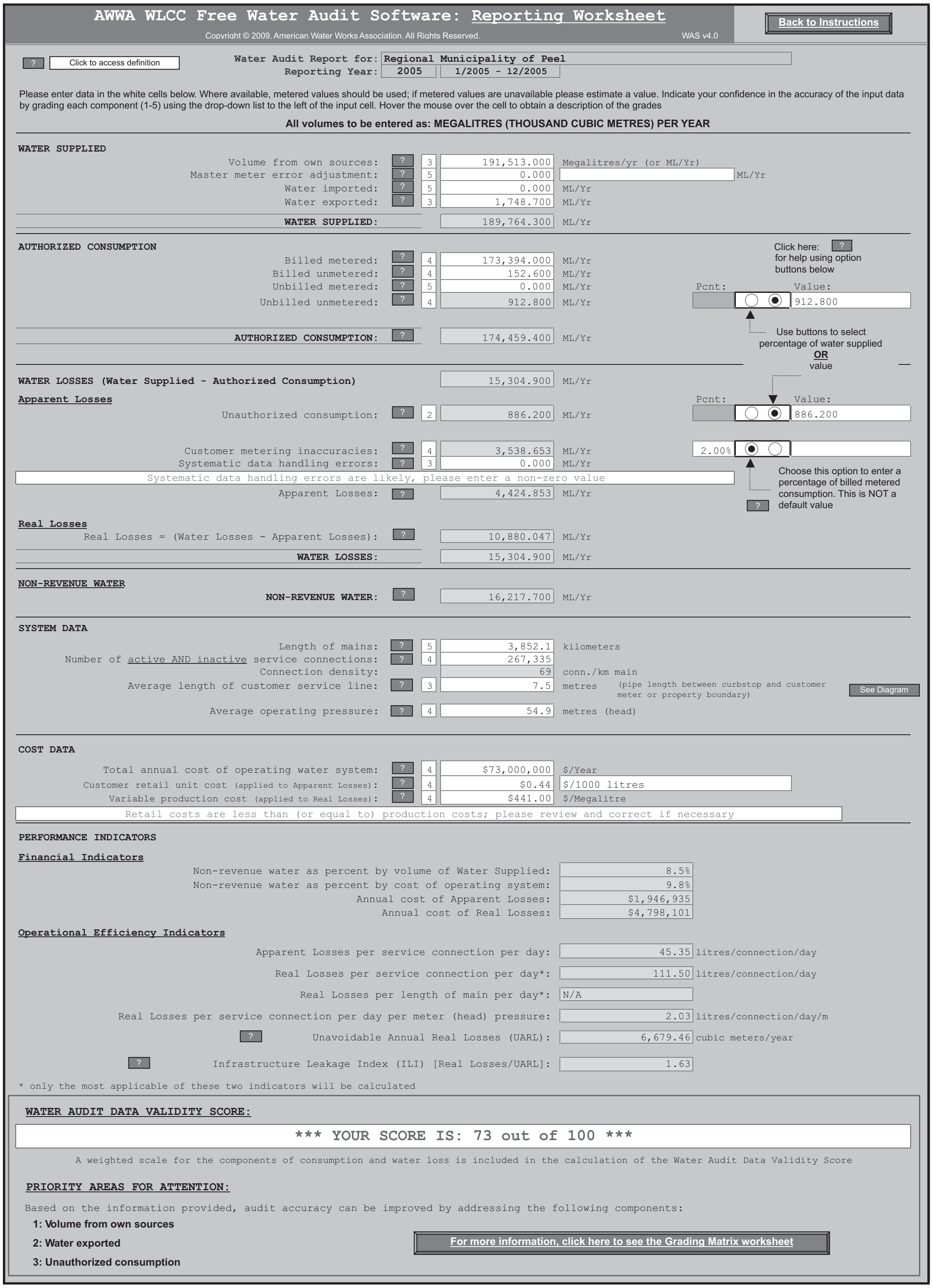
A weighted scale for the components of consumption and water loss is included in the calculation of the Water Audit Data Validity Score

PRIORITY AREAS FOR ATTENTION:

Based on the information provided, audit accuracy can be improved by addressing the following components:

1: Volume from own sources
2: Unbilled metered
3: Master meter error adjustment

Figure C-2 AWWA Water Loss Control Committee's Free Water Audit Software—Reporting Worksheet: Philadelphia Water Department water audit data in gallons units



AWWA WLCC Free Water Audit Software: Reporting Worksheet

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Water Audit Report for: Regional Municipality of Peel
Reporting Year: 2005 1/2005 - 12/2005

Please enter data in the white cells below. Where available, metered values should be used; if metered values are unavailable please estimate a value. Indicate your confidence in the accuracy of the input data by grading each component (1-5) using the drop-down list to the left of the input cell. Hover the mouse over the cell to obtain a description of the grades

All volumes to be entered as: MEGALITRES (THOUSAND CUBIC METRES) PER YEAR

WATER SUPPLIED

Volume from own sources:	3	191,513.000	Megalitres/yr (or ML/Yr)
Master meter error adjustment:	5	0.000	ML/Yr
Water imported:	5	0.000	ML/Yr
Water exported:	3	1,748.700	ML/Yr
WATER SUPPLIED:		189,764.300	ML/Yr

AUTHORIZED CONSUMPTION

Billed metered:	4	173,394.000	ML/Yr
Billed unmetered:	4	152.600	ML/Yr
Unbilled metered:	5	0.000	ML/Yr
Unbilled unmetered:	4	912.800	ML/Yr
AUTHORIZED CONSUMPTION:		174,459.400	ML/Yr

Click here: ? for help using option buttons below

Pcnt: ○ ● Value: 912.800

Use buttons to select percentage of water supplied **OR** value

WATER LOSSES (Water Supplied - Authorized Consumption) 15,304.900 ML/Yr

Apparent Losses

Unauthorized consumption:	2	886.200	ML/Yr
Customer metering inaccuracies:	4	3,538.653	ML/Yr
Systematic data handling errors:	3	0.000	ML/Yr

Pcnt: ○ ● Value: 886.200

2.00% ● ○

Systematic data handling errors are likely, please enter a non-zero value

Choose this option to enter a percentage of billed metered consumption. This is NOT a default value

Apparent Losses: 4,424.853 ML/Yr

Real Losses

Real Losses = (Water Losses - Apparent Losses): 10,880.047 ML/Yr

WATER LOSSES: 15,304.900 ML/Yr

NON-REVENUE WATER

NON-REVENUE WATER: 16,217.700 ML/Yr

SYSTEM DATA

Length of mains:	5	3,852.1	kilometers
Number of active AND inactive service connections:	4	267,335	
Connection density:		69	conn./km main
Average length of customer service line:	3	7.5	metres (pipe length between curbstop and customer meter or property boundary)
Average operating pressure:	4	54.9	metres (head)

COST DATA

Total annual cost of operating water system:	4	$73,000,000	$/Year
Customer retail unit cost (applied to Apparent Losses):	4	$0.44	$/1000 litres
Variable production cost (applied to Real Losses):	4	$441.00	$/Megalitre

Retail costs are less than (or equal to) production costs; please review and correct if necessary

PERFORMANCE INDICATORS

Financial Indicators

Non-revenue water as percent by volume of Water Supplied:	8.5%
Non-revenue water as percent by cost of operating system:	9.8%
Annual cost of Apparent Losses:	$1,946,935
Annual cost of Real Losses:	$4,798,101

Operational Efficiency Indicators

Apparent Losses per service connection per day:	45.35	litres/connection/day
Real Losses per service connection per day*:	111.50	litres/connection/day
Real Losses per length of main per day*:	N/A	
Real Losses per service connection per day per meter (head) pressure:	2.03	litres/connection/day/m
Unavoidable Annual Real Losses (UARL):	6,679.46	cubic meters/year
Infrastructure Leakage Index (ILI) [Real Losses/UARL]:	1.63	

* only the most applicable of these two indicators will be calculated

WATER AUDIT DATA VALIDITY SCORE:

*** YOUR SCORE IS: 73 out of 100 ***

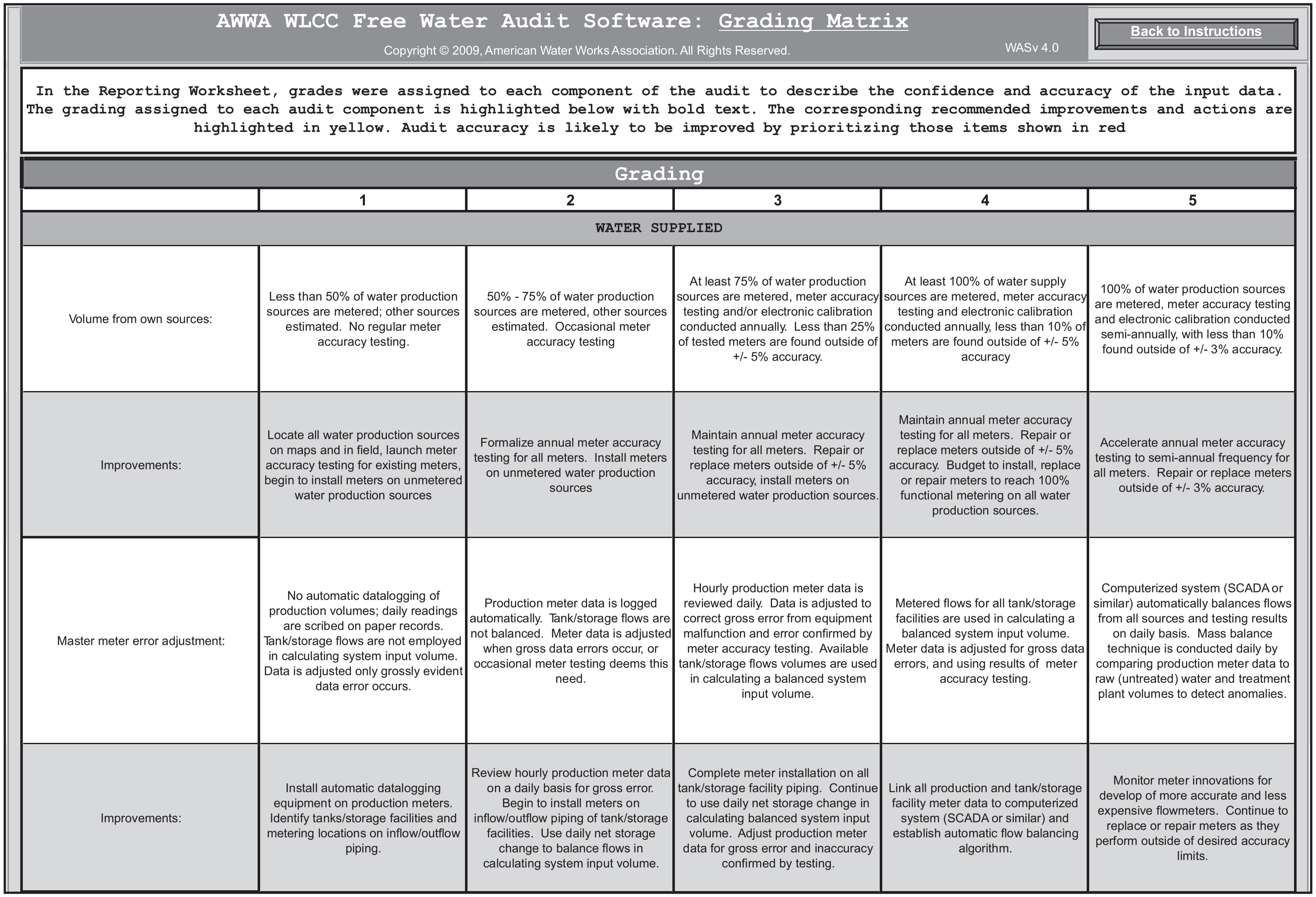
A weighted scale for the components of consumption and water loss is included in the calculation of the Water Audit Data Validity Score

PRIORITY AREAS FOR ATTENTION:

Based on the information provided, audit accuracy can be improved by addressing the following components:

1: Volume from own sources
2: Water exported
3: Unauthorized consumption

Figure C-3 AWWA Water Loss Control Committee's Free Water Audit Software—Reporting Worksheet: Region of Peel, Ontario, California water audit data in megaliters (1,000 cubic meters)



AWWA WLCC Free Water Audit Software: Grading Matrix

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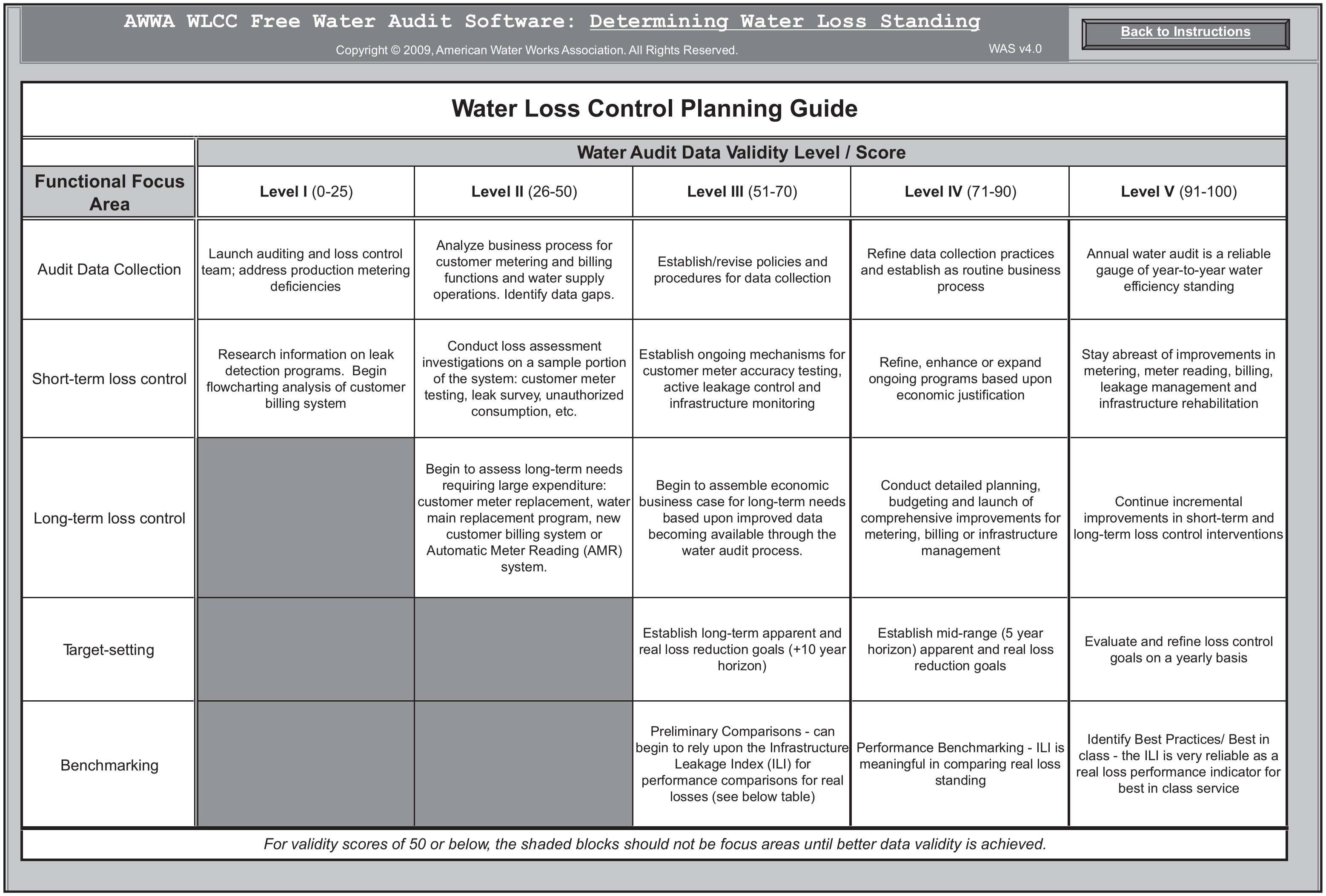
WASv 4.0

