BY AWWA WATER LOSS CONTROL COMMITTEE

COMMITTEE REPORT: Applying worldwide BMPs in water loss control

IN 2000, AN IWA TASK FORCE—WITH AWWA PARTICIPATION—ASSEMBLED A WATER AUDIT METHODOLOGY AS A BEST MANAGEMENT PRACTICE THAT IS APPLICABLE WORLDWIDE FOR TABULATING WATER USE AND LOSS.

For an expanded version of this article, go to e-JOURNAL AWWA at www.awwa.org.

Water resources today are less expensive and more accessible than they ever will be again, according to participants at a recent AWWA conference workshop on water resources. The North American water industry is facing growing challenges in developing new drinking water supplies, and the demands are staggering: source water protection, finished water quality, public health risks, infrastructure needs, competition, drought, customer expectations, limited funding, and, suddenly, security. Water resources management is further challenged as populations continue to grow and shift, often moving to warmer climates that are far removed from available water resources. Climate change, drought, and water shortages seem to be exerting an increasing impact on water supplies, and water is becoming a major factor in smart growth policy. It is a stark reality that the human population continues to grow, but the planet's available water is finite. Because new water resources have become increasingly difficult and costly to develop, it is evident that society must conserve water through efficient use and active loss control if it is to sustain this precious resource.

In recent years, water conservation has seen major advances in research, public education, and development of water-efficient fixtures in the home and the workplace. It is essential that all communities continue to promote effective conservation practices. However, in North America, water conservation tends to focus largely on the end user. In the wider context of demand management, water suppliers also have a duty to manage water responsibly and efficiently. The North American water industry has traditionally operated without consistent standards for water accounting and, not surprisingly, incurs high loss of both its treated water and a portion of the revenue to which it is entitled. It is striking that even during significant drought occurring in many areas of the United States since 2001, little emphasis has been placed on the need to motivate water suppliers to quantify and control their losses. With perhaps hundreds of water utilities billing sales of half or less of the total water they manage, it is essential that industry professionals, regulators, and policymakers begin to place emphasis on sound water accounting and loss control by water suppliers. Water and

TABLE 1 States Survey Project summary of findings*

Issue	Jurisdictions	States n = 43	Other n = 3	Total n = 46
Water loss policy	Ariz., Calif., Conn., Fla., Ga., Hawaii, Ind., Iowa, Kan., Ky., La., Md., Mass., Minn., Mo., N.C., Nev., N.H., N.Y., Ohio, Ore., Pa., R.I., S.C., Tenn., Texas, Utah, Vt., Va., Wash., W. Va., Wis., Wyo., DRBC,† SWFWMD,‡ SJRWMD§	33	3	36
Definition of water loss	Ariz., Calif., Ga., Hawaii, Kan., Md., Mass., Minn., Mo., Ore., Pa., R.I., S.C., Texas, Wis., DRBC, SJRWMD	15	2	17
Accounting and reporting	Ariz., Calif., Ga., Hawaii, Iowa, Kan., Ky., Md., Mass., Minn., Mo., N.Y., Ohio, Ore., Pa., R.I., Texas, W. Va., Wis., Wyo., SWFWMD, SJRWMD	20	2	22
Standards and benchmarks	Ariz., Calif., Ga., Hawaii, Ind., Kan., Ky., La., Md., Mass., Minn., Mo., N.C., Ohio, Ore., Pa., R.I., S.C., Texas, Utah, Wash., W. Va., Wis., DRBC, SWFWMD, SJRWMD	23	3	26
Goals and targets	Ariz., Calif., Fla., Ga., Hawaii, Kan., Ky., Maine, Md., Minn., Mo., N.M., Ohio, Ore., Pa., R.I., Texas, Wis., SWFWMD, SJRWMD	18	2	20
Planning requirements	Ariz., Calif., Conn., Fla., Ga., Hawaii, Iowa, Kan., Md., Mass., Minn., Mo., Nev., N.H., Ore., Pa., R.I., S.C., Texas, Vt., Va., Wash., W. Va., Wis., SWFWMD, SJRWMD, DRBC	24	3	27
Compilation and publication	Ariz., Calif., Hawaii, Kan., Ky., Minn., Pa., R.I., Wis., SWFWMD	9	1	10
Technical assistance	Alaska, Calif., Fla., Ga., Hawaii, Kan., Ky., Maine, Nev., N.D., Ore., Pa., R.I., S.C., Tenn., Texas, Vt., Wis., SWFWMD	18	1	19
Performance incentives	Calif., Ga., Hawaii, Ind., Iowa, La., Minn., N.C., R.I., Texas, Vt., SJRWMD	11	1	12
Auditing and enforcement	Ariz., Ga., Hawaii, Kan., Md., Minn., N.H., Ohio, Ore., Pa., S.C., Texas, Wis., SWFWMD, SJRWMD	13	2	15

*Source: Beecher Policy Research Inc., 2002
†DRBC—Delaware River Basin Commission
‡SWFWMD—Southwest Florida Water Management District
§SJRWMD—St. Johns River Water Management District

revenue loss recovery stands among the most promising water resource initiatives in North America. It makes sense to take steps to recover this water and revenue in order to mitigate the effects of drought and water shortages and to do so before developing new water sources and expensive supply infrastructure.

Because of high water loss, many drinking water systems have "untapped" water resources that can be cost-effectively recovered. These untapped resources are

- already treated to prevailing standards and ready for consumer use,
- energized to provide adequate pressure to reach the consumer,
- often sufficient to provide for the future expanding needs of the community, and
- sometimes unintentionally provided free to the consumer because no revenue is recovered.

ARTICLE DESIGNED TO PROVIDE TOOLS

The primary purpose of this article is to provide an AWWA-endorsed set of tools specifically designed to promote reliable water use tracking and to control unnecessary water and revenue loss in drinking water utilities. The article provides a brief description of the nature of losses occurring in water utilities and the traditional difficulties suppliers have encountered in managing this issue. The article also offers an internationally recognized methodology developed through the International Water Association (IWA) with AWWA as a major participant. This methodology is designed specifically for measuring and evaluating both valid water consumption and unnecessary water loss. Successful international approaches to control both water and revenue losses are also given. These methods represent an advancement in technology and policy and are submitted as current best management practices (BMPs) available in the emerging discipline of water loss control.

CURRENT UNDERSTANDING IS A MIX OF CONFUSING PERCENTAGE INDICATORS AND HIGH LOSSES

Historically, the quantitative management of drinking water supplies in North America—and most of the world—has been poorly executed, with only casual "water accounting" and high losses prevailing. Because water loss stresses water and energy resources, increases operating costs, and strips revenue, it is curious that this apparent lapse of effective water resource management has persisted. Water has been taken for granted in many parts of North America because of relatively abundant water resources. Lack of strong public opinion regarding water loss gives water suppliers shelter to allow their water loss status to remain inconspicuous. It is now evident, however, that casual attitudes toward water management threaten sustainability of supplies.