In the Reporting Worksheet, grades were assigned to each component of the audit to describe the confidence and accuracy of the input data. The grading assigned to each audit component is highlighted below with bold text. The corresponding recommended improvements and actions are highlighted in yellow. Audit accuracy is likely to be improved by prioritizing those items shown in red

Grading

	1	2	3	4	5
WATER SUPPLIED					
Volume from own sources:	Less than 50% of water production sources are metered; other sources estimated. No regular meter accuracy testing.	50% - 75% of water production sources are metered, other sources estimated. Occasional meter accuracy testing	At least 75% of water production sources are metered, meter accuracy testing and/or electronic calibration conducted annually. Less than 25% of tested meters are found outside of +/- 5% accuracy.	At least 100% of water supply sources are metered, meter accuracy testing and electronic calibration conducted annually, less than 10% of meters are found outside of +/- 5% accuracy	100% of water production sources are metered, meter accuracy testing and electronic calibration conducted semi-annually, with less than 10% found outside of +/- 3% accuracy.
Improvements:	Locate all water production sources on maps and in field, launch meter accuracy testing for existing meters, begin to install meters on unmetered water production sources	Formalize annual meter accuracy testing for all meters. Install meters on unmetered water production sources	Maintain annual meter accuracy testing for all meters. Repair or replace meters outside of +/- 5% accuracy, install meters on unmetered water production sources.	Maintain annual meter accuracy testing for all meters. Repair or replace meters outside of +/- 5% accuracy. Budget to install, replace or repair meters to reach 100% functional metering on all water production sources.	Accelerate annual meter accuracy testing to semi-annual frequency for all meters. Repair or replace meters outside of +/- 3% accuracy.
Master meter error adjustment:	No automatic datalogging of production volumes; daily readings are scribed on paper records. Tank/storage flows are not employed in calculating system input volume. Data is adjusted only grossly evident data error occurs.	Production meter data is logged automatically. Tank/storage flows are not balanced. Meter data is adjusted when gross data errors occur, or occasional meter testing deems this need.	Hourly production meter data is reviewed daily. Data is adjusted to correct gross error from equipment malfunction and error confirmed by meter accuracy testing. Available tank/storage flows volumes are used in calculating a balanced system input volume.	Metered flows for all tank/storage facilities are used in calculating a balanced system input volume. Meter data is adjusted for gross data errors, and using results of meter accuracy testing.	Computerized system (SCADA or similar) automatically balances flows from all sources and testing results on daily basis. Mass balance technique is conducted daily by comparing production meter data to raw (untreated) water and treatment plant volumes to detect anomalies.
Improvements:	Install automatic datalogging equipment on production meters. Identify tanks/storage facilities and metering locations on inflow/outflow piping.	Review hourly production meter data on a daily basis for gross error. Begin to install meters on inflow/outflow piping of tank/storage facilities. Use daily net storage change to balance flows in calculating system input volume.	Complete meter installation on all tank/storage facility piping. Continue to use daily net storage change in calculating balanced system input volume. Adjust production meter data for gross error and inaccuracy confirmed by testing.	Link all production and tank/storage facility meter data to computerized system (SCADA or similar) and establish automatic flow balancing algorithm.	Monitor meter innovations for develop of more accurate and less expensive flowmeters. Continue to replace or repair meters as they perform outside of desired accuracy limits.

Figure C-4 AWWA Water Loss Control Committee's Free Water Audit Software—Grading Matrix Worksheet (page 1 only)



AWWA WLCC Free Water Audit Software: Determining Water Loss Standing

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WAS v4.0

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 C-5 AWWA Water Loss Control Committee's Free Water Audit Software—Water Loss Control Planning Guide Worksheet (page 1 only)

Appendix D

Case Studies

CASE STUDY A: SMALL SYSTEM (WASHINGTON COUNTY SERVICE AUTHORITY, ABINGDON, VIRGINIA)

The Washington County Service Authority (WCSA) is a public utility that provides water to the residents of Washington County, Virginia. Washington County is located in the Appalachian Mountains of southwest Virginia. This historic region has the distinction of being the first in the United States to be named after General George Washington before he was elected president. Washington County covers approximately 566 square miles. In 2000, the county's estimated population was 51,130.

WCSA was originally chartered in 1953 as the Goodson Kinderhook Water Authority; however, its roots go back to 1910 when the Abingdon Water Authority was established. A large portion of the heart of WCSA's distribution system was established in the 1930s through President Franklin Roosevelt's Works Progress Administration. WCSA was formed in 1976 through the consolidation of the Goodson Kinderhook Water Authority, the Washington County Sanitation District #1, and the Mahanaim Water Company. Today, WCSA serves almost 90 percent of the residents of Washington County and is the third largest waterworks in Southwest Virginia.

One difficulty with serving a rural community is the distance water must travel to reach the customer. WCSA's distribution system covers approximately 300 square miles with 900 miles of pipeline. WCSA currently has more than 19,000 customers and, therefore, must maintain almost 240 feet of pipeline per customer. Furthermore, a majority of the pipeline in WCSA's system was installed in piecemeal fashion with inadequate planning or design for future growth. Thus, there is a system with pipe sizes ranging from ½ in. to 20 in. in diameter and pipe materials of galvanized steel, cast iron, ductile iron, asbestos cement, polyvinyl chloride (PVC), and stainless steel.

Other challenges with serving customers in a mountainous region are the elevation changes encountered within the service area. Washington County's lowest elevation point is 1,698 feet above sea level and its highest is 5,520 feet above sea level—a vertical range of 3,822 feet. Within the water system itself, the elevation change from the lowest to highest point is 1,147 feet. The distribution system has 27 water pumping stations and 39 pressure zones. The maximum normal operating system pressure is 250 psi.

WCSA-owned source capacity is 6.11 mgd. WCSA operates one membrane filtration plant, one conventional surface water treatment plant, one spring, and one well. Additionally, WCSA purchases water from two municipalities. In total, WCSA's average distribution of water is approximately 7 mgd.

WCSA's Strategies to Achieving Water Loss Control

In 1997, WCSA began to look at its nonrevenue water (NRW) and take steps to overcome the challenges it faced in measuring and controlling it. One invaluable step in this process was WCSA's participation in AWWA's QualServe Self-Assessment and Peer Review Program. Through the QualServe Program, several key areas for improvement were identified and included in the utility's "Agenda for Improvement." From the agenda, improvement areas were prioritized, and NRW was identified as one of the top priorities. This began an effort to reduce NRW that is currently ongoing.

Meter replacement program. For WCSA, the first step in reducing NRW was a meter replacement program. In looking at NRW, WCSA made an assumption that it was not receiving revenue for a portion of its distributed water simply because of the under-registration of its customer's water meters. This assumption was based on two basic components. One was the age of WCSA's customers' meters. The majority of WCSA's customer meters were more than 20 years old. The second was the size of the meters. An in-house evaluation that considered the volume of water passing through the meters found many of the meters to be too large for their estimated flow range. Random meter accuracy testing was also employed for the first time in the system to better confirm the assumptions. While data was somewhat limited, WCSA found there was sufficient evidence to believe that this would be a valuable endeavor.

Yet another contributing factor that influenced WCSA's decision to implement the meter replacement program was the prospect of moving to a radio-read metering system. The radio-read system would allow the WCSA to read all customer meters in one week by one person. This is in contrast to the manual-read method used at the time that required five employees to do the job in nearly two months. Because of the new radio-read system, WCSA was able to read meters in less time with fewer personnel, redeploy labor into other areas of the utility, obtain monthly meter reads for billing as opposed to bi-monthly meter reading and billing, as well as develop a routine meter testing program. Combined, this formed the justification for the meter replacement program.

In 1999, WCSA began replacing every customer meter by using staff already in the meter department as well as summer workers, most of whom were college students from the area. During the first year of this program, WCSA replaced a total of 18,900 customer meters. When meters were replaced, care was taken to properly size the new meters for flow requirements. By the end of the replacement process in 2000, the WCSA's NRW had been reduced by more than 11 percent. This translated to an 11 percent increase in water and wastewater revenue, as wastewater bills are generated by water meter readings.

Process and blow-off metering. The next steps taken by the WCSA were very valuable in that they helped the utility identify and measure more than 4 million gallons of NRW each month. These steps involved the installation of process and blow-off meters at the treatment plants.

WCSA's process water, taken from the distribution system, was comprised of, but not limited to, the water used for chlorination at the drinking water plants, semiannual cleaning of the sedimentation basins, the operation of the office, cleaning purposes at the wastewater lift stations, the warehouse facility, and water and wastewater treatment facilities for potable purposes. Meters for these processes provided measurement of the water used in these areas, and their installation enabled WCSA to review process water use on a regular basis. Process water use is now captured monthly and incorporated into WCSA's record system.

WCSA also installed automatic blow-off valves with meters on all regularly used water blow-offs. Because of the miles of pipe relative to the number of customers as well as the large quantity of the galvanized pipe within our system, WCSA must regularly flush water through its blow-off locations to maintain water quality. By installing automatic blow-off valves with meters, WCSA decreased the labor involved in blowing off water and optimized the water quality maintenance process. Previous to the automatic metered blow-off installations, a valve would be manually opened to allow water to flow freely and indefinitely until the chlorine residual reached a desired level or the customer complaints ceased or in some cases increased as a result water shortages related to the water being blown off. The automatic metered blow-offs allowed WCSA to first meter the flow, and then optimized the process so that only the minimal amount of water needed to achieve optimal water quality was used. Because the blow-offs can be programmed to operate at night, they also helped reduce customer complaints related to low water pressure and reduced higher pressures normally seen at night as demands decrease. The water that is being blown off is also recorded in WCSA's record system monthly.

Capital Improvement program and line replacement program. In 1999, WCSA recognized that a systematic and planned approach to distribution system improvement and replacement was needed. To facilitate this, WCSA hired a consulting firm to develop a hydraulic model of the distribution system and to create a master plan for water infrastructure replacement. From this master plan, a Capital Improvement Program (CIP) was developed that prioritized 18 major projects in the distribution system. Additionally, WCSA also identified more than 25 improvement projects to be included in its CIP. From 1999 to the present, the CIP has been reviewed, reprioritized, and implemented annually. Thus far, 8 of the 18 master plan CIP projects have been completed, and all 25 of WCSA identified projects have been completed. The total project cost for the combined 33 projects was $12.6 million, of which, $3.9 million was related to the meter replacement project. Direct results of the implementation of the WCSA's CIP have been the elimination (without replacement) of more than 12 water pumping stations with six additional water pumping stations scheduled for elimination later this year, along with five welded steel storage tanks and seven pressure zones.

Funding for WCSA's CIP was achieved through various means. WCSA's rates over a 10-year period prior to 1996 increased considerably. This was largely because of extending water service to unserved areas and the provision of service and infrastructure improvements to new development at little or no charge to the developer. When it was recognized that the aging infrastructure demanded attention, WCSA began to focus on a more balanced approach between replacement and extension. WCSA embraced a new strategy for development within the system that provided for more equitable growth. Connection fees were restructured such that they reflected the volume of water being used, with higher volume users paying higher connection fees, which in turn provided capital for infrastructure and treatment improvements/upgrades needed for growth. This approach impacted the new user in that they paid an equitable connection fee for becoming a customer, while the existing customer was no longer bearing the entire burden of subsidizing growth. This, coupled with aggressively seeking and receiving a modest amount of no/low interest loan and some grant funds from various funding agencies, allowed WCSA to accomplish the improvement projects recognized in the CIP.

WCSA also found that improvements made through its QualServe participation saved almost 10 percent of their operating budget. Annual savings were passed on to customers in the form of minimal rate increases over the past 8 years. From 1997 to

2005, WCSA raised its water rates three times. On July 1, 1997, water rates were set for the first tier of billing at $26 for 2,000 gallons with billing on a bi-monthly basis. This was equivalent to $13 per 1,000 gallons per month. Beginning July 1, 2002, WCSA increased the minimum to $14 for 1,000 gallons with the billing interval switched to a monthly basis. In April 2005, the minimum was increased by $1.00, to $15 for 1,000 gallons. WCSA has shown that its focus on efficiency improvements has resulted in cost savings for the water utility and affordable water rates for its customers.

WCSA's CIP includes a line replacement program. WCSA recognized that the replacement of substandard lines would not only reduce water loss by replacing the lines that leak or break frequently, but in most cases, these lines are also hydraulically deficient and often experience poor water quality. A large portion of the existing lines in the WCSA distribution system are old, small, or of a material that does not allow for optimum hydraulics or water quality. In fact, a detailed inventory conducted by WCSA staff through the development of a geographic information system of the water system was undertaken to identify pipe sizes and types, lines with a high number of leaks and breaks, and lines with a high number of water quality complaints. From this study, WCSA identified almost 200 miles of 2 in. or smaller galvanized pipe. Galvanized pipe accounts for more than 22 percent of the entire system. Furthermore, it is estimated that almost 8,000 of WCSA's customers are directly tapped to a galvanized line, which represents 40 percent of the customer base.

By tracking and measuring characteristics of all of WCSA's water lines, it was demonstrated that there will be significant savings from the implementation of its CIP and line replacement program. Eighty-six percent of the inventoried leaks and breaks that were repaired from January 2004 through December 2005 involved galvanized line. WCSA has calculated that each repair costs an averaged of $550. Repair costs alone for galvanized line are estimated at $270,000 annually. The replacement of galvanized line will significantly reduce WCSA's corrective maintenance budget. Moreover, assuming that half of the WCSA's NRW is caused by leaks in galvanized lines, it is estimated that water lost in galvanized lines is costing more than $340,000 annually in production costs (not including distribution costs). Such savings will not be limited to a reduction in NRW or leak and break repairs. Galvanized line is also the number one contributor to customer complaints related to both water quality and hydraulic deficiencies.

WCSA initiated its line replacement program in 2000 when it introduced its CIP. Since 2000, WCSA has replaced an average of 40,000 feet of line or 1 percent of its distribution system yearly. The line replacement program is to be reevaluated in an effort to prioritize and increase the amount of galvanized line that is replaced each year.

System pressure modifications. Residents of southwest Virginia appreciate the beautiful mountainous terrain and the variations in elevations; however, the splendor of the mountains does present some challenges for water distribution operations. System pressures are more challenging to minimize when water must transverse such variations in elevation. However, WCSA has seen the need to make system pressure modifications and continues to work toward optimal yet adequate pressures throughout its distribution system. In 1997, WCSA had only six pressure-reducing valves (PRVs) in its entire distribution system. Of these six, only two were operational. Currently, 20 PRVs have been installed and are operational. WCSA has consciously planned and made modifications to reduce excess pressure throughout the distribution system. Two pressure zones were modified to reduce pressure by 20 psi, and with this modification, there was a significant decrease in water demand, which translated into a reduction in NRW.

WCSA has experienced a significant system-wide reduction in the number of monthly breaks identified and repaired that has been attributed to pressure reduction.

In 1997, WCSA averaged eight to ten breaks (not leaks) per month. By 2003, this number was reduced to about two breaks per month. It is believed that WCSA's system pressure modification has directly contributed to this drastic reduction of line breaks.

SCADA system. WCSA has automated 90 percent of its distribution system operations through a computer-based telemetry system. This supervisory control and data acquisition (SCADA) system monitors every storage tank, pump station, and control valve within the system. WCSA's SCADA system is monitored by on-duty operators 24 hours a day, seven days a week. SCADA has allowed WCSA to identify and correct problems within the distribution system before they adversely affect its customers. It serves as an early warning system for leaks by catching unusual drops in pressure or tank levels and increases in flow. Flow and pressure data from the SCADA system is used to watch for leaks and breaks within the system. When unusual changes in flows and pressures occur, crews are dispatched to investigate, which leads to early detection of line breaks and the avoidance of significant real water losses.

The SCADA system also promotes the reduction of real water losses through the control and the monitoring of tank levels. Prior to the installation of the SCADA system, WCSA relied on physical site checks for tank elevations. This process was time-consuming and inefficient for monitoring a constantly changing distribution system. With the more efficient SCADA monitoring, tank elevations are controlled automatically, and tank overflows have been almost eliminated. WCSA has also seen significant improvements in water quality because of the improved tank turnover accomplished by the SCADA system. SCADA has improved distribution system records as well. Historic data of distribution monitoring is maintained and stored electronically. This data is indispensable for design purposes, prioritizing line replacements, and regulatory reporting.

District metered area monitoring. To monitor the distribution system for real and apparent losses, WCSA undertook what it has identified as its *district metered area monitoring program*. For this program, the entire distribution system was divided into smaller systems for the purpose of identifying NRW within specific areas. These smaller systems are referred to as *district metered areas* or DMAs. The DMAs were established largely by pressure zones. Magnetic flow meters were installed at points in the system where a change in pressure occurs, such as at a pump station or PRV. The magnetic flowmeters record the amount of water flowing into each DMA. Customer, process, and blow-off meters record the amount of water consumed in each DMA. By comparing the amount of water flowing into the DMA to the amount flowing out, WCSA has a good representation of NRW within each DMA and has effectively narrowed down the areas of greatest concern. This allows WCSA to not only locate but prioritize labor in addressing NRW.

WCSA's magnetic flowmeters, referred to as *master meters*, are read weekly and used to calculate the total volume of water flowing into each of its 26 DMAs. This information is recorded in a database and compared to previous DMA readings. Weekly comparisons help indicate unusual events within a DMA. Not all events indicate a major leak or break within a DMA. A spike in the amount of water entering a DMA could indicate unauthorized use, unusual customer consumption, or operational changes within the DMA. However, each spike is investigated, and its cause is recorded in the database for future reference.

Through WCSA's district metered area monitoring program, four DMAs have been identified with significant NRW concerns. Of the four DMAs, two are highly industrialized and two are residential and largely comprised of older, lead-joint, cast iron, and galvanized pipe. The four DMAs combined contain 10 percent of the system's pipe, 12 percent of the customer base, but nearly 50 percent of the NRW. In 2003, system-wide NRW averaged 51 million gallons a month, and the NRW within these four DMAs alone was 25 million gallons a month. WCSA's efforts for NRW control were concentrated on these four DMAs. WCSA intends to begin metering dynamic fire suppression systems throughout the entire customer base. Both static and dynamic fire suppression lines are unmetered. WCSA believes that a significant amount of NRW within the industrialized DMAs could be caused by water use in these fire suppression systems.

WCSA's resources in achieving water loss. How did the WCSA as a small rural utility set and accomplish these goals? It required a lot of hard work and plenty of patience from each and every department of WCSA. WCSA employed both a top-down and bottom-up approach using existing resources and employment base. In 1996, WCSA's Board of Commissioners employed a general manager (GM) who believed in entrusting, equipping, and supporting existing personnel not only to manage every department of the utility, but also to accomplish the changes that needed to take place for quality improvements within the utility. Each department collaborated with one another to find areas for improvement and develop an approach to be implemented in the identified areas. Through this collaboration, the GM and senior staff developed strategies that were presented to WCSA's board for action. The board considered these strategies and approved the delegation of resources that has led to a perception of increasing success in managing water losses.

WCSA employs almost 65 full-time employees. Through seven distinctive departments, five senior staff members rely on the historic knowledge and experience of all WCSA employees, AWWA, and consulting engineers to help establish and accomplish its goals. This requires communication within the organization, a commitment to educating senior staff through attendance and participation in AWWA, and reliance on consulting engineers when either the resources or expertise are not available internally.

A good analogy of WCSA's approach to improvement is that of gardening versus farming. The consultant engineers could be considered the farmer who plants and tends large fields, and WCSA is a gardener who plants a small plot. Many of the strategies embraced by WCSA began as seeds planted from attending AWWA conferences, participating in AWWA's quality improvement programs, and listening to the experience of other utilities. Senior staff took these strategies and incorporated them into the utility to meet its needs. However, WCSA has found that it does not require a full-time farmer, equipped to farm thousands of acres, to care for the garden. It requires a proper balance of what seed to use and when to call in the full-time farmer to help out. The majority of WCSA's improvement efforts were accomplished from within. Existing employees were equipped through education and trial and error to work toward the utility's goal of improvement. The result has been continuous efforts to improve and seeing significant results.

Future Plans for WCSA's Water Loss Control

WCSA remains committed to overcoming the challenges it faces with NRW and continues to look for ways to reduce NRW within utility operations. While important and cost-saving steps have been taken, there are still many left to take. WCSA looks forward to continuing to improve NRW optimization and increasing the efficiency of the WCSA water system in southwest Virginia.

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CASE STUDY B: MEDIUM SYSTEM (EL DORADO IRRIGATION DISTRICT, PLACERVILLE, CALIFORNIA)

From Humble Beginnings to Present Day

The El Dorado Irrigation District (EID) was formally organized in 1925 under California's Irrigation District Law to provide water for agriculture and domestic uses in the Sierra Nevada foothills between Sacramento and South Lake Tahoe. EID holds water rights that date back to the gold rush days when water was conveyed by open ditch for mining purposes. The location where James Marshall discovered gold in 1848 at Sutter's Mill is part of EID's current service area. Over the past 80 years, EID has transitioned from delivering irrigation water through ditches to conveying treated water through a complex system of pipes. Other services currently offered by EID include wastewater collection and treatment, production of recycled water for commercial and residential irrigation, generation of hydroelectric power, and various recreational opportunities.

EID's service area covers 220 square miles, ranging in elevation from 460 to 4,300 feet above mean sea level—a vertical range of 3,840 feet. At the end of 2005, the potable water facilities included more than 1,240 miles of pipeline, three main and two satellite water treatment plants, 36 storage tanks and covered reservoirs, 200 pressure-reducing stations, and 38 pumping stations. Delivering piped water currently in the rolling foothills requires 274 pressure zones, with booster pumps needed to maintain a minimum of 40 psi on some hilltops, and pressure-reducing stations needed to manage high pressures in the valleys and ravines. The highest recorded pressure is 435 psi in a cross-country transmission main, with an average system pressure of 108 psi. The transmission mains are predominately ductile iron or mortar-lined concrete-coated steel, ranging in diameter from 18 to 48 inches. The distribution system consists mostly of asbestos cement (AC) or polyvinyl chloride (PVC), ranging in diameter from 2 to 16 inches. More than 36,700 fully metered customers are served by the main system, which includes 11 municipal connections to the City of Placerville.

Another challenge in this arid, west region is the peak summertime water consumption that can be more than four times that of wintertime consumption. Maximum day demands are more than two times that of average day. In 2005, the treatment plant production was 32.8 million gallons per day (mgd) for average day, with a maximum day production of 78.7 mgd. EID diverts water from the following three surface water sources for use in the main piped system (excludes two small satellite systems):

- Folsom Reservoir—a US Bureau of Reclamation (USBR) water service contract with an entitlement to 7,550 acre-feet per year (2,460 mil gal), plus a state water right permit for 17,000 acre-feet per year (5,539 mil gal) issued to EID in 2001.

- Sly Park's Jenkinson Lake—a storage reservoir with a two-year capacity of 41,033 acre-feet (13,371 mil gal) originally built by the USBR in the early 1950s and operated by EID; owned by EID since 2003.

- El Dorado Hydroelectric Project—a 15,080 acre-feet per year (4,914 mil gal) pre-1914 water right from four storage reservoirs, diversion dam, and conveyance system completed in 1876 for hydraulic mining, rehabilitated for use as a hydroelectric system by 1923, owned and operated by EID since 1999.

History of Water Loss Control

The EID Board of Directors issued a resolution "Declaring an Emergency Condition of Water Shortage" on March 12, 1990, and thereby suspended the issuance of new water meters. The findings of the resolution indicated that the total firm yield of EID's water sources was less than the recent demand for water. Chaos ensued after this declaration and the resulting moratorium, as it came in the midst of a housing boom. The lack of confidence in EID caused by the emergency declaration would be felt for years to come, and unfortunately, the emergency turned out to be more a lack of accurate data than a lack of water. A citizens Water Advisory Group was formed to analyze EID's supply and demand data, and in June of 1990, EID's general manager requested that a *water distribution system audit* be performed. An initial review of diversion and consumption records revealed that approximately 32 percent of all water being diverted (system input) was not "specifically accounted for."

Although errors in generated consumption data and meter inaccuracies were found to account for some of the reported losses, manual water treatment plant operations that caused excessive spills from open reservoirs contributed to a big portion of the losses. A management team was organized to investigate and correct these operational deficiencies, and EID's first water loss reduction program was underway. The water emergency was eventually lifted in June of 1992—without any new water supply—only better data. As illustrated in Figure D-1, for more than 15 years, EID has continued to install new water meters and meet the increasing demands of new and existing customers through careful tracking of water supply and demand, and by reducing losses.

Many changes have occurred at EID since 1990, including the automation of treatment facilities and the replacement of open reservoirs with steel or concrete tanks, all monitored by a supervisory control and data acquisition (SCADA) system. Aggressive replacement of waterlines with known leaks was performed, along with an ongoing Capital Improvement Program (CIP). Many miles of ditches were either piped, lined, or removed from service. An extensive program was undertaken to meter or measure all miscellaneous uses of water. All private fire service installations have water meters installed, and construction water used for dust control must go through a fire hydrant meter. Water quality flushing and sampling is measured by operations.

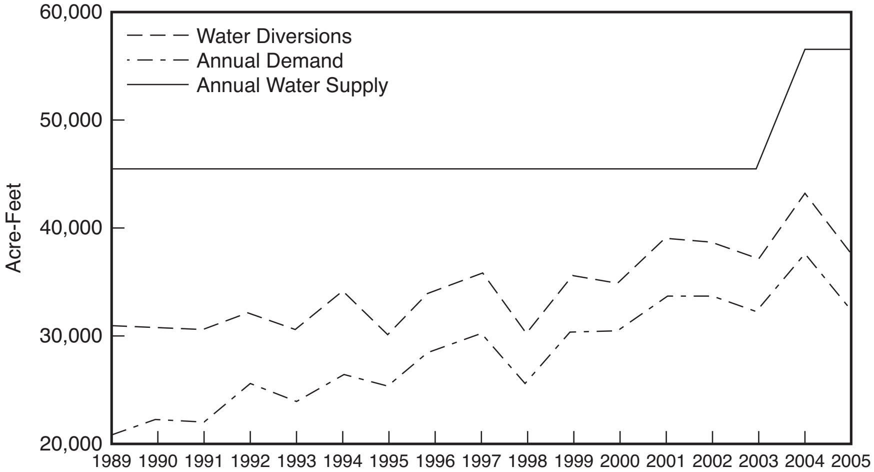

Figure D-1 Supply/Demand trends for El Dorado Irrigation District (Courtesy of Water Systems Optimization)

A meter testing, repair, and replacement program was developed, and discharges during meter testing are recorded. Meters were also installed at all sewage lift stations, and water used for collection system cleaning and flushing is measured.