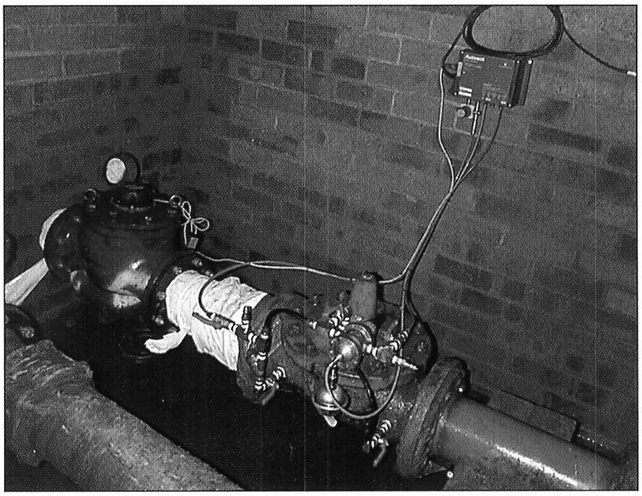


PHOTO: WRP (PTY) LTD.

This metering and pressure control chamber was used in a water loss project in Risidale, South Africa.

Although many think that "water loss" is synonymous with "leakage," the nature by which it occurs is actually threefold (Lambert & Hirner, 2000):

- **Terminology.** There has been a lack of standardized definitions of water and revenue losses.
- **Technical.** Not all water supplied by a water utility reaches the customer.
- **Financial.** Not all of the water that reaches the customer is properly measured or paid for.

The North American water industry has traditionally used the term "water accountability" to refer to its effectiveness in moving its product (water) to its customers. Water accountability, however, has never existed as a well-defined discipline, and a great inconsistency of methods exists among water supply managers and regulators. Often quoted but poorly defined, the "metered water ratio" and similar percentage indicators more frequently confuse rather than inform analysts when they attempt to evaluate the water loss status of suppliers (Kunkel & Beecher, 2001). Similarly, no standard definition has been found for the term "unaccounted-for water," a label whose nonperformance connotation reflects negatively on the water industry. Without reliable auditing methods, the actual scope of water loss remains a mystery. Still, numerous case-study accounts exist in the literature to confirm that water loss is a significant and overlooked occurrence in many water utilities (Buie, 2000; Lipton, 1999; Saltzgaber, 1999; Counts, 1997).

Most water utilities in North America do not regularly compile any type of formal water audit. This is a major shortcoming for the water industry. Often, the systems that do audit their supply merely conduct a simple comparison between water input to the distribution system and the total water consumption billed to customers. This difference, taken over the system input, has been used inconsistently for decades as an "unaccounted-for water percentage," the sole performance indicator of water loss status. The pitfalls of this ill-defined practice include the following:

- No consistent definitions for the various components of consumption or loss have been used throughout the United States. For example, many utilities include some amount of known system leakage (a loss) in an accounted-for category of their water audit, distorting their true water loss standing.
- Worldwide no consistent definition has been found for the term "unaccounted-for" water (Brown et al, 2000).
- Percentage indicators have been found to be suspect in measuring technical performance because the percentages can be skewed by varying levels of end-user consumption. Also, sundry definitions for the numerator and denominator are applied throughout the United States, making reliable performance comparisons impossible.
- Percentage indicators translate nothing about water volumes and costs—the two most important parameters in water loss assessments.

Guidance provided in the past by the AWWA Water Loss Control Committee (formerly the AWWA Leak Detection and Water Accountability Committee) also exhibited shortcomings typical of the times when its last report was published (Liston et al, 1996). This report was valuable in its auditing recommendation that all water consumption and losses should be quantified in terms of volume and cost impact to the supplier. Unfortunately, the report also recommended that "the goal for unaccounted-for water should be less than 10%," despite the fact it simultaneously recommended that "regardless of the water system's size, water loss should be expressed in terms of actual volume, not as a percentage." These conflicting statements reflect the difficulty the committee encountered in steering utilities away from weak practices, while not having adequate performance indicators to replace the traditional "percentage."

States Survey Project sets baseline. In an effort to determine a baseline for the current extent of accounting and loss control policies existing in the United States, the committee proposed a project to AWWA's Technical and Educational Council. The project was funded as a comprehensive survey of state and regional water agencies on their current water consumption and loss reporting requirements for drinking water suppliers. The project,[1] titled Survey of State Agency Water Loss Reporting Practices (Beecher Policy Research Inc., 2002), or the States Survey Project, was conducted in 2001. The survey was successful in garnering valuable

Ten Practices

Covered in the States Survey Project*

1. Water loss policy. Does the state have a policy regarding the loss of water by water utility systems? If so, where is the policy stated (statute, regulation, directive, other)? Which agency or agencies are responsible for implementing the water loss policy?

2. Definition of water loss. Does the state or agency provide a definition of water loss or unaccounted-for water?

3. Accounting and reporting. Does the state or agency provide a method to account for and report water loss?

4. Standards and benchmarks. Does the state or agency identify a standard or benchmark for water losses, such as a specific percentage?

5. Goals and targets. Does the state or agency specify a goal or target for water loss reduction?

6. Planning requirements. Does the state or agency address water loss issues in the context of water resource, conservation, or other planning requirements?

7. Compilation and publication. Does the state or agency compile and/or publish data on water losses by water utility systems?

8. Technical assistance. Does the state or agency provide any form of direct technical assistance to water utility systems to help reduce water losses?

9. Performance incentives. Does the state or agency provide any form of performance incentive for water loss reduction?

10. Auditing and enforcement. Does the state or agency implement any form of auditing or enforcement in relation to the water loss policy?

*Source: Beecher Policy Research Inc., 2002

information from 46 jurisdictions, including 43 state agencies and 3 regional agencies. The survey attempted to seek information regarding 10 practices, as shown in the sidebar on this page.

The reported findings note, "Proper management of any resource must include accurate measurement of the resource throughout its lifecycle. In any proper accounting system, checks and balances must be provided via the use of independent audits, consistent reports, and rational procedures. US water systems do not consistently account for water or apply consistent methods of water accounting." Additionally, the findings state, "Most analysts agree that a better system of accounting is the foundation for a better system of accountability for the drinking water supply industry." Figure 1 shows that state standards, as expressed by varying definitions of "unaccounted-for water percentages," vary from 7.5 to 20%, with some states using different standards set by different agencies. Table 1 gives a summary of findings for all 10 practices and shows that only one state—Hawaii—currently has jurisdictions with programs addressing all areas.

THE WAY FORWARD IS STANDARDIZED WATER ACCOUNTING AND ACTIVE WATER LOSS CONTROL

Without reliable methods to track water use and control loss in North America, the committee sought to gain knowledge of the best practices being used worldwide. Research found that considerable progress to better understand and control leakage losses had been made in the United Kingdom. With the implementation of privatization and a new regulatory structure in the UK water industry in 1989, water companies sought to gain efficiencies and found that leakage losses were a startling inefficiency in their operations. The companies banded together to jointly fund the National Leakage Initiative, a three-year research venture that studied existing leakage management practices and advanced a number of new approaches. The results of this endeavor were published in 1994 in the 10-volume series of reports *Managing Leakage* (WRc, 1994). During severe drought in 1995–96 the UK government regulator, the Office of Water Services, drew upon the findings of the National Leakage Initiative to impose new conditions on the water companies. Being regulated by the results of their own research, however, motivated the UK water industry to establish what is now likely the most advanced national system of water loss control in the world today. According to estimates (Lambert, 2001a), up to 85% of the recoverable leakage initially measured has been eliminated in England and Wales within this structure.

The IWA organized the Task Force on Water Losses in 1996. This international working group was chaired by Allan Lambert, former technical secretary to the UK National Leakage Initiative and chair of the working group that authored two of the *Managing Leakage* reports (WRc, 1994). Timothy G. Brown was the AWWA North American Task Force representative, which also included participants from France, Germany, and Japan. The task force conducted research over a three-year period to develop a well-defined water audit methodology and an array of rational performance indicators for water losses. This method was designed to serve as a recognized standard that could be applied internationally by eliminating the confusion of terms that hindered reliable water tracking in the past. The task force also developed an array of rational performance indicators that allow systems to set targets, measure progress, and conduct reliable performance comparisons with other utilities. This work was published in 2000 in the IWA's *Manual of Best Practice: Performance Indicators for Water Supply Services*. The international water audit method has been tested in more than two dozen countries and serves as the basis for improved national and international performance comparisons in several of them.

A structured approach to reduce both real losses (physical losses) and apparent losses (paper losses) also exists and has proven successful in driving down losses in a number of international settings. The discipline of leakage management—effectively the control of real losses—has developed largely through the experience in the United Kingdom. Although not as advanced, the control of apparent losses has also begun to see a more structured approach. This article provides an overview of these international methods and provides them as the current BMPs in the field of water loss control. It is recommended that they become the standard methods for North American water suppliers to establish reliable water accounting and loss control practices in drinking water supplies.

INTERNATIONAL WATER AUDIT AND PERFORMANCE INDICATORS CREATED

Having a reliable water audit is the foundation of proper resource management for drinking water utilities. Just as banks provide statements of monies flowing into and out of accounts, the water audit displays how quantities of water flow into and out of the distribution system. Yet, as essential and commonplace as the financial balance sheet is to the world of commerce, water audits have been surprisingly uncommon in the water supply arena throughout most of the world (Thornton et al, 2002). In order for suppliers to reliably audit their supplies, a rational auditing method must be available. The international water audit methodology, shown as a chart in Figure 2, meets this requirement. Incorporating routine water auditing will require a long-term effort on the part of regulators to promote new policy into water resources statutes, as well as to see change in the mindset and habits of water utility managers.

All water is accounted for. The international water audit methodology was designed to include several essential features that have been lacking in the patchwork of auditing practices used traditionally throughout the world, including

- rational, standard terms and definitions;
- the tenet that all water is accounted for as either a consumptive use or a loss; thus, no water is classified as "unaccounted for";
- all components of water usage and loss are initially presented in units of volume for the period of reference;
- all components of water usage and loss are assigned an appropriate cost that reflects their impact to the water utility based on the prevailing economics; and
- an array of robust performance indicators that outperform simplistic, poorly defined output/input percentage indicators.

Fundamental to the international methodology is its use of rational terms and definitions. Also, because all water is accounted for, it is advocated that the term "unaccounted for" no longer be used in any manner in the water supply industry. Continued use of this aberration will only hinder efforts to implement true water accountability in drinking water supplies.

Water loss—the volume left after subtracting all authorized billed and unbilled water consumption from the system input volume—exists in two distinct components: real losses and apparent losses. Real losses are the physical loss of water from the distribution system and include leakage and tank overflows. These losses represent a waste of water resources, causing unnecessary infrastructure capacity, inflated production and energy costs, and undue stress on available water resources solely to meet the nonbeneficial demand of (mostly) system leakage. Apparent losses, or the "paper" losses, include customer meter inaccuracy, all manners of billing accounting errors, and unauthorized use, all of which result in lost revenue to the water utility. Apparent losses, reflecting error in the water measurement and documentation process, also compromise the compilation of accurate water usage data. Water usage data from 1995 (USGS, 1998) shows that of 40 bgd (15,145,000 m^3/d) of water withdrawn in the United States by water utilities, only 34 bgd (12,873,000 m^3/d) is documented as end-user consumption. The missing 6 bgd (2,272,000 m^3/d) is categorized simply as "public use/loss," reflecting the US Geological Survey's recognition that unmonitored municipal water use, accounting shortcomings, and leakage inhibit the ability to attain a true balance of withdrawal and use totals. Public use/loss—which is more than enough to meet the water needs of the 10 largest US cities—reflects the huge margin of error that exists in quantifying actual water consumption amounts versus water loss amounts in water utilities. By using a reliable water audit method, the North American water industry can greatly improve the reporting accuracy of valid consumption and losses for its water delivery components.

The financial distinction between real and apparent losses is also important. Real losses are usually valued at the short-term, marginal treatment/production costs or the price to purchase bulk water, whereas apparent losses exert an impact according to the retail sales cost. Because most systems charge more in their retail costs than the production or purchase price of their water, apparent losses are usually more

TABLE 2 City of Philadelphia, Pa., annual water audit in International Water Association format*

Category	Water *mgd (m³/d)*	Cost *$*	Fiscal Year 2002 Financial Data	
Water delivery	261.10 (988,640)		$3,465	Apparent losses per million gallons—small meter accounts (0.63 and 0.5 in. [16 and 13 mm])
Master meter adjusted	–1.900 (–7,194)		$3,035	Apparent losses per million gallons—large meter accounts (1 in. [25 mm] and larger)
Corrected input volume	263.00 (995,834)		$2,988	Apparent losses per million gallons for municipal property accounts
Billed metered	177.60 (672,472)		$3,285	Apparent losses—overall average customer rate
Billed unmetered	0.594 (2,249)		$121.70	Real losses—short-term marginal cost per million gallons
Unbilled metered	0.548 (2,075)	24,342	$295,600	Real loss indemnity costs—added to total real loss cost
Unbilled unmetered	1.935 (7,327)	121,642	Water supply operating costs (fiscal year 2001 data)—$155,060,248	
Total authorized water consumption	180.677 (684,123)			
Water losses†	82.323 (311,711)			

Apparent losses	Water *mgd (m³/d)*	Cost *$*	Real Losses	Water *mgd (m³/d)*	Cost *$*
Customer meter underregistration	0.176 (666)	211,448	Operator error/overflows	0 (0)	0
Bypassed flow to separate fire system	0.100 (379)	4,442	Unavoidable annual real loss	5.299 (20,064)	235,403
Unauthorized consumption	5.087 (19,262)	1,506,610	Recoverable leakage		
SCADA‡ system error	0 (0)	0	Active service lines	15.691 (59,413)	697,002
Customer meter malfunction	0.173 (655)	205,958	Abandoned service lines	17.345 (65,676)	770,456
Meter-reading/estimate error	0.973 (3,684)	1,166,958	Transmission and distribution main leaks	29.098 (110,178)	1,292,550
Accounts lacking proper billing	2.250 (8,519)	2,697,806	Measured leakage in district metered areas	0.358 (1,356)	15,903
Municipal properties	4.000 (15,146)	2,793,181	Main breaks	0.062 (235)	2,754
Billing adjustments	0.375 (1,420)	449,634	Other	1.336 (5,059)	59,361
Apparent loss total	13.134 (49,731)	9,036,038	Real loss total	69.189 (261,981)	3,369,029§
			Water losses total	82.323 (311,711)	12,405,066

*Fiscal year 2002: July 1, 2001–June 30, 2002
†Water losses equal Corrected input volume minus Total authorized water consumption.
‡SCADA—supervisory control and data acquisition
§Real loss total cost includes the sum of Real loss component costs plus Real loss indemnity cost of $295,600

costly than real losses, on a relative basis. Apparent losses occur at the "cash register" of the water utility, given that service is rendered but revenue is not recovered. It is usually appropriate that the costs of real losses include more than just marginal production costs. Particularly when source water is scarce or infrastructure development is contentious, additional environmental, construction, political, or social costs should be built into the real loss cost analysis. For many water systems, significant leakage recovery can extend the capacity of existing supply infrastructure, resulting in infrastructure expansion being deferred well into the future. New concepts, such as the economic level of leakage, or the appropriate level of leakage reduction a given utility should strive to attain based on prevailing economics, have evolved as a result of careful assessment of water loss costs.