EID recognized many years ago that its water supply was finite, especially in the California foothills, and that new water supplies can take decades to acquire, if at all. Nonetheless, in recent years the reduction of losses as a new source of supply has become more difficult and has lacked focus. The timing was right for EID to undergo another system-wide water audit.

Participation in AwwaRF Project No. 2928

EID learned about Project No. 2928 *Leakage Management Technologies* administered by the AwwaA Research Foundation (AwwaRF) through the California Urban Water Conservation Council, and with encouragement and support from its general manager, joined the study in August of 2004. The scope of the project included two phases, with EID scheduled to participate as a full scope (level two) utility. As a requirement of this participation, it was necessary to undertake a full water audit and component-based analysis. AwwaRF had previously selected a consultant, and EID contracted directly with this consultant by approving a $200,000 contract for the two-phase, two-year project. Phase One, the standard International Water Association/American Water Works Association (IWA/AWWA) recommended water balance and audit, was completed in September 2005; while Phase Two, testing leak detection and intervention technologies in the field, was completed in June 2006. Key staff members were identified for the project team from various internal departments, including engineering, operations, meter services, billing, construction, maintenance, drafting, SCADA, and database support.

Lessons Learned From a System-wide Water Audit

Verification of system input volume. The system input volume (SIV) for EID was being measured through source meters upstream of the water treatment plant, rather than at a downstream location through finished water flowmeters as recommended in the IWA/AWWA method. Although the flow transmitters had been periodically calibrated, the flowmeters had not been independently checked for accuracy through a separate test port and meter. Therefore, verification of the SIV through the three main water treatment plants (El Dorado Hills, Sly Park, and Forebay) was the first step in the audit process. Photos of these challenge (verification) tests are shown in Figure D-2.

The raw water flowmeter at Sly Park was tested using a strap-on ultrasonic meter because finished water flowmeters were only available on two of the three downstream mains. At El Dorado Hills, space limitations prevented testing of the raw water meter, but insertion magnetic meters were used to test the two existing finished water flowmeters. At Forebay, the SIV was being measured by a Parshall flume flowmeter at the point of diversion, and then conveyed through three miles of open ditch to the water treatment plant where it was measured again by another Parshall flume at the beginning of the treatment works. The audit stated that "Parshall flume flowmeters are not appropriate for providing the accuracy required for operating and managing a drinking water distribution network." Two finished water flowmeters at Forebay were also tested and found to be inoperable. Changing the point of measurement for the SIV was a major change for EID. It was also the most costly of the audit recommendations to implement but was a desired change. Additional taps and meters were needed at both Sly Park and Forebay to measure SIV. At El Dorado Hills, a plant expansion facilitated new permanent taps and flowmeters. EID selected averaging insertion magnetic meters for installation at these sites.

Figure D-2 Verification of system input volume through source meter tests (Courtesy of Water Systems Optimization)

Calibration and data chain analysis. The water audit compared the calibration flow range with the operational flow range for each raw or finished water meter. These meters had not been subjected to comprehensive calibration with only the flow transmitters calibrated each year. EID learned that the calibration flow ranges were much wider than the actual operational ranges. The corresponding resolution could be improved if these ranges were narrowed.

A data chain analysis was also performed at each site to test if any inaccuracies existed in the transfer of data from the raw (4–20 mA) signal produced by the flowmeter to the final flow values recorded by the SCADA system. At the El Dorado Hills site, the results were mixed with one finished water flowmeter showing no significant error and the other showing a 4 percent difference. The values recorded by the SCADA system were 4 percent less than the values measured by the flowmeter itself. At the Sly Park site, the data chain for the raw water meter was also tested, and a 3 percent difference was found with the SCADA system recording less than the flowmeter. No data chain analysis was performed at the Forebay site because of the inoperable finished water flowmeters and Parshall flumes used for the raw water measurements. The SCADA system also smoothed the raw data to facilitate water treatment plant operations, which was acceptable if the overall SCADA trend corresponded with the flowmeter measurements. Figure D-3 illustrates the results of the Sly Park data chain analysis.

Apparent losses. Apparent losses (also known as *paper losses*) can include consumption data handling errors, unauthorized consumption (theft or illegal use), and inaccuracies associated with customer metering. The analysis of EID's billing system did not find any data handling errors. Theft and illegal uses exist within EID like any other water system, but compared to the other nonrevenue water components, the impact was marginal and did not justify any further intervention at the time. The greatest source of apparent losses was found in the area of customer metering. Specifically, large meters (2 to 14 in.) accounted for 76 percent of the apparent losses but represented only 2 percent of the meter population. Small meters (⅝ to 1½ in.), which comprise 98 percent of all meters and are replaced at 15-year intervals, were found to be AWWA compliant with only 1.5 percent under-registration. The audit determined that the total apparent losses for both the large and small meters equaled 3.4 percent of the system input volume.

Although it was EID's policy to test large meters in accordance with the AWWA Manual M6, *Water Meters—Selection, Installation, and Maintenance*, several years ago a decision was made to have the large meter technicians also test backflow prevention devices, a program that is mandated by the State of California. As a result of the

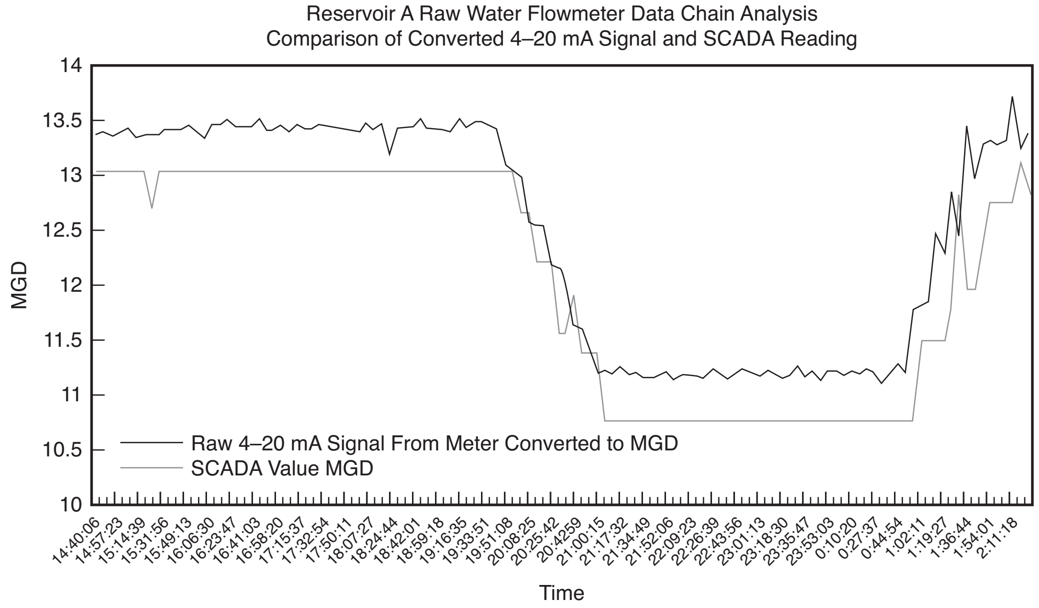

Figure D-3 Flowmeter data chain analysis (Courtesy of Reinhard Sturm)

reduction in large meter testing, the audit revealed losses from under-registration in customer consumption that ranged from 3.1 percent for 8- to 14-in. meters, to 15.7 percent for 3-in. meters, and approximately 9 percent for 2- and 4-in. meters. The value of these apparent losses was estimated at $300,000 annually using the average retail price of water at EID. In retrospect, EID realized that reallocating staff rather than adding staff was a costly decision.

Real losses. Real loss is the physical water lost from the pressurized piped system caused by overflows, leaks, and breaks up to the point of measurement at the customer's meter. The audit determined that real losses equal 10.2 percent of EID's system input volume. Although storage overflows have been minimized in recent years, any overflow is estimated and reported. The audit included an extensive leak and break component analysis, which required specific data from the asset management system used to track trouble calls and generate work orders. EID learned that specific fields had not been set up to record pipe size or material, or the type of leak or break (e.g., lineal or round crack). Data that were not recorded in the comments section were referenced on maps or assumed. Additional fields have been added to the work order system for data collection that can be used for future analysis or development of rehabilitation programs.

The leak and break component analysis revealed that pipe break frequencies for EID are higher than average because of high system pressures (average of 108 psi). Repair times were also found to be considerably long for leaks on smaller-diameter pipes, and the audit estimated that real losses could be reduced by 67 percent if these reported leaks were repaired within 2 days and customer service connection piping repaired within 5 days. All trouble calls were prioritized, with full breaks under high pressure considered emergencies that were fixed within a matter of hours, while smaller breaks must wait 48 hours for the underground service alert notification before being excavated. EID has one construction crew dedicated to repairing or replacing customer service connection piping. Even so, response to small-diameter pipelines and customer service connection piping with leaks that are not causing any property damage or posing a safety hazard does run longer than desirable.

Two other factors also contribute to the repair delays—seasonal underground springs and unpaved surfaces. Much of the ground conditions in the Sierra Nevada foothills include rock and clay, so when it rains during the winter and spring months, seasonal underground springs surface and can be mistaken for pipeline leaks. Chlorine residual testing can be inconclusive at times, causing staff to wait and return before determining if the water is associated with a leak or spring. A large portion of EID's service area is rural in nature with some pipelines traversing cross-country or along unpaved roadways. Wet and muddy conditions can be unsafe for excavation, and repairs have to be delayed until the ground dries sufficiently.

Economic level of leakage. A water utility reaches the economic level of leakage (ELL) when it is no longer cost-effective to recover real losses through additional intervention activities. The water audit determined a range in the ELL for EID by calculating two costs for real losses: (1) the variable production costs of power and chemicals for the treatment and distribution of the water; and (2) the retail value that considers what the water is worth if sold to new or existing customers. For EID, the variable production cost of water was $181 per million gallons during the study year (2003), and the retail value was $968 per mil gal. The audit revealed that EID had already reached its variable production value ELL, and according to this scenario, the status quo could be maintained with no further intervention to reduce real losses. For the retail value ELL, EID could make improvements to reduce system pressures and improve repair times for leaks and breaks. EID decided that for the time being, it would not add construction crews to reduce the repair time for leaks and breaks. Being at the variable production cost, ELL already did not justify the expense, and there were concerns about the reliability of the extracted and assumed data from the work order system.

Advanced pressure management. The audit report contained recommendations for medium- to long-term ELL achievement, which was predominately for EID to have more aggressive pressure control. One focus of Phase Two of Project No. 2928 was to explore the technology that was available to achieve reduced system pressures while not compromising customer satisfaction or fire flow capability. EID pilot-tested flow-modulated pressure control equipment and retrofitted an existing pressure-reducing valve (PRV) into a metering PRV, as shown in Figure D-4.

The flow-modulated pressure controller on the 6-in. PRV reduced the system pressure under low demand conditions, such as nighttime, and then increased pressures for higher demands during the day, therefore maintaining customer satisfaction. A bypass sleeper PRV was also available to meet fire flow requirements. EID did find that the older 8-in. PRV shown in Figure D-4 was slow to respond to a rapid increase and decrease of flow when a water truck filled from a hydrant. This situation caused pressure problems, and it was decided that the sleeper PRV must be capable of responding quickly. Even with the conservative control profiles used to build confidence in the technology, the preliminary results showed that reducing pressures during periods of low demand did reduce system leakage. EID is considering future application of this technology in other high pressure areas, along with policy decisions to lower fixed outlet pressures where possible.

Performance indicators. Performance indicators are tools used for benchmarking performance, measuring baselines and targets, and making comparisons of performance with other utilities. The water audit included the calculation of performance indicators for EID. One performance indicator is the infrastructure leakage index (ILI), which is the ratio of current annual real losses to unavoidable annual real losses. This performance indicator allows a mostly rural and low density utility like EID to be compared with mostly urban and high density utilities on an equal playing field. One explanation of what an ILI number means is to consider a reasonable range of

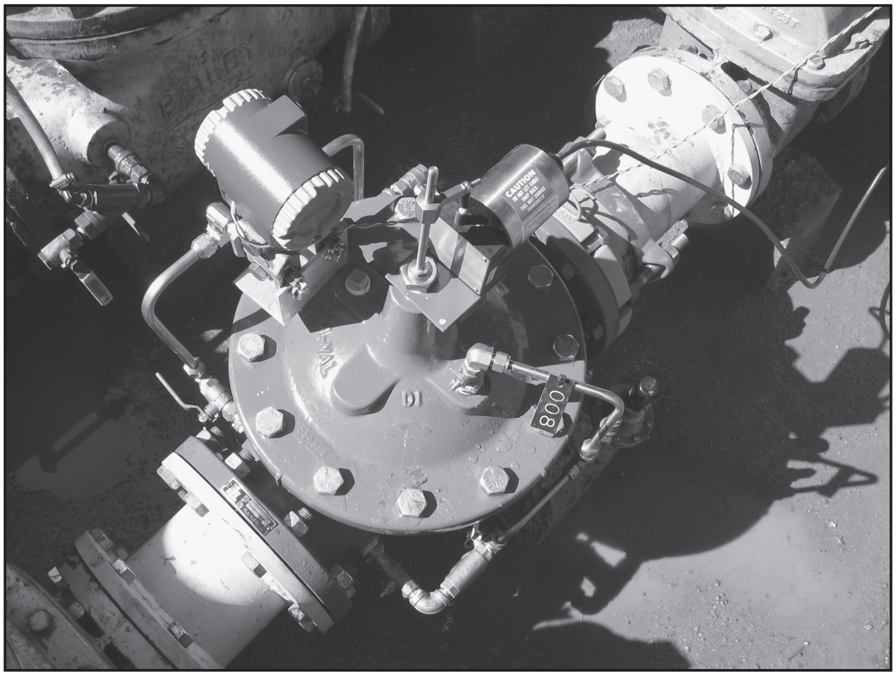

Figure D-4 Installation of advanced pressure controller and flowmeter (Courtesy of Reinhard Sturm)

factors influencing the target ILI of a utility. For example, a water system targeting an ILI of 1.0 would indicate that water resources are limited, treatment and delivery are costly, and the utility maintains leakage at the unavoidable leakage level. On the other hand, a water system allowing an ILI of 8.0 indicates that significant leakage is occurring, but may reflect that water resources are plentiful with treatment and delivery costs reasonable. For many water utilities, however, an ILI of 1.0 might not be economically justified. For EID, an ILI of 1.0 would be a desirable target because the water resources are limited, although this target is not necessarily cost-effective and therefore not economically justified.