Steps in constructing the water audit. The mechanics of compiling a good water audit are twofold—an initial "top-down" approach complemented by gradual "bottom-up" refinements. The top-down approach is largely a desktop exercise, whereby general information from readily available documentation is collected and reviewed to assemble a basic audit. Records that should be collected include water system input, customer billing summaries, leak repair summaries, average pressures, meter accuracy tests, permitted fire hydrant use, and any other records that substantiate how water was used and lost. By its nature, the top-down audit includes the use of a considerable number of estimates for components of water use and loss. While approximate in its reliability, the top-down audit can be assembled quickly and is advisable for water utilities compiling their first water audit. The bottom-up approach involves taking field measurements and conducting investigations and research into the policy and practices of the water utility. Using night-flow analysis to obtain inferred measurements of leakage is an example of using actual field measurements in a bottom-up approach to replace rough estimates about the amount of system leakage used in a top-down water audit. It also serves to confirm any assumptions made regarding the volumes of apparent losses. Researching water utility policy and permit records regarding water use from fire hydrants is another bottom-up example. The bottom-up approach improves the accuracy of the water audit but requires more effort to gather field data and research practices. It is best for water utility managers to incorporate bottom-up methods into the water audit incrementally over time. Within several years a reliable water audit will begin to take shape. Several researchers have started to develop statistical methods to improve the accuracy of the top-down water audit in reflecting actual supply conditions.

A summary of the annual water audit and performance indicators for a recent year for the city of Philadelphia, Pa., is given in Table 2 and the sidebar on page 74. The Philadelphia Water Department and Water Revenue Bureau implemented the international method when it became available in 2000. The major categories of water use and loss shown on the summary sheet are supported in a detailed water audit document. If a water utility has historically conducted a water audit using the method outlined in *Water Audits and Leak Detection* (AWWA, 1999), it is relatively straightforward to reassign the components of this audit into the structure of the international method in a top-down approach.

Performance indicators for water loss control discussed. The international method includes a set of rational, well-defined performance indicators that are superior to the poorly defined output/input percentage often used in North America. The indicators give utilities the tools to set internal goals, as well as to make performance comparisons and to assist water loss benchmarking and accreditation efforts. Table 3 shows performance indicators that are defined in three distinct performance areas: water resources, operational, and financial (Alegre et al, 2000). IWA performance indicators are also distinguished as basic, intermediate, or detailed indicators. For water loss control the IWA methodology includes only basic and detailed indicators.

As shown in Table 3, the performance indicators for water losses, real losses, and apparent losses are merely the normalized version of the amount of water losses, real losses, and apparent losses in the water utility, respectively. The infrastructure leakage index (ILI) is a dimensionless ratio, and the remaining indicators are rationally and specifically defined percentage indicators. The indicator "nonrevenue water by volume" might be the one most closely associated by North American practitioners as the "percentage" so often quoted. This indicator has some value but only as a basic financial indicator. It is not useful for operational purposes because it does not indicate the amount of losses (real and apparent) occurring in the utility. The design of these indicators makes them amenable to use across a variety of system conditions and units of measure, thus allowing reliable performance comparisons and benchmarking. Performance indicator values for Philadelphia are shown in the sidebar on page 74.

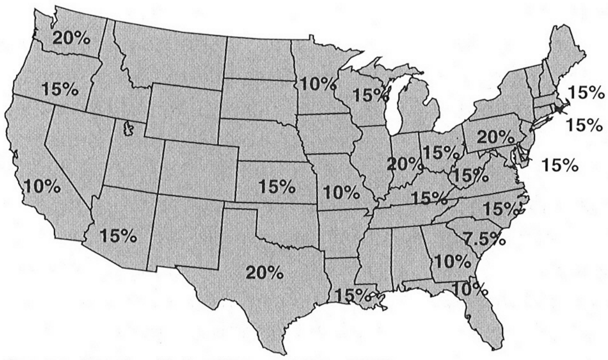
Many North American water utility managers have long held unsubstantiated beliefs that leakage cannot be reliably measured and that a certain (large) portion of system leakage is considered unavoidable or not economically justified to abate. These water loss misconceptions are rapidly giving way to several new realizations of the fast-developing discipline

TABLE 3 IWA* water audit methodology—performance indicators for water loss control†

Point of View	Water Resources	Operational	Financial
Basic, level 1	Inefficiency of use of water resources: real losses as a percentage of system input volume	Water losses: volume/service, connection/year Real losses: volume/service connection/day *x*‡ when the system is pressurized	NRW_V§: volume of nonrevenue water as a percentage of system input volume
Intermediate, level 2			
Detailed, level 3		Apparent losses: volume/service connection/year ILI** (dimensionless); ratio of real losses to UARL††	NRW_C‡‡: value of nonrevenue water as a percentage of the annual cost of running the water system

*IWA—International Water Association
†Source: Alegre, H. et al, 2000. *Manual of Best Practice: Performance Indicators for Water Supply Services.* Published by IWA Publishing, London. www.iwapublishing.com. Used with permission
‡No water loss performance indicators exist for the intermediate point of view *x* in which service connection density is less than 32 per mile of mains; use "per mile of main" instead of "per service connection" for this indicator
§NRW_V—nonrevenue water by volume
**ILI—infrastructure leakage index
††UARL—unavoidable annual real losses
‡‡NRW_C—nonrevenue water by cost

FIGURE 1 Selected quoted standards from the States Survey Project



Source: Beecher Policy Research Inc., 2002
"Standards" are various forms of the inconsistently defined "unaccounted-for" water percentage indicator.

of leakage management, which recognizes the following:

- Leakage levels can be reliably measured using night-flow analysis in discrete zones of the water distribution system known as district metered areas (DMAs).
- Although all systems have a leakage component that is considered unavoidable, the international method features a calculation (Table 4) that is system-specific and gives a much lower level of leakage than amounts derived by dated, rule-of-thumb methods such as the Kuichling equation, which is still used by many North American water utilities.
- Conceptually for any water utility, an appropriate minimal level of leakage exists that is economically justified to seek. Striving to reduce current leakage levels to this "economic level of leakage" makes sense for most water utilities.

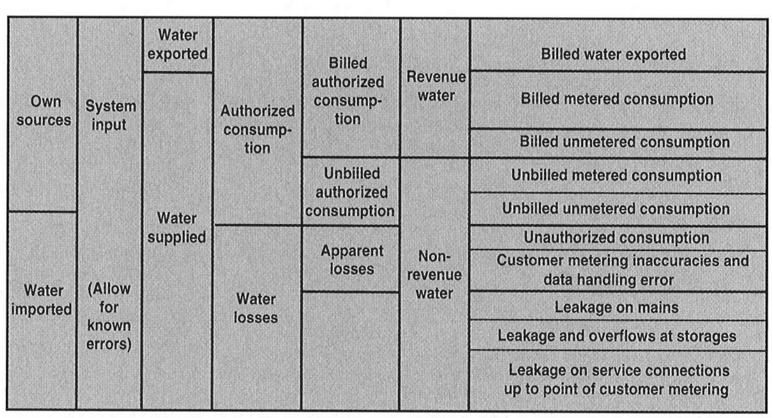
In applying the international method, the level of unavoidable annual real losses (UARL) represents the technically low level that could exist in a system if it successfully applies the current BMPs for leakage management. The calculation for UARL is system-specific; thus, the UARL level for one water supplier is not the same as another. The calculation takes into account the key variables that influence the amount of leakage existing in a distribution network. Factors include the length of water mains, average water pressure, number of service connections, and the average length of service connection piping from the curb-stop valve to the customer meter or property line for systems that do not use meters.