According to the IWA/AWWA methodology, the water audit determined that EID had an ILI of 2.3, which falls into the upper 50th percentile when compared against the North American data set in the study (16 utilities). Figure D-5 illustrates EID's placement in this data set. According to the audit report, an ILI of 2.3 shows a very good performance by EID, which can be attributed to reported leaks because of the high average system pressures, ground conditions that cause breaks to surface quickly, and good asset management. EID is certainly proud of its good placement with other North American utilities but, at the same time, can continue to plan for cost-effective interventions that will result in additional water loss reduction.

Other performance indicators include real losses expressed as gallons per service connection per day (gal/serv-conn/d), or gallons per mile of distribution main per day (gal/mi/d). According to IWA recommendations (Op24), if the connection density of a utility is higher than 32 service connections per mile of main, then the gal/serv-conn/d indicator is appropriate. If the density is less than 32, as it is with EID at only 28 service connections per mile of main, then the gal/mi/d performance indicator is more suitable. The lower connection density of EID reflects the rural nature of the service area, and it should be noted that not a single utility in the North American

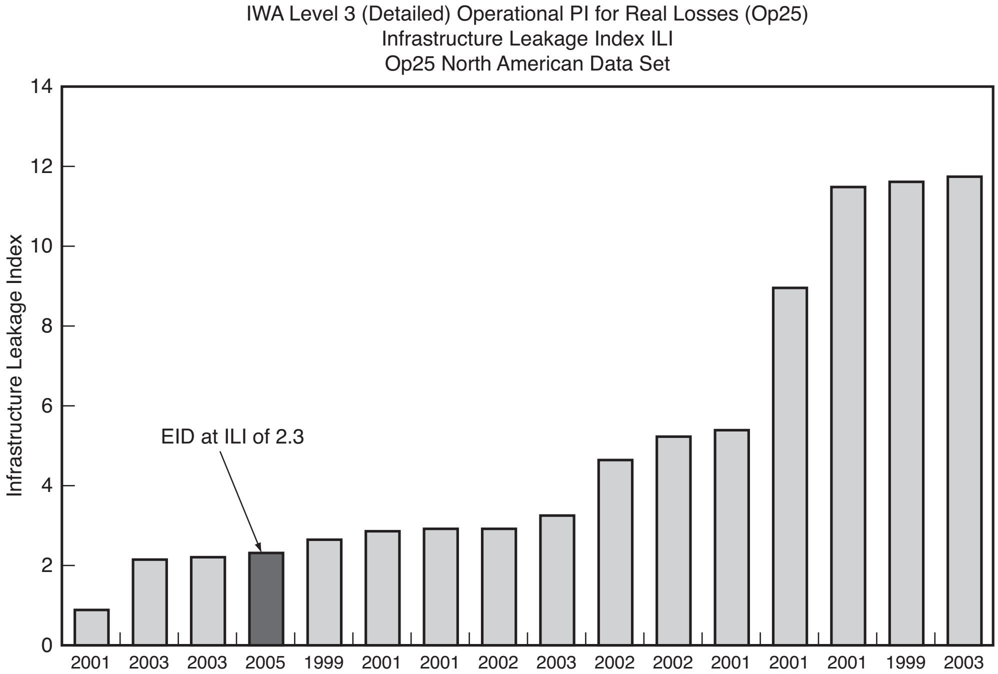

Figure D-5 Infrastructure leakage index comparison for EID (Courtesy of Reinhard Sturm)

data set had a connection density below 32 per mile. This provides a good example of why the ILI is preferred by EID, and why caution should be used when applying and comparing some performance indicators.

Leak detection and intervention technologies. *Leak detection.* The audit determined that it would not be cost-effective for EID to perform additional leak detection surveys beyond the limited scope performed in Phase Two of Project 2928. The analysis revealed that leaks within EID's piped system will usually surface within the same time period as can be found by annual leak detection surveys. The contributing factors for the reported nature of most leaks includes high system pressures, ground conditions that cause leaks and breaks to surface quickly, and good asset management. Limited accessibility to waterlines that traverse cross-country also diminishes the cost effectiveness of leak detection.

There were lessons learned from the field tests that were of interest though, and the leak detection did find two leak/breaks in the study area, a 6-in. main in a remote location and a 1-in. customer service connection pipe. In EID's high pressure system, virtually every water meter installation includes a PRV immediately downstream of the meter. The turbulent flow through these pressure regulators created background interference that sounded very similar to leaks. The pressure-reducing station in the distribution system also caused sound interference that could be heard a mile downstream. Hence, leak detection is more suitable to be conducted during the winter period, where demand is at a minimum and leak sounding conditions are much better.

District metered area. Phase Two of Project 2928 also included the identification and design of a district metered area (DMA) within EID to test other leakage management technology. EID evaluated several DMA possibilities that were each rejected because of the multiple feeds needed to meet fire flow requirements and the additional costs of metering flow into the DMA. An area called North Shingle was eventually selected, which had one feed through an existing pressure-reducing station (Figure D-4). The DMA included 17 miles of waterlines and 444 service connections.

An assessment of nighttime consumption had to first be determined before the minimum night flow analysis could be completed. The DMA was comprised of different land use types, including agriculture, and low-, medium-, and high-density residential parcels. EID took a sampling of meter readings between 12:30 and 1:30 a.m., and then again between 2:30 and 3:30 a.m. for each land use type. These results were then statistically applied to the remaining parcels. After this usage had been determined, the inflow and pressure were measured for the minimum nighttime flow analysis. The effects of the flow-modulated pressure control in the DMA were tracked for several months, and the results showed a reduction in the background real losses of 2,752 gpd within the DMA using the conservative control profiles.

Application of Lessons Learned

Participation in the AwwaRF project exposed EID to a new methodology and the opportunity to field test leak intervention technology. EID found a new synergy in working with other North American utilities that have performed the IWA/AWWA recommended water audit, and like these other utilities, EID has converted out-of-date methods and terminology to the new standards.

As a member of the California Urban Water Conservation Council (CUWCC), EID presented the results of this water audit at the CUWCC's plenary session to expose more California utilities to the new methodology. The CUWCC's Utility Operations Committee is working toward revising their best management practice on water loss control (BMP No. 3), and EID is an active participant in these discussions.

EID also beta tested the AWWA Free Water Audit Software using calendar year 2004 data, and then used the published version for 2005 data. EID found this Excel-based audit software to be an excellent way to organize and analyze the water balance data. EID learned through participation in this AwwaRF project that performing a system-wide water audit can focus attention where it is needed most, making it possible to obtain effective results for the intervention dollars invested in the strategy.

Next Steps for Further Improvements

EID needs to set specific goals for further reduction of losses and to continue with implementation of the recommendations in the final reports. The Board of Directors for EID are expecting further reductions in real losses that would make more water supply available to customers and in reducing apparent losses that would mean recovered revenue. Continuing to reduce these losses will help EID ensure that adequate water supply remains available for new and existing customers until additional water supplies can be realized.

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CASE STUDY C: MEDIUM SYSTEM (HALIFAX REGIONAL WATER COMMISSION, HALIFAX, NOVA SCOTIA, CANADA)

Background

In 1996, the Halifax Regional Water Commission (HRWC) was formed as part of the amalgamation of four municipal units to make up the Halifax Regional Municipality (HRM). The amalgamation brought immediate challenges and opportunities as the utility dealt with the pressing need to construct a new water treatment plant and transmission main in Dartmouth. The $60 million project was completed in 1998, on time and on budget. With the completion of this project, HRWC embarked on a continuous improvement program under the vision of becoming a world class utility. A priority that emerged for the utility was to reduce aggravated leakage in the distribution system. This was particularly important in the Dartmouth system where losses were in the order of 35 percent and the new plant produced the highest cost water in the region, predominantly because of the requirement to boost the water from the plant. A reduction in leakage would see immediate reduction in plant costs and deferral of capital costs associated with future upgrades to increase plant capacity.

A cross-departmental team was created to determine the best practice for water loss control. The investigation initially focused on North American efforts where the water profession was centered on the reduction of "unaccounted-for water," which was also the traditional approach followed by HRWC. Because this approach had obvious shortcomings, HRWC expanded its search and discovered an emerging methodology being promoted by the Water Loss Task Force of the International Water Association (IWA), which included a representative from the American Water Works Association (AWWA). The IWA/AWWA approach was holistic in nature but required a paradigm shift to implement. It was based on the concept of *accountability*. HRWC put the methodology into action in 1999 and formally adopted it as a best practice in April 2000. HRWC was the first utility in North America to adopt the IWA/AWWA methodology. By March 31, 2006, HRWC had reduced leakage in the Dartmouth system by 16 ML/d (4.22 mgd) with a corresponding plant output reduction from 59 to 43 ML/d (15.58 to 11.35 mgd). In addition, HRWC tackled leakage within the Halifax distribution system and reduced system input by an additional 18 ML/d (4.75 mgd). The total leakage reduction of 34 ML/d (8.97 mgd) represents annual savings of $550,000. In addition to direct savings, the customers of HRWC see increased public health protection (a leaking system has more potential for contamination) and reduced service disruption and property damage as leaks are now found in a proactive manner.

Innovation and Excellence

The IWA/AWWA methodology is all about accountability and an integrated approach to water loss control. The IWA/AWWA standard water balance and corresponding strategies were adopted by HRWC, which required a change in thinking. It started with a ban on the term *unaccounted-for water* and a recognition that the standard water balance had a place for everything and everything in its place (see Figure D-6, which is the same as Figure 2-1).

Four key real loss strategies support the IWA/AWWA methodology: active leakage control, pressure management, speed and quality of repairs, and asset management (see Figure D-7 same as Figure 5-1).

Active leakage control includes leak detection encompassing noise mapping surveys of the system twice a year using acoustic equipment and digital noise correlation to supplement acoustic methods to pinpoint leaks. Leak detection activities are also

<table>
<tr><td rowspan="10">Water From Own Sources (corrected for known errors)</td><td rowspan="11">System Input Volume</td><td>Water Exported</td><td rowspan="5">Authorized Consumption</td><td rowspan="3">Billed Authorized Consumption</td><td>Billed Water Exported</td><td rowspan="3">Revenue Water</td></tr>
<tr><td rowspan="10">Water Supplied</td><td>Billed Metered Consumption</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>Unauthorized Consumption</td></tr>
<tr><td>Customer Metering Inaccuracies</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>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Water Imported</td><td>Leakage on Service Connections Up to Point of Customer Metering</td></tr>
</table>

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

Figure D-6 IWA/AWWA standard water balance

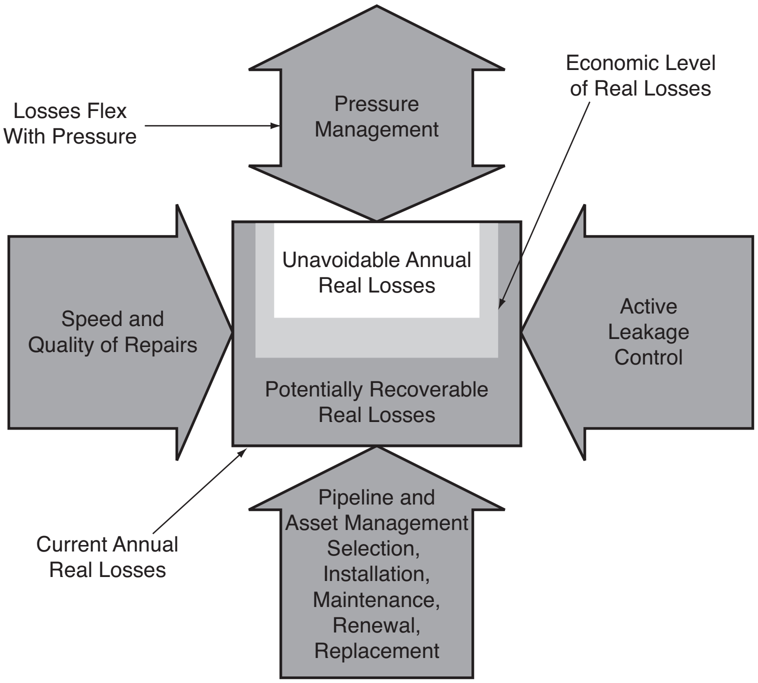


Figure D-7 Real loss control strategies

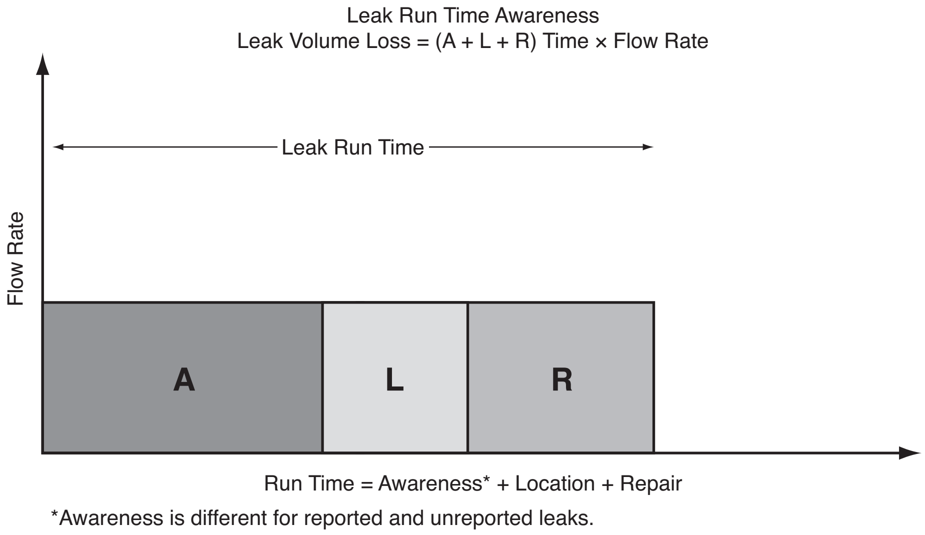


Figure D-8 Component phases of leak occurrences

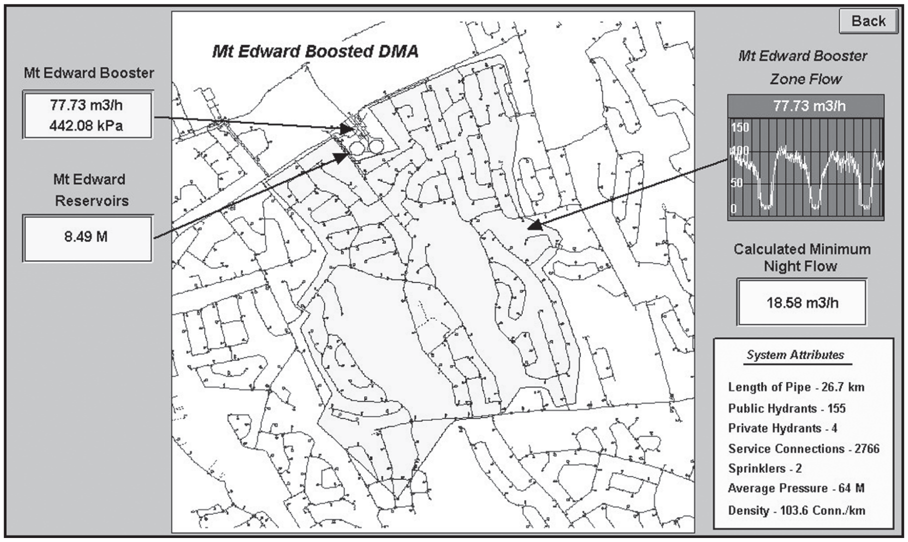
supported by a supervisory control and data acquisition (SCADA) system that is used for flow trend analysis within each district metered area (DMA) of the distribution system. In this manner, leak crews can be sent to zones of the distribution system immediately when trends indicate active leakage.

Pressure management has been actively pursued by HRWC to ensure that pressure within the distribution system is optimized for customer service and kept at levels to minimize leakage. There are clear correlations between pressure and leakage, as identified in the concepts of fixed and variable area discharges paths and component analysis of burst and background leakage estimates. HRWC is also exploring the more mature applications of pressure management whereby the pressure in the distribution system is intentionally reduced in the nighttime when water usage normally drops off with a corresponding pressure and leakage increase. HRWC has had initial success with flow-modulated pressure control as part of the Awwa Research Foundation (AwwaRF) *Leakage Management Technologies* (Project No. 2928).

Speed and quality of repairs are centered on the reduction of leakage run times. Accordingly, speed of repairs in this context does not solely mean the actual repair of the leak itself. There are three components that make up the leakage run time: the awareness time of the leak, the location time for pinpointing, and repair time (see Figure D-8 and also Figure 4-4). In some utilities where leak surveys are only carried out once every two years, the average leak will have been active for one year. Even a small service leak can add up to large loss volumes over a one-year period.

Asset management is more of a long-term strategy but an important one. Funds should be set aside to replace or rehabilitate aging and leak-prone mains on a regular basis. The HRWC has a proactive main renewal program with funding through dedicated depreciation reserves and capital from operating revenue. The establishment of depreciation as an operating expense is by itself being recognized as a best practice and in all likelihood will be incorporated with the implementation of Bill 175 in Ontario. In addition to pipes, another important asset to install and maintain is meters. HRWC has universal metering for monitoring customer consumption and a fleet of master meters within the DMAs of the distribution system.

All of these strategies make up a holistic approach to water loss reduction, but it is worthy to comment on the importance of DMAs and SCADA. The HRWC has over



Mt Edward Booster
77.73 m3/h
442.08 kPa

Mt Edward Reservoirs
8.49 M

Mt Edward Booster Zone Flow
77.73 m3/h

Calculated Minimum Night Flow
18.58 m3/h

System Attributes

Length of Pipe - 26.7 km
Public Hydrants - 155
Private Hydrants - 4
Service Connections - 2766
Sprinklers - 2
Average Pressure - 64 M
Density - 103.6 Conn./km

Figure D-9 Mount Edward DMA, Dartmouth, Nova Scotia

65 DMAs and a robust SCADA system. These tools are used in tandem for night flow analysis for leakage assessment and to determine best achievable benchmarks in system flows. A typical DMA incorporates a zone in the distribution system with a maximum pipe length of 30 km (18.6 mi) or approximately 2,500 customer connections (see Figure D-9). Some zones can be smaller if there is a discreet elevation boundary or the zone is boosted. If DMAs are not established, finding a leak is like finding a needle in a haystack. The basic purpose of the DMA establishment is to break up the haystack into smaller ones and use the SCADA system to indicate which one has the needle.

Night flow analysis is important to determine how “low you can go” with a bottom-up approach. With night flow input information from SCADA, HRWC can compare it to actual usage. HRWC staff calculate the nighttime consumption of residential customers, measure the exceptional commercial/industry consumption, and estimate the remaining background and active leakage in the system. Efforts can then be zeroed in on zones where active leakage intervention will give the biggest return, that is, “bang for the buck.” The utility’s investment in leakage control can be measured in terms of recaptured water and corresponding value of the water. This economic assessment should influence a utility’s decision to either increase or reduce leak detection activities in a particular zone of the distribution system.

In accordance with the IWA/AWWA methodology, the overall assessment to measure performance is the infrastructure leakage index (ILI). The ILI is the ratio of real system losses to the unavoidable annual real losses (UARLs). Real losses are derived from the IWA/AWWA standard water balance, a calculated volume, and UARL are derived from an established empirical database. UARL are related to the length of piping in the public system, the density of service connections, and normal system operating pressure. It is logical that a system with higher service connection densities and higher water pressure are assigned higher UARL values. The benefit of using the ILI as a performance indicator is that utilities can compare themselves against any other utility in the world (see Figure D-10). The old way of comparison based on “unaccounted-for water” was inconsistent and subjective without a standard approach and terminology. A new way has emerged. In 2003, AWWA and the Canadian National Research Council InfraGuide recognized the IWA/AWWA methodology as best practice, three years after it was formally adopted by HRWC.

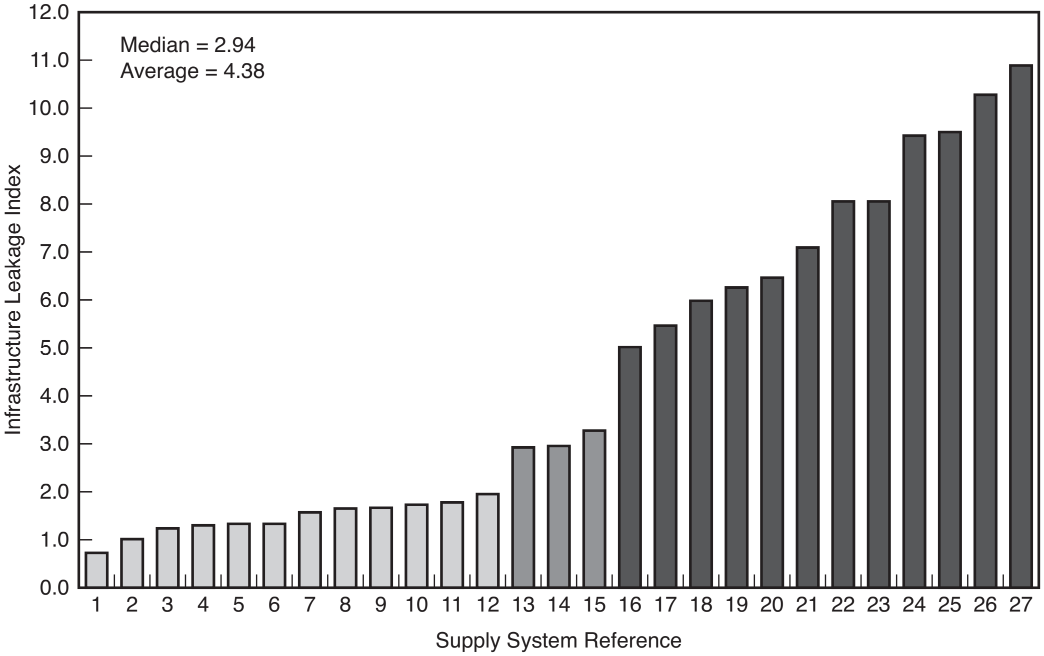


Figure D-10 ILI worldwide comparison (Courtesy of Ronnie McKenzie [IWDC Ltd.])

Implementation, Results, and Lessons Learned

Adoption of the IWA/AWWA methodology for water loss control was carried out with HRWC's vision of becoming a world class utility. To start the initiative, a steering committee was formed with representation from all departments, namely, distribution system operations, engineering, plant operations, finance, and customer service. Interdepartmental cooperation can sometimes be a double-edged sword, and many initiatives are stalled because of the extra coordination required. When cross-department initiatives go well, however, they can produce breakthrough results. Such is the case with the water accountability venture put forward by HRWC.

With the operations department playing a leadership role and the support of senior management, staff conducted an international search to find the best practice for water loss control. This search took them to water professionals working with the Water Loss Task Force of the IWA. The Water Loss Task Force was given a mandate to develop a world class methodology and strategies for leakage reduction. In 2000, the task force completed the project with the standard water balance and strategies as currently known.

In 1999, HRWC hired an international expert associated with the IWA/AWWA methodology development to ensure that staff understood the loss reduction strategies and documentation of inputs to the standard water balance. More than 50 employees of HRWC were exposed to the methodology with operations staff receiving advanced training with a standing order for annual workshops to keep abreast of leading edge applications. The engineering department played a strong supporting role to operations with the development of drawings for regular noise mapping of the distribution system. In addition, engineering used the corporate geographic information system to assist with DMA design. Several areas of the distribution system were transformed to incorporate DMA principles.

HRWC Regions Results	ILI 1997/98	ILI 1999/00*	ILI 2000/01	ILI 2001/02	ILI 2002/03	ILI 2003/04	ILI 2004/05	ILI 2005/06
Central	n/a	1.6	1.2	1.0	1.0	1.5	1.1	0.7
East	n/a	4.4	4.5	2.9	3.1	2.4	2.4	2.0
West	n/a	11.7	11.7	11.5	9.2	7.3	6.9	5.2
Corporate	9.0	6.4	6.3	5.5	4.7	4.0	3.8	2.8

*Formal adoption of IWA/AWWA methodology.

Figure D-11 Regional ILI performance results

The meter department associated with finance and customer service carried out a thorough review of large meters to maximize revenue potential and eliminate any unauthorized consumption otherwise known as *apparent losses*. This review extended to waterfront properties where additional unauthorized usage was curtailed.

As part of this initiative, it became apparent that for public health, security, and accountability, withdrawals from fire hydrants for other than fire safety or water distribution system maintenance would no longer be permitted. Accordingly, the engineering department coordinated the design and construction of automated bulk fill stations for water haulers and contractors. The stations were well received by commercial users and the general public, with a special water rate approved by the Nova Scotia Utility and Review Board after a full public review process.

HRWC also embarked on an exciting project to monitor flows to large customers in real time through the SCADA system in support of water loss strategies. This was a mutually beneficial installation as the customer knows when they have aggravated leakage on their internal plumbing system, and HRWC does not send crews out to look for false leaks in the distribution system. HRWC notifies the customer of large increases in flow, and the customer hires a work crew to find and fix the leak if one is identified.

The success of the water accountability program is well documented. The performance of the program is measured by the reduction in ILI, which fell from 9.0 in 1998 to 2.8 as of March 31, 2006 (see Figure D-11). The ILI is reported on a quarterly basis as a rolling annual measurement. The total real losses recovered by HRWC amount to 34 ML/day, which represents annual savings of $550,000. System inputs have been reduced from 168 to 134 ML/day with the adoption of leakage control strategies promoted by IWA/AWWA.

Although it is recognized that an ILI of 1.0 is attainable from a theoretical viewpoint, many utilities have challenged themselves to demonstrate economic viability. In other words, a utility should not spend more than a dollar to save a dollar. HRWC is no different, but it is interesting to note that HRWC is pushing the envelope with a reported ILI of <1 in one of its operating regions (see Figure D-11). This seemingly "lower than achievable" ILI value is not the result of poor data on the behalf of HRWC, as the instrumentation and SCADA system is highly robust. Instead, HRWC has advanced its leakage control to such a level in one region of its service area that it may be challenging the allowances that were set forth in the development of the calculations for UARL and ILI as defined in Table 2-20 and discussed under Task 10 in Chapter 2. It may indeed be that HRWC has achieved results better than those determined to be best achievable by the IWA Water Loss Task Force when they developed the UARL calculation in the late 1990s. If HRWC and several other efficient water utilities are able to repeat such performance under a variety of water utility conditions, this may serve as justification to lower some of the values in Table 2-20, thereby recalibrating the level of the UARL calculation. In this regard, HRWC is serving as a field laboratory to better validate the leakage performance indicators. Repeatability must be proven, however, before such a recalibration is ventured because results for one year represent a snapshot in time, and minor fluctuation in the ILI value can be expected from year to year because of weather and other short-term variables.

As a result of its leakage management success, HRWC was requested to participate in the AwwaRF research project *Evaluating Water Loss and Planning Loss Reduction Strategies* (Project No. 2811), which included an assessment of economic levels of leakage using the IWA/AWWA methodology.

In addition to direct economic benefits associated with leakage reduction in the distribution system, other direct and indirect benefits are realized. A reduction in system inputs allows for the deferral of capital investment if plant capacity needs to be increased to match future demand. Because the production and distribution of drinking water is energy intensive, other indirect benefits include reduction of greenhouse gases. When it comes to promoting water conservation, it is also easier to get buy-in from customers to reduce consumption if a utility can demonstrate it is doing everything that it can to reduce wastage.

There are also good service and social reasons to reduce water leakage proactively. Because the vast majority of leaks are found proactively using the IWA/AWWA methodology, they can be repaired under controlled conditions to minimize service disruption and property damage to adjacent properties. Adoption of the IWA/AWWA methodology can also help minimize the liability of the water utility from damage claims as it demonstrates a commitment to best practice in water loss control.

Last but not least, it should be recognized that water utilities are in the public health protection business. A distribution system with aggravated leakage is much more prone to contamination, in recognition that water and sewer pipes often share a common trench.

Project Sustainability and Policy Framework

The water accountability program of HRWC directly supports its strategic plan and the sustainability goals of its parent organization, HRM. HRWC has utilized a balanced corporate scorecard to measure the performance of its strategic plan, which places an emphasis on stewardship of the environment and infrastructure. One of the key scorecard performance indicators to measure success and establish objectives is the ILI, which is the key benchmark associated with the IWA/AWWA methodology.