The numerical derivation of the UARL is based on data obtained from a substantial number of countries (Lambert et al, 1999). The UARL component values, given in Tables 4 and 5, were developed from analysis of night flows in DMAs just after all detectable leaks and breaks had been located and repaired (Bristol Water Services, 2001). They are representative of the minimum leakage that remains in well-run systems after active leakage control has been successfully used. The component values include minimal leakage amounts for background leakage, reported leaks, and unreported leaks (Lambert et al, 1998). Each component value amount is assigned to mains or pipelines, service connections from the water main to the curb-stop, and service connections from the curb-stop to the customer meter or property line. For water systems worldwide, the majority of the annual volume of leakage losses occurs on customer service connection piping, not water mains; therefore, the inclusion of service connection piping variables in this equation is most appropriate. Also, the role of water pressure levels on leakage rates has been determined to be a highly significant factor on minimal leakage levels that can be attained. Finally, the system age is not a factor in the calculation of the UARL.

The values shown in Tables 4 and 5 can be recalculated in pressure-dependent terms that are easier to apply for individual systems. The calculated UARL value for Philadelphia is listed in Table 6 as 5.299 mgd (20,064 m³/d) for its 2002 fiscal year. This represents the theoretical minimum level of leakage that could exist in the city if all possible leakage reduction methods were successfully in place.

The ILI, defined as the dimensionless ratio of current annual real

FIGURE 2 International standard water audit format



Source: Alegre, H. et al, 2000. Manual of Best Practice: Performance Indicators for Water Supply Services. *Published by IWA Publishing, London. www.iwapublishing.com. Used with permission*
All data are in volume, or average volume per day, for the standard reporting period—typically one year.

TABLE 4 Values assigned for the calculation of UARL via the IWA method*

Infrastructure Component	Background (undetectable) Leakage	Reported Leaks and Breaks	Unreported Breaks and Leaks
Mains	8.5 US gal/mi/h (20 L/km/h)	0.20 breaks/mi/year (0.124 breaks/km/year) at 50 US gpm (12 m^3/h) for 3 days' duration	0.01 breaks/mi/year (0.006 breaks/km/year) at 25 US gpm (6 m^3/h) for 50 days' duration
Service connections, main to curb-stop	0.33 US gal (1.25 L) /service connection/h	2.25 leaks/1,000 service connections/ year at 7 US gpm (1.6 m^3/h) for 8 days' duration	0.75 leaks/1,000 service connections at 7 US gpm (1.6 m^3/h) for 100 days' duration
Service connections, for 50 ft (15 m) average length from curb-stop to meter	0.13 US gal (0.50 L) /service connection/h	1.5 leaks/1,000 service connections at 7 US gpm (1.6 m^3/h) for 9 days' duration	0.50 leaks/1,000 service connections at 7 US gpm (1.6 m^3/h) for 101 days' duration

*The original metric units shown have been converted to US units and rounded; all flow rates are specified at a reference pressure of 50 m (70 psi); UARL—unavoidable annual real losses, IWA—International Water Association; Source: Lambert et al, 1999; reprinted from *Aqua*, vol. 48, issue 6, pp. 227–237, with permission from the copyright holders, IWA Publishing, ©IWA Publishing 1999

TABLE 5 Standard unit values used for the calculation of UARL*

Infrastructure Component	Background Leakage	Reported Leaks and Breaks	Unreported Leaks and Breaks	UARL Total
Mains—*US gal/mi of main/day/psi (L/km of main/day/m of pressure)*	2.87 (9.6)	1.75 (5.8)	0.77 (2.6)	5.4 (18.0)
Service connections, main to curb-stop—*US gal/service connection/day/psi (L/service connection/day/m of pressure)*	0.112 (0.60)	0.007 (0.04)	0.030 (0.016)	0.15 (0.80)
Service connections, curb-stop to meter—*US gal/mi of service connections/day/psi (L/km of service connections/day/m of pressure)*	4.78 (16.0)	0.57 (1.9)	2.12 (7.1)	7.5 (25.0)

*The original metric units shown have been converted to US units and rounded; all flow rates are specified at a reference pressure of 50 m (70 psi); UARL—unavoidable annual real losses; Source: Lambert et al, 1999; reprinted from *Aqua*, vol. 48, issue 6, pp. 227–237, with permission from the copyright holders, IWA Publishing, ©IWA Publishing 1999

TABLE 6 IWA calculation for UARL for a water distribution system*,†

Infrastructure Component	Quantity	Unit Rate for UARLs	Average Pressure	UARL *mgd (m^3/d)*
Mains	3,160 mi (5,084 km) of main	5.40 gal/mi/day/psi (18.0 l/km of main/day/m of pressure)	55 psi (38.7 m)	0.939 (3,554)
Service connections, main to curb-stop	474,657 service connections	0.15 gal/service connection/day/psi (0.80 L/ service connection/day/m of pressure)	55 psi (38.7 m)	3.916 (14,826)
Service connections, curb-stop to meter	(474,657)(12 ft)/5,280 ft per mi ([474,657][3.66 m]/1,000 m per km)	7.5 gal/mi/day/psi (25.0 L/km of service connections/day/m of pressure)	55 psi (38.7 m)	0.445 (1,684)
				5.299 (20,064)

*Calculation is for city of Philadelphia, Pa.—fiscal year 2002: July 1, 2001–June 30, 2002; IWA—International Water Association, UARL—unavoidable annual real losses, BMP—best management practice

†The IWA calculation for UARL is based on the theoretical minimal level of leakage that would still exist in well-run water distribution systems after all of today's BMP leakage interventions have been implemented. The calculation is system-specific and includes allowances based on key leakage factors: the miles of water main, the number of service connection pipes, the length of service connection piping beyond the curb-stop or property line, and the average operating pressure in the system. As a system-specific indicator, the UARL is a superior method to the generic methods traditionally referred to in North America, such as the Kuichling equation. This dated equation (circa 1880s) was derived as the number of "drops per second" from various system joints and appurtenances, leading to a rough number of 2,500–3,000 gpd/mi (5.88–7.06 m^3/d/km) of main. It does not include key leakage factors of system pressure and number of service connections. The calculation for UARL has been confirmed on data from more than 20 countries and is recognized by the IWA as the BMP measure of unavoidable leakage losses in water distribution systems.

City of Philadelphia, Pa., Annual Water Audit in International Water Association Format*

(Refer to data shown in Table 2)

PERFORMANCE INDICATORS FOR WATER SUPPLY SYSTEM LOSSES

Water resources performance indicator.

Inefficiency of use of water as a resource

= real losses over system input volume, %

= 69.189 mgd/263.000 mgd (261,981 m^3/d/995,834 m^3/d) 100% = **26.25%**

Operational performance indicators.

Water losses 82.323 mgd (311,711 m^3/d)

Apparent losses 13.134 mgd (49,731 m^3/d)

Real losses 69.189 mgd (261,981 m^3/d)

UARL† 5.299 mgd (20,064 m^3/d)

Infrastructure leakage index = ratio of real losses to UARL = 69.189/5.299 (261,981/20,064) = 13.1

Financial performance indicator for nonrevenue water.

Nonrevenue water = real and apparent losses and unbilled authorized consumption = 69.189 + 13.134 + 0.548 + 1.935

= 84.806 mgd (261,981 + 49,731 + 2,075 + 7,327 = 321,114 m^3/d)

Nonrevenue water by volume = nonrevenue water over system input volume, %

= 84.806 mgd/ 263.000 (321,114 m^3/d / 995,834 m^3/d) 100% = 32.24%

Nonrevenue cost ratio is the annual cost of nonrevenue water over the annual running costs for the water supply system—%

Nonrevenue water costs	$ 24,342	Unbilled unmetered water
	121,642	Unbilled unmetered (authorized usage)
	9,036,038	Apparent losses
	3,369,029	Real losses
	$12,551,051	Total nonrevenue water

Nonrevenue water cost ratio = ($12,551,051/$155,060,248) × 100% = 8.09%

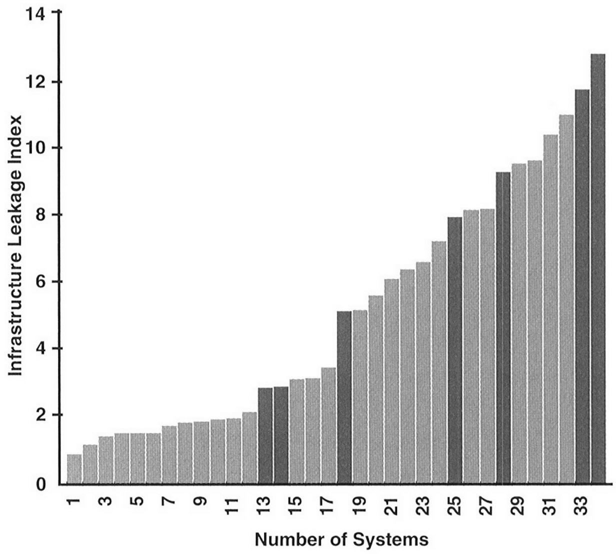
*Fiscal year 2002: July 1, 2001–June 30, 2002
†UARL—unavoidable annual real losses

losses over the UARL, gives a measure of leakage relative to the best level currently obtainable with today's technology for that system. During the development of the international method, data from more than 20 countries were gathered to test the reliability of the indicator. Figure 3 (Brown et al, 2000) shows ILI ratings for 34 systems from around the world, with seven North American systems shown in bold. Twelve systems operate with an ILI less than 2.0, or an admirably small level of active leakage that is less than two times the technically achievable low. Conversely, seven of the systems are observed to have ILI values greater than 8.0, or leakage greater than eight times the technically achievable low. Such systems likely have good reason—both economically and environmentally—to seek reduction of their relatively high level of loss. The largest group of systems—15 in all—have ILI values between 2.0 and 8.0, reflecting reasonable control of their leakage but a need to continue to seek further leakage reductions.

What level of ILI value should a water utility target? Again, prevailing economics should dictate this. As described in Table 7, where water is scarce, expensive, or both, justification exists to fund leakage reduction efforts to bring the ILI down toward a value of 1.0, or current annual real losses close to the UARL. If water resources are reliable and inexpensive, a level of leakage corresponding to an ILI somewhat higher than 1.0 can be targeted. The economic level of leakage (ELL) is defined as the appropriate leakage level for water suppliers to target. In theory, the ELL is derived as the level at which the cost of leakage reduction activities meets the cost of water saved through leakage reduction. For most systems, this translates to an ILI value somewhere between their current annual real losses and the UARL. The relationship between current annual real and apparent losses and their economic and unavoidable levels are shown in Figures 4 and 5, respectively.

Work continues internationally to devise a consensus means to assign the ELL, including part of the scope of work of the 2002–03 Evaluating Water Loss and Planning Loss Reduction Strategies project, which is being funded by the AWWA Research Foundation (AWWARF). A proper economic analysis of leakage should take into account not only the short-term costs—which are often relatively straightforward to calculate—but also the long-term, subjective costs of water loss. Environmental, social, and political costs also exist with any water resource, but such costs are more difficult to quantify. Until an accepted method is available, water utilities may attempt to determine their ELL using their own means.

FIGURE 3 Infrastructure leakage index for systems in the international data set



North American systems are shown in bold.

Alternatively, Table 7 was devised by the committee to offer general guidance to establish a long-term target ILI for utilities that have not determined an ELL.

The sidebar on page 74 shows that Philadelphia has an ILI of 13.1 or current annual real losses of 69.189 mgd (261,981 m^3/d) that are 13.1 times greater than its UARL of 5.299 mgd (20,064 m^3/d). The city's Water Accountability Committee is moving to set long-term leakage reduction targets that attempt to include specific Philadelphia economic and infrastructure influences to determine an approximate ELL. In the meantime, it suffices that leakage reduction is well justified in Philadelphia given that its ILI level above 8.0 warrants improved water resource management.

As advocated in this article, the IWA water audit methodology and performance indicators now stand as an available and highly effective means for drinking water suppliers worldwide to audit both the use and loss of the water that they manage. Systems applying the international performance indicators can move forward to implement water loss control interventions to reduce their losses and measure progress against targets.

REAL LOSSES CAN BE CONTROLLED BY IMPLEMENTING ACTIVE LEAKAGE MANAGEMENT TECHNOLOGY

Leakage causes many problems, indirectly requiring water suppliers to extract, treat, and transport greater volumes of water than their customers actually require. Also, the additional energy needed to supply leakage unnecessarily taxes energy-generating capabilities. It is estimated that water utilities consume from 2 to 10% of all power used in any country, and power can consume up to 65% of a water utility's operating budget (Crapeau, 2000; Pelli et al, 2000). Collectively, water utilities are the largest single user of electricity in the United States, consuming an estimated 75 billion kW·h annually, or about 3% of all electric power generated in the country (Von Sacken, 2001). It is possible that 5–10 billion kW·h of power generated in the United States is expended each year on water that is either leaked away or not paid for by customers. Obviously, water loss control is also a pertinent energy management issue.

Leaks and breaks often cause considerable damage and increase liability for water suppliers. They may also have a distinct effect on distribution system water quality because they are a potential source of contamination during low-pressure or backflow conditions. Leakage often finds its way into wastewater or stormwater collection systems and may be treated at a wastewater treatment plant—two rounds of expensive treatment without ever providing any beneficial use (Thornton et al, 2002). Watersheds are taxed unnecessarily by inordinately high withdrawals, sometimes limiting growth in a region because of restrictions on available source water. Leakage also requires larger infrastructure than is necessary to meet customer demand, a compelling factor in the infrastructure debate now occurring in the United States.

British leakage management terminology distinguishes among reported, unreported, and background leaks. Broken water mains are the most recognizable example of reported leaks, which, because of their damage-causing nature, are usually quickly reported and contained. However, unreported and background leaks (the smallest of leaks at joints and fittings) frequently escape the attention of the public and water suppliers but account for larger volumes of lost water because they run undetected for much longer periods of time. Most water utilities provide able response to reported leaks, but many never conduct regular searches (leak surveys) to find unreported leaks.

The four-component approach to control of real (leakage) losses, shown in Figure 4 (McKenzie & Lambert, 1992) has been developed as a template for water systems to maintain low leakage operations over a long-term horizon. The graphic shows that any system has a certain amount of recoverable leakage that can be reduced to its ELL value with the

TABLE 7 General guidelines for setting a target level ILI* (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 because of 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 imposed 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	Although 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.		