HRM has established sustainability goals with the development of its own corporate scorecard. One of the themes of HRM's scorecard is preservation of the environment with ties to the HRWC scorecard through the ILI measurement. The adoption of the IWA methodology by HRWC also directly supports HRM's objective to reduce greenhouse gases because reduced water system inputs mean there are less chemicals and energy used at water treatment plants.

Reducing leakage in the distribution system is like doing the laundry; it is never done. In this regard, HRWC is committed to the IWA/AWWA methodology for the long term and expects to make further inroads in water loss reduction. The goal of HRWC is to at least get to its economic level of leakage, which correlates to an ILI of approximately 2.5. This represents a further leakage reduction of 1.5 ML/day within the distribution network.

The IWA/AWWA methodology for water loss reduction is expected to continue indefinitely at HRWC because all departments have bought in and breakthrough results have already been attained. These breakthrough results reflect an integrated approach to a significant problem and have strengthened interdepartmental relationships. The holistic approach of the IWA/AWWA methodology to water loss reduction is like the multiple-barrier approach to maintain water quality, which is also paramount to HRWC.

The commission has received national and international recognition for its water accountability. HRWC is believed to be the first water utility in North America to adopt the IWA/AWWA methodology as a best practice. In June 2005, HRWC was awarded the Sustainable Community Award in the water category through the Federation of Canadian Municipalities for its approach to water loss control. In September 2005, HRWC hosted the IWA Leakage 2005 conference.

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CASE STUDY D: LARGE SYSTEM (PHILADELPHIA WATER DEPARTMENT AND WATER REVENUE BUREAU, PHILADELPHIA, PENNSYLVANIA)

Philadelphia's Water Supply: A History of Firsts

The City of Philadelphia has been a leader in water supply technology in the United States for more than 200 years. By 1822, a dam and water-driven turbines were incorporated into the Fairmount Water Works, which was widely recognized as both an engineering marvel and a place of architectural splendor. The distribution piping of this early system consisted of bored wooden logs joined by iron bands and caulking. The city's first water loss problem was realized as these pipes leaked badly. Philadelphia began to import British-made cast-iron pipe to expand its water distribution system. The longevity of iron pipes—in use in Europe for hundreds of years—has been confirmed in Philadelphia, where several thousand feet of pipe segments installed in the 1820s still provide reliable service.

Philadelphia continued to demonstrate innovation by becoming one of the first large cities in the United States to construct water filtration plants between 1903 and 1911. More recently, the city installed the largest water utility automatic meter reading (AMR) system in the United States, with more than 400,000 residential units outfitted between 1997 and 1999. At the start of the new millennium, Philadelphia continued its tradition of firsts, by becoming the first water utility in the United States to initiate use of the progressive water loss management methods and technology developed internationally during the 1990s.

Despite some early water conservation efforts, the city has not historically operated with a high level of water efficiency. With relatively abundant and inexpensive water resources, Philadelphia's primary water supply goal was to provide a safe, sufficient supply of water for customer consumption and fire protection, and the city has met this goal for over two centuries.

Philadelphia began to scrutinize its water loss status in 1980 when an Unaccounted-for Water Committee undertook a comprehensive study to identify

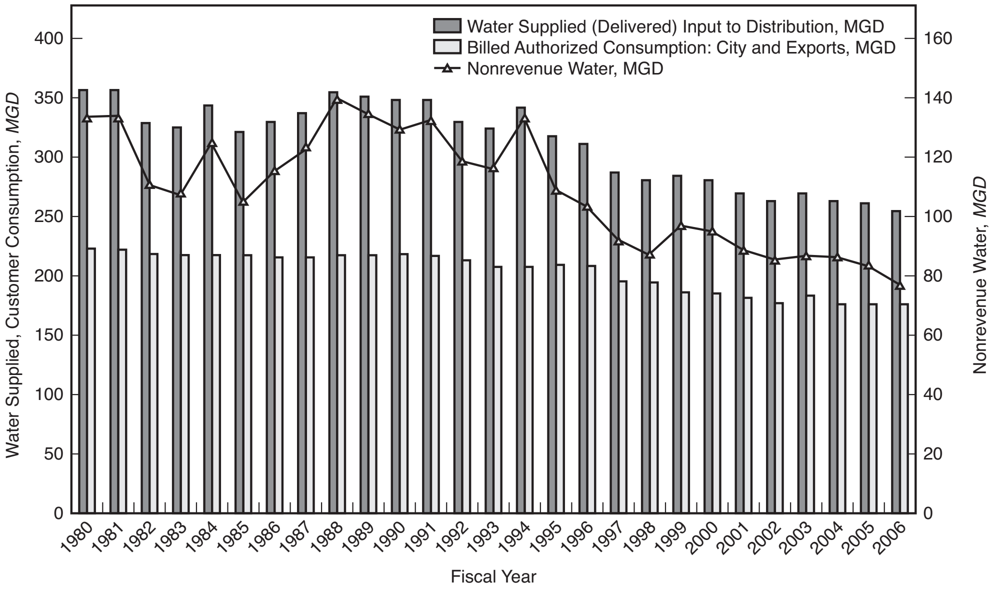

Figure D-12 Philadelphia's water supply/demand trend (Courtesy of Philadelphia Water Department)

sources of lost water and propose loss reduction actions. Improvements, including master meter calibration, leak detection crews, and meter replacement, soon followed. Still, quantities now defined as nonrevenue water (NRW) remained well above 100 mil gal/day (mgd) in the decade following this work. Water loss came under scrutiny in 1993 after a proposed 30 percent water rate increase was rebuked, and a series of single-digit increases totalling 7 percent was implemented. A standing Water Accountability Committee was created to pursue sustained water loss reductions. Expansion of the main replacement and leak detection programs and a switch from quarterly to monthly billing were implemented shortly thereafter. Figure D-12 shows a notable decline in NRW after 1994. NRW averaged between 120 and 130 mgd before 1994, but stood at 76.8 mgd for the business year ending June 30, 2006. This success in cutting water loss is attributed to reductions in both real losses (leakage) and apparent losses (customer meter inaccuracy, unauthorized consumption, and systematic data handling error). Real losses have been reduced by a combination of stepped-up leak detection effort, improved leak repair job routing, piloting district metered areas (DMAs), and pipeline replacement. Cuts in apparent losses occurred from residential meter replacement (installed with AMR), large meter right-sizing, billing error corrections, thwarted unauthorized consumption, and creation of billing accounts for city-owned properties. While these improvements are significant, city managers recognize that the current level of NRW remains excessive and reduction efforts should continue.

In Search of Best Management Practices for Water Loss Control

During the 1990s, Philadelphia's Water Accountability Committee began participation on AWWA's Water Loss Control (formerly Leak Detection & Water Accountability) Committee. Initially, Philadelphia developed a water audit based on the first edition of the AWWA Manual M36, *Water Audits and Leak Detection*. To stay abreast of current developments, Philadelphia became the first American water utility to employ the water audit method developed by the Water Loss Task Force, the five-country committee formed by the International Water Association (IWA). The task force included AWWA participation that represented North America.

By converting its water audit to this best practice in 2000, the city was able to use the robust performance indicators included in this method. Its initial infrastructure leakage index (ILI)—the ratio of current leakage to the unavoidable annual real losses (UARL) measure—was calculated at 12.3, meaning the city's leakage stood at 12.3 times the technically achievable low level. This level benchmarked high among a data set of international utilities, but it was viewed as realistic for an older United States city that was just starting to embark on a progressive leakage management program. With water relatively available and inexpensive, Philadelphia does not have an economic justification to attain technically very low leakage levels or an ILI close to 1.0. It should, however, seek to determine an appropriate economic leakage target that is based on the city's direct and indirect costs of water. While an economic assessment of leakage has not yet been carried out, Philadelphia targets the guideline published in the 2003 Water Loss Control Committee report *Applying Worldwide Best Management Practices in Water Loss Control* that suggest an ILI of 8.0 as a maximum allowable level. In following this guideline, the city should seek an additional reduction of 4,138 million gallons per year (11.3 mgd), reducing its 2006 level of 21,619.5 mil gal (59.2 mgd) to 17,481.6 mil gal (47.9 mgd). Six years into focused leakage reduction, Philadelphia has good potential to achieve leakage reduction commensurate to an ILI of 8.0 within the next 5–8 years. By the fiscal year ending June 30, 2006, Philadelphia had reduced its ILI to 9.9, which indicates considerable improvement from its initial water audit in 2000. The city's water audit report summary for the year ending June 30, 2006, is given in Table D-1.

Managing Real Losses: The Leakage Management Assessment Project and Beyond

While establishing an annual water audit as a routine business practice, Philadelphia also contracted with international leakage experts in 2000 to conduct the Leakage Management Assessment (LMA) project, which evaluated the city's leakage standing and control practices. Consultant services funded at roughly $60,000 were utilized as part of this effort.

A comprehensive assessment of Philadelphia's active leakage control practices was conducted as part of the LMA. General conclusions recommended that Philadelphia improve its leak repair activities by better work order management that emphasizes timely reporting and repair execution. Refinements to its leak survey scheduling were also suggested along with considerations to refine its capital planning for water main rehabilitation by adding investigation of trenchless technologies in addition to full trench replacement of pipelines.

Moderate potential was found to exist to control water pressure to prevent surge-driven ruptures and to reduce background leakage, that is, weeps at pipe joints. An important policy recommendation was also forwarded to reassess Philadelphia's regulations that require customers to bear full responsibility to arrange repairs of leaks found on their customer service connection piping. The worldwide practice of customer-arranged leak repairs has been found to be inefficient as many customers are slow to implement repairs, resulting in long leak run times and mounting losses. While most US water utilities require their customers to implement leak repairs on a portion of their customer service connection piping, Philadelphia requires that customers hold the responsibility for the entire customer service connection pipe from the water main to the serviced premises. Philadelphia is investigating potential changes in policies and programs to improve the response to customer service connection piping leaks.

Table D-1 City of Philadelphia annual water audit summary for the fiscal year ending June 30, 2006

Water Supplied	Water Volume, MG	Volume per day, mgd	Costs
System Input	92,931.5	254.6	
Minus Correction for Master Meter and Data Handling Error	294.2	0.8	
Corrected System Input	92,637.3	253.8	
Minus Exports	6,971.5	19.1	
Water Supplied (City only)	85,665.8	234.7	
Authorized Water Consumption			
Billed Metered	57,633.5	157.9	
Billed Unmetered	0	0	
Unbilled Metered	0.3	0.0	$1,176
Unbilled Unmetered	892.5	2.4	$191,084
Authorized Consumption Total	58,526.3	160.3	$192,260
Water Losses			
Apparent Losses:	27,139.5	74.4	
Customer Meter Inaccuracy	114.6	0.3	$520,206
Unauthorized Consumption	1,579.0	4.3	$3,139,437
Systematic Data Handling Error	3,826.4	10.5	$16,616,968
Apparent Loss Total	5,520.0	15.1	$20,276,611
Real Losses:			
Operator error/ Overflows	0	0	$0
Reported and Unreported leakage			
Transmission mains leaks	5.7	0	$916
Distribution mains leaks	927.5	2.6	$148,850
Customer service leaks	9,003.5	24.7	$1,444,858
Hydrant and valve leaks	474.0	1.3	$76,065
Measured leakage in DMAs	1,094.3	3.0	$175,606
Background leakage	10,114.5	27.7	$1,623,154
Leakage liability costs			$759,198
Real Losses Total	21,619.5	59.3	$4,228,646
Water Losses Total	27,139.5	74.4	$24,505,257

	Fiscal Year 2006 Financial Data
$4,791	Apparent Losses per mil gal—Small Meter Accounts (⅝ in. and ¾ in.)
$4,143	Apparent Losses per mil gal—Large Meter Accounts (1 in. and larger)
$4,070	Apparent Losses per mil gal for City Property Accounts
$4,500	Apparent Losses—Overall Average Customer Rate
$160.48	Real Losses—Variable Cost per mil gal
$759,198	Real Loss Indemnity costs—added to total of Real Losses
$190,162,000	Water Supply Operating Costs for Fiscal Year 2006
	Fiscal Year 2006 Customer Account Data
13,137	Number of Large Meter Accounts, 1-in. and greater
458,043	Number of Small Meter Accounts, ⅝ and ¾ in. (includes some large)
	Performance Indicators
76.8	Nonrevenue Water, mgd (2.4 + 15.1 + 59.3)
32.7%	Percent Nonrevenue Water by Volume (76.8/234.7)
$24,697,517	Nonrevenue Water Cost ($1,176 + $191,084 + $20,276,611 + $4,228,646)
13.0%	Percent Nonrevenue Water by Cost ($24,697,517 / $190,162,000)
27.4	Apparent Losses Normalized, gallons/service connection/day
107.3	Real Losses Normalized, gallons/service connection/day
6.0	Unavoidable Annual Real Losses (UARL), Mgd—calculation that includes allowances for leakage on various system components. This is a system-specific caclulation and includes key Philadelphia parameters: Average pressure = 55 psi, miles of water mains = 3,014, Total service connections and fire hydrants = 551,959, and average service distance from curb stop to customer water meter is taken as 12 feet
9.9	Infrastructure Leakage Index—Ratio of Real Losses over UARL = 59.3/6.0 (dimensionless)
	The breakdown among leakage categories is approximate and based largely on estimates rather than measured night flows in DMAs.

The LMA also included analysis of data from four pilot DMAs using the bursts and background estimates (BABE) leakage modeling concept. These four areas were selected to investigate a variety of conditions including different levels of water pressure, leakage histories, demographics, and infrastructure age. The DMAs were created by closing pipeline valves to surround a single supply main servicing a discrete area of approximately one thousand properties. Twenty-four-hour flow measurements were obtained using an insertion metering device on the sole supply main. One of the four test areas—DMA4—displayed a consistently high flow rate even during minimum night hours, suggesting high leakage. The initial BABE analysis estimated that 54 equivalent service connection piping leaks (ESCLs) existed in this DMA. Several leak surveys and sewer examinations were conducted but found insufficient leaks to account for the high nightglow. In 2003, a review of customer consumption data found a number of high consumption accounts in this largely residential area. The city then arranged with its AMR provider to obtain—on a single night—two meter readings for most of the active accounts in the DMA, one reading taken at 2:00 a.m. and another at 4:00 a.m. A number of properties gave constant high consumption through the minimum night hours, suggesting leakage on building plumbing. These findings are significant in that they confirmed that much of the high nightglow occurring in DMA4 goes into customer properties rather than out of water distribution piping as leakage. In applying the AMR night readings to the BABE model, only 11.5 ESCLs were believed to exist in the DMA, compared to the initial assessment indicating 54. The integrated use of DMA and AMR technology is providing outstanding capability to accurately identify where wasteful water flow trends are occurring in the city.