*Infrastructure leakage index

proper combination of the four leakage controls. Although the graphic adequately explains "Speed and quality of repairs" and "Pipeline materials management," elaboration is given for the other components:

Active leakage control (Lambert et al, 1998).

- regular inspection and sounding of all water main fittings and connections—leakage surveys;
- innovative leakage modeling methods—the bursts and background estimates (BABE) model (Lambert & Morrison, 1996);
- metering of individual pressure zones;
- DMA metering—measuring total inflow per day, week, or month;
- continuous or intermittent night-flow measurements;
- short-period measurements at any time of day; and
- temporary or permanent placing of leak noise detectors and loggers.

Pressure management.

- pressure modeling using internationally applicable concepts such as the fixed and variable area discharge (FAVAD) paths model (Lambert, 2001b; May, 1994),
- controlling pressure close to but greater than the minimum standard of service,
- operating discrete pressure zones configured based on topography,
- limiting maximal pressure levels or surges in pressure, and
- nighttime pressure reduction where feasible to reduce losses from small background leaks.

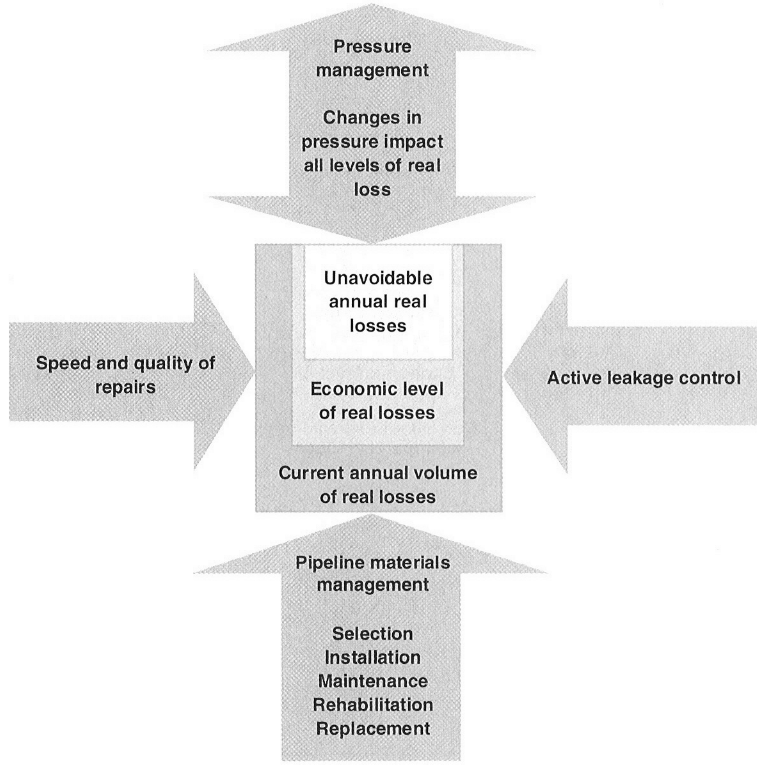
Several innovations in the structure now existing in England and Wales stand out as particularly effective in driving down leakage losses. By creating DMAs that range in size from several hundred to several thousand properties, water usage patterns are monitored closely to infer leakage rates based on minimal night-flow rates. Important findings from the National Leakage Initiative spurred the development of leakage modeling concepts such as BABE, allowing development of software (McKenzie & Lambert, 1992) that quantifies various components of leakage and usage within a DMA. Better understanding of pressure–leakage relationships has resulted in the development of the FAVAD model. Establishing DMAs and using leakage-modeling techniques effectively provide a quantitative measure of leakage to the water utility manager. The amount of active leakage in a system can truly be measured. This information is available as the "bottom-up" contribution to the water audit, improving the accuracy and reliability of that document. Such measurements also form the basis for leakage reduction targets on a DMA basis. Flexibility exists in the manner in which DMAs are configured so that possible concerns for fire flow restrictions, closed valves, and customer expectations can be safely and economically managed. The effect of leakage run time has been exposed and incorporated as strategy. Leaks left to run for long periods of time create large annual loss volumes. In well-run systems worldwide, the greatest annual volume of real losses occur from long-running, small- to medium-sized leaks on customer service connections, except at very low densities of service connections (Brown et al, 2000). To achieve successful leakage control, water utilities must be effective in actively identifying leaks and in executing timely, lasting repairs.

Severe drought in the mid-1990s prompted the UK regulator to institute a key policy change, initially as an emergency measure, but one that is now permanently in place. This change requires water companies to conduct leak repairs on customer service connections, a responsibility that had traditionally rested with the customer. Shifting the responsibility for these repairs to the companies has been highly successful in reducing leakage losses by reducing long leak run times. In the United States, many systems rely on their customers to repair leaking service connection pipes, an often inefficient practice that should be reevaluated.

Another major innovation of leakage management is the science of pressure management. Common engineering design of water supply systems calls for adequate pressure to ensure a specified minimal level of service. However, it is now understood that certain types of leaks are very sensitive to pressure. Excess pressure—which is not always carefully assessed by water system operators—has a cost in terms of higher leakage and unnecessary energy usage. Better understanding of high- and low-pressure variations gives suppliers more control in preventing surging ruptures and backflow conditions, thereby extending the life of infrastructure and safeguarding distribution system water quality. Pressure control has proven to be particularly effective in reducing background leakage. The use of selective pressure reduction during nighttime hours is an effective technique in economically reducing background leakage. This technique greatly challenges the levels set by the dated concepts of unavoidable leakage.

Leakage management methods are now widely recognized in many parts of the world as effective tools that have been applied successfully in a great variety of water system settings. These methods are viewed by the committee as current BMPs for controlling leakage losses in water distribution systems and are recommended for use by the North American water industry. Guidance publications describing the details of these methodologies are now available (Thornton et al, 2002; Alegre et al, 2000; McKenzie & Lambert, 1992).