Philadelphia has stepped up its pursuit of leakage reductions by participating in the *Leakage Management Technologies* project administered by the Awwa Research Foundation (Project 2928). According to the objectives of the project, the Philadelphia Water Department (PWD) constructed its first permanent DMA by confining a small zone of the distribution system and installing permanent flowmeter and two pressure-reducing valves (PRVs). The PRVs are used to demonstrate advanced pressure management. The area selected by the PWD is one of relatively high pressure (over 100 psi) with a strong potential for background leakage control via nighttime pressure reduction. Nighttime AMR readings were gathered in this DMA to measure customer consumption and water quality sampling has been routinely conducted to verify that the closed valves and specific flow pattern of the DMA do not create adverse water quality effects. By employing a DMA, leakage was reduced by over 365 mil gal annually (1 mgd), and the payback for the design and installation of the DMA equipment was determined to be just over 5 years. This project successfully demonstrated the use of DMAs, pressure management, and other effective international leakage management techniques in a number of North American water utilities. Its findings should help convince other water utilities to implement advanced leakage control methods to reduce wasteful leakage in their water distribution systems. Philadelphia will continue to apply successful leakage management policies and methods that have potential for significant, sustainable leakage reductions in its water distribution system.

Addressing Apparent Losses

Philadelphia's fiscal year 2006 water audit indicates that the city's real losses of 21,619.5 mil gal (59.3 mgd) are almost four times its apparent losses of 5,520 mil gal (15.1 mgd) on a volume basis. Conversely, apparent losses ($20 million) exert a much greater annual financial impact than real losses ($4 million). This stark difference occurs because apparent losses are valued at the retail cost charged to customers, which is much higher than the variable cost of production used to value real losses. Because apparent losses represent service rendered without revenue recovered, these losses are highly cost-effective to recover.

Prior to 1997, Philadelphia was greatly hampered in reliably assessing its apparent losses. Although its customer population is fully metered, poor access to meter readings resulted in an average of only one out of every seven water bills issued being based on an actual customer meter reading. While compromising the accuracy of customer water consumption data, large numbers of estimated water bills also resulted in frequent billing adjustments and a high call volume of customer billing complaints. From 1997–1999, Philadelphia successfully installed the largest water utility AMR system in the United States with over 400,000 properties read remotely via radio transmission by vans patrolling set meter reading routes. With a primary intention of improving customer satisfaction with the billing process, AMR is also assisting water loss reduction. During its first 10 years of operation, Philadelphia's AMR system has greatly improved the integrity of customer consumption data because relatively few estimates exist and accurate monthly customer meter readings are the norm.

Forthcoming improvements in the city's billing software will allow closer tracking of consumption and billing trends. Directly assisting water loss reduction, the AMR system includes tamper-detection capabilities to thwart unauthorized consumption. While employing AMR, the city reorganized its metering and meter reading groups because manual meter reading was no longer necessary. A *revenue protection* mission was added to the metering group, which now focuses on customer account investigations as well as meter replacement and repair. With most of the customer population having new water meters, attention is directed at a notable number of suspect accounts. Such accounts include hard-to-install holdouts from the initial AMR installation as well as the city's *nonbilled* accounts. The latter represent customer accounts that have had billing suspended for one of a variety of administrative reasons. As the number of nonbilled accounts grew without close monitoring over recent years, they came to represent a high potential for apparent loss. Often, many of these accounts remained in nonbilled status even after normal consumption resumed on the account. The city's Revenue Protection Program completed its seventh year of operation on June 30, 2006, at which time its cumulative recoveries totalled over $17 million. In the course of conducting its investigations, Revenue Protection identified a number of gaps in permitting, accounting, and information handling procedures that have since been corrected. The program is also focusing on adding many overlooked municipal buildings to the city's billing roles. The program revealed that up to 12,000 *zero consumption* accounts exist during any month. These accounts record the same meter reading for at least three consecutive months. In almost 2,000 investigations conducted in 2005–2006, 32 percent of these properties were found to be vacant with no water consumption, meaning the meter readings correctly reflect no consumption. However, 22 percent of these accounts incorrectly missed consumption because of malfunction of the meter of meter reading equipment; and a concerning 46 percent were vandalized by tampering. Further effort is needed to stem meter tampering and to thwart unauthorized consumption from fire hydrants, where success has been gained by installing center compression locks on most of its problem fire hydrants.

Reducing apparent losses is attractive because it offers high economic payback. In this way, it creates previously unrealized sources of revenue and allows utilities to delay rate increases by equitably spreading costs among all customers. Additional revenues can also fund real loss control activities, which can lead to further savings. Philadelphia has made considerable headway in reducing apparent losses, but, with an annual estimate of over $20 million of such nonrevenue water still existing, much work remains.

Philadelphia's Water Loss Future

The City of Philadelphia has taken a leadership role with AWWA to raise awareness of water loss in the industry and the need for consistent reporting and loss control structures. Additionally, the city continued its tradition of water supply innovation by becoming the first US water utility to employ the best practice water audit methodology developed by IWA and AWWA and making significant reductions in its nonrevenue water. The city piloted progressive leakage management technologies including the use of a permanent DMA of part of the AwwaRF project *Leakage Management Technologies*. By these and related endeavors, the city remains committed to the efficient management of its valuable water resources to keep water rates affordable for residents and attractive for economic development in southeastern Pennsylvania.

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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. Permanent monitoring can be established by creating district metered areas (DMAs). Leak noise monitors can be deployed to routinely record leak noise in a given area during optimum times for listening. *See* district metered area (DMA), passive leakage control, unreported leaks, rate of rise of unreported leakage, and leak noise monitor.

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 error, plus unauthorized consumption (theft or illegal use of water). Apparent losses represent 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. It also includes water exported across operational boundaries. Authorized consumption can also 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, etc. These may be billed or unbilled, metered or unmetered. *See* water audit and water balance.

average zone point (AZP) – the average pressure point is the location in a zone or area of the water distribution system with typical pressure variation that reflects the average pressure variation across the entire zone. This location is useful for periodic or continuous monitoring of system pressure conditions when designing, or after implementing, a pressure management scheme.

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 sonic 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. *See* system leakage and pressure management.

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 disaggregate leakage from customer consumption. An example of a bottom-up approach for apparent losses is rotating 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 provides highly accurate data to the water audit, greatly improving its effectiveness in gauging water loss standing and planning loss control activities.

break – in most of North America, this term is used to refer 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.

breaks 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 loss calculation.

commercial water consumption – potable water delivered to business customers; typically a higher rate of consumption than residential consumption but less than industrial or agricultural consumption.

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. *See* breaks and background estimates (BABE) model.

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 area of the water distribution system with the lowest pressure caused by topography 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 operator error (storage tank overflows) during the water audit reporting period. The ratio of the CARL to the unavoidable annual real losses (UARL) is the infrastructure leakage index (ILI). *See* infrastructure leakage index (ILI) and unavoidable annual real losses (UARL).

customer meter inaccuracies – customer meter inaccuracies are a major component of apparent losses. Meter inaccuracy can occur as a result of meter wear, improper sizing or installation, aggressive water, and other causes. Well-functioning mechanical meters will wear as volumes of water are passed through them over time, eventually under-registering the flow.

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 – costs associated with the facilities 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 assist 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 discreet 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 hour periods (night flow analysis) is used to segregate estimates of legitimate consumption versus leakage occurring in the DMA. Data from DMAs are used to quantify leakage volumes to enter as real losses in the International Water Association/American Water Works Association water audit.

domestic consumption – water consumption by the general population consumed in dwelling units (residential consumption).

economic level of apparent losses (ELAL) – ELAL is found by determining the level of apparent losses where the sum of the cost of the apparent loss reduction actions (meter changeout, 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 as 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) – ELL is found by determining the level of real (leakage) losses where 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 as 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.

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 to the power of 1.5. As there will be a mixture of fixed and variable area leaks in any distribution system, loss rates vary with pressure 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^{N1} or $L_1/L_0 = (P_1/P_0)^{N1}$

The higher the N1 value, 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 was the foundation for pressure management applications that have been found to be very economical in reducing leakage, particularly background losses, 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 pressure levels. Also known as a *fire flow test*.

hydrant pitot gauge (also known as a *pitot blade*) – 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.

industrial water consumption – water consumed in industrial activities such as power generation, steel manufacturing, pulp and paper processing, and food processing.

infrastructure condition factor (ICF) – ICF is the ratio between the actual level of background leakage in a zone or district metered area and the calculated unavoidable background leakage of a well-maintained system. Several methods exist to quantify the ICF; the more accurate methods require greater effort to calculate.

infrastructure leakage index (ILI) – ILI is 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 level of the UARL, or the theoretical technical low limit of leakage achievable. As a dimensionless indicator, ILI is a leading benchmarking leakage performance indicator used in international performance comparisons. *See also* current annual real losses (CARL) and unavoidable annual real losses (UARL).

leak noise monitor – units measuring sound characteristics of leak noise frequencies that can be deployed strategically in the distribution system. There are two types. 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 to send information.

leakage – water escaping from the pressurized distribution system caused by defects, ruptures, or failures in piping. 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* system leakage and real losses.

leakage management – the collective activities that provide water utilities with the capabilities to economically minimize real leakage losses. Specifically, it includes the capability to detect, quantify, abate, or minimize water distribution system leakage. It also provides insight into the means to prevent new leaks from occurring. Activities include leak surveys, use of district metered areas and nightflow analysis, pressure management, system rehabilitation, and sound repair policies.

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 hour 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 discreet 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 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. Accounting for legitimate night consumption by customers (any residential consumption, 24-hour industrial consumption, nighttime irrigation systems), nightflow analysis segregates legitimate consumption from system leakage. By continuously monitoring discreet zones leakage, trends can be observed and leakage quantities gathered for inclusion in the annual water audit. *See* minimum night flow and minimum hour consumption.

nonrevenue water – those components of system input volume that are not billed and produce no revenue; equal to unbilled authorized consumption plus apparent losses plus real losses.

passive leakage control – a reactive policy and program in which no systematic attempt is made by a water utility to be aware of, to locate, or to repair unreported leaks. With such a policy, only reported leaks and breaks are repaired. *See also* reported leaks, unreported leaks, and rate of rise of unreported leakage.

pressure management – a generally effective method to optimize 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. *See* fixed and variable area discharge path (FAVAD) model and step testing.

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 surveys, at a specified average system pressure. The rate of rise is not necessarily a linear variable as it can change quickly because of seasonal 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 (or kilometer) of mains per day in a year.

real losses – 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 (the largest component by volume for most systems), storage tank overflows, or similar operator error. *See* water audit and water balance.

reported leaks – those leakage 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, or of consumer complaints such as poor pressure or noise in plumbing systems. A break or leak that evidences 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 as 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 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.

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 discernable. 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 step test can be 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 as leakage rates are impacted 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. *See also* fixed and variable area discharge path (FAVAD) model and pressure management.

system input volume (SIV) – 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 own source waters plus water imported or 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 pressurized to provide service to customers; 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 error – specifically defined in the International Water Association/American Water Works Association water audit method, systematic data handling error pertains to customer consumption and billing data error that occurs 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—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.

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 detection 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, although helium gas requires that the main be removed from service and dewatered.

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) – real (leakage) losses in water utilities cannot be totally eliminated. UARL represents the lowest loss technically achievable in a water utility based on its key characteristics. UARL calculation is based on leakage data gathered from well-maintained and well-managed systems. Equations for calculating UARL for individual systems were developed and tested by the International Water Association's Water Loss Task Force 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):

$$\text{UARL (gal)} = (5.41\text{Lm} + 0.15\text{Nc} + 7.5\text{Lc}) \times \text{P}$$

Where:

Lm = length of water mains, mi
Nc = number of service connections
Lc = total length of private pipe, mi
= Nc × average distance from curb stop to customer meter, Lp (see Figures 2-9 through 2-11 to determine Lp)
P = average pressure in the system, psi

The ratio of current annual real losses (CARL) to the UARL is the infrastructure leakage index, which is a powerful leakage benchmarking performance indicator. *See also* current annual real losses (CARL) and infrastructure leakage index (ILI).

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 of current best pressure management technology to address. UBL parameter multiplied by the infrastructure condition factor gives the targeted background leakage (TBL) value, which represents a portion of the potentially recoverable leakage and is needed to set the leakage management strategy. The calculation for UBL is

$$\text{UBL (1,000 gal/day)} = [(0.20 \times \text{Lm}) + (0.008 \times \text{Nc}) + (0.34 \times \text{Lc})] \times (\text{Pav}/70)^{1.5}$$

Where:
Lm = total length of water mains, mi
Nc = number of service connections, main to curb stop
Lc = Nc – Lp,total length of private pipes, curb stop to customer meter, converted to mi
Pav = average system pressure, psi

unreported leaks – these leaks, usually hidden, 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, allows the volume lost from unreported leaks to be managed economically.

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 segregating volumes reaching customers from volumes of loss. Water audits are essential to assess the quantitative efficiency of water utilities and their water resources, operational and financial impacts. Water audits can be performed in top-down fashion (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 table:

System Input Volume (corrected for known errors)	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption (including water exported)	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non-revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Unauthorized Consumption	
			Customer Metering Inaccuracies	
			Data Handling Errors	
		Real Losses	Leakage on Transmission and Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections Up to Point of Customer Metering	

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 loss – the difference of system input volume and authorized consumption. 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. Water losses consist of real losses plus apparent losses. *See* water audit and water balance.

water supplied – the volume of treated and pressurized water input to the retail water distribution system of the water utility. It is equal to the system input volume minus the volume of water exported or sold in bulk to other water utilities during the audit period. *See* water audit and water balance.

water withdrawal – the volume of water drawn or abstracted from a water source such as a well, lake, stream, river, quarry, or other source in a given period of time.

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Note: *f.* indicates figure; *n.* indicates (foot)note; *t.* indicates table.

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