FIGURE 4 Four-component approach to the control of real (leakage) losses



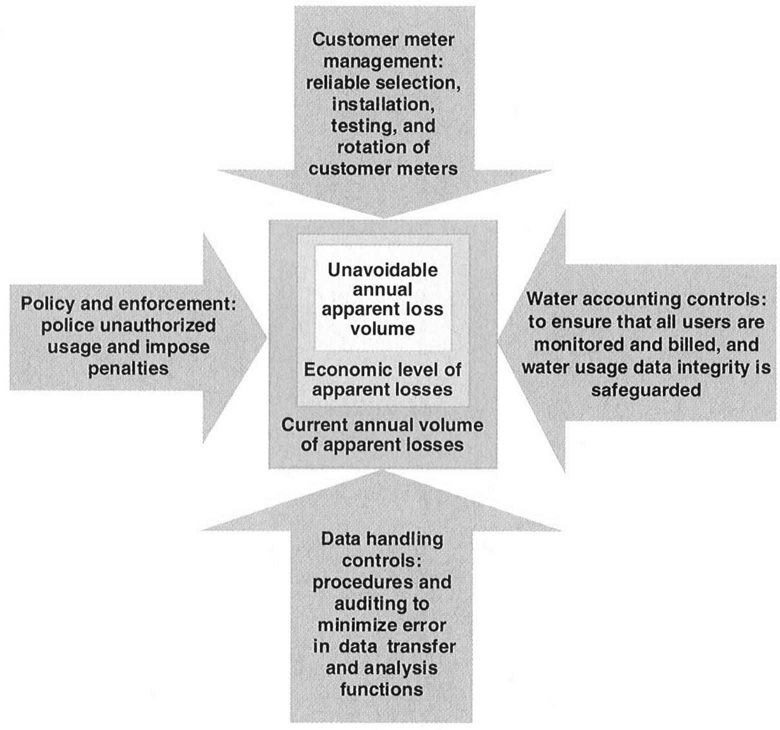
METHODS ARE NEEDED FOR CONTROLLING APPARENT LOSSES

Apparent losses exert a significant financial effect on suppliers and customers and compromise efforts to reliably distinguish water consumption from real loss volumes. The latter impact undermines water resources' decision-making processes, which rely on accurate data. Financially, apparent losses represent service rendered without payment recovered. The short-term economic impact of apparent losses is usually much greater than real losses because apparent losses occur at the retail rate charged to customers, whereas short-term real losses occur at the lesser marginal production cost. Recovering apparent losses usually offers a speedy payback and requires few new resources to implement. Controlling apparent losses also improves equity in customer collections because a portion of apparent losses occurs when some active customers are inadvertently left out of the billing process. Paying customers effectively subsidize these nonpaying customers, exacerbating tensions surrounding water rate increases.

Apparent losses compromise the reliability of water consumption and real loss tabulations. Many water suppliers extract customer water consumption data from computerized billing systems that were established to manage billing operations—a cost accounting function. Unfortunately, many billing systems lack water accounting controls that ensure that needed cost adjustments for valid billing purposes do not corrupt actual water consumption data. Some utilities trigger needed billing cost adjustments by modifying customer metered consumption data to obtain the right cost adjustment. Many water professionals perceive customer meter inaccuracy as the sole paper loss that occurs in water supply systems. While numerous utilities have documented accountability improvements by replacing old and worn residential meters, or by right-sizing large meters, apparent losses have a number of components, including

- customer meter inaccuracy usually occurring because of meter wear, malfunction, or inappropriate size or type of meter;

FIGURE 5 Four-component approach to the control of apparent losses



- data transfer error in getting customer metered consumption data into a database or billing system;
- data analysis error, including poor estimates of unmetered or unread accounts;
- poor accounting, including lack of controls that ensure accounts exist for all water users and that bills are issued or tabulated (even if water is supplied at no cost). (This includes procedural gaps that allow legitimate water users to exist in "nonbilled" status.);
- all forms of unauthorized consumption, including meter or meter-reading tampering, illegally opening fire hydrants, unauthorized tapping into service mains, or unauthorized restoration of water service connections after violation discontinuance by the water supplier;
- weak or nonexistent policy, including the often-used practice of not metering and billing municipally owned and public facilities, allowing unrestricted use of fire hydrants, lack of enforcement of existing statutes, and lack of promotion of the value of water.

Similar to real losses, a four-component approach to control apparent losses is offered in Figure 5. The notion that current, economic, and unavoidable levels of apparent loss exist for any water system follows the same logic as the assessment of real losses in a water supply system. The four-component approach guides the water manager in determining where the greatest amounts of apparent loss are believed to exist and offers interventions available to reduce overall apparent losses to the appropriate economic level. The nature of the interventions needed to control apparent loss in water supply systems parallels policies and controls that are used in the world of financial accounting. Here, all monies are placed in accounts that are routinely reported, audited, and reconciled. The approach to apparent loss control in water supply systems is in its infancy, and much work remains to bring it to a par with available real loss interventions. The approach given in Figure 5 is a framework that can guide water professionals in launching apparent loss reduction programs.

CONCLUSION

AWWA's States Survey Project substantiated long-held perceptions of many water analysts that weak and inconsistent water accounting structures exist in drinking water supply systems in North America. Water losses, manifested as both real (physical) losses and apparent (paper) losses, constitute a major inefficiency in water supplies because water and energy resources are wasted, revenue is not fully recovered, and water use and loss data integrity are compromised. With many pressures confronting today's water industry, water professionals can no longer regard water loss as an uncontrollable inevitability. And indeed they need not, as the discipline of water loss control has developed rapidly internationally and offers great potential as a resource and revenue recovery opportunity for North American water suppliers.

Working in cooperation with international water loss practitioners and the IWA, AWWA's Water Loss Control Committee participated in the development of new water auditing methods that were designed to serve as BMP structures in the field of water loss control. The committee recommends the following:

- The IWA methodology for the water audit (balance) and performance indicators should be recognized as the current BMP for quantitatively monitoring water use and water loss in drinking water systems.
- Water suppliers should make use of the performance indicators included in the international methodology, particularly the ILI. The percentage measure of nonrevenue water (all water not included in billings) over the delivery system input volume should be used with great caution as a general financial indicator only, having been found to be a poor operational performance indicator.

• The term "unaccounted-for water"—lacking a consistent definition—should no longer be used.

• The four-component approaches to controlling real and apparent losses should be used to economically control these losses.

Further work is needed in the field of water loss control, particularly to devise ways to calculate the economic loss levels that can assist in setting long-term loss reduction targets for water systems. Similarly, additional manuals and software are needed to provide these specific tools for water utility managers and regulatory officials. Recent publications and the forthcoming results of AWWARF's *Evaluating Water Loss and Planning Loss Reduction Strategies* project are making new material available to water utility managers. AWWA's *Water Audits and Leak Detection*, M36 (1999) will require rewriting or replacement by virtue of this committee report, and the committee is poised to undertake this initiative.

The international water audit methodology and loss control interventions represent a leap forward in technological and managerial advancement. With the extraordinary skills and dedication of North American water professionals, coupled with new and effective water loss methods, a new level of efficient water resources management can be realized in the twenty-first century.

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FOOTNOTES

[1]Beecher Policy Research Inc., Indianapolis, Ind.

If you have a comment about this article, please contact us at journal@awwa.org.

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executive. summaries

Page 54 Cost savings and enhanced reliability for main rehabilitation and replacement

Leonard L. Wilson, Feryal Moshavegh, Jeffery Frey, Lee Kolokas, and Angus R. Simpson

Water utilities across the United States anticipate a growing need to rehabilitate and replace aging water mains because of a convergence of pipe life spans. Shortfalls in funding for this activity will contribute to an estimated water infrastructure funding gap of $480 billion over the next 20 years. The city of San Diego (Calif.) Water Department (SDW) undertook this pilot study to determine whether significant cost savings could be achieved in its rehabilitation and replacement (R&R) program by using genetic algorithm (GA) optimization.

Wilson and colleagues discuss how the use of GA optimization will save SDW millions of dollars compared with simulation trial and error. During this study, the GA evaluated millions of trial solutions to develop low-cost alternatives that met all of the design and emergency criteria specified by SDW. The GA identified a near-optimal mix of new pipe and R&R choices that were not only low cost but also redundant and reliable in the event of a source outage or a main break.—LH

Page 65 Committee Report: Applying worldwide BMPs in water loss control

AWWA Water Loss Control Committee

Despite growing pressures on water suppliers from drought, water shortages, and other challenges, the North American water industry has been slow to implement reliable and consistent water supply auditing and loss control. AWWA's Technical and Educational Council funded a survey that confirmed that US water loss reporting practices are limited and vary widely. In 2000, an International Water Association task force—with AWWA participation—assembled a water audit methodology as a best management practice (BMP) that is applicable to water suppliers worldwide, providing a framework to tabulate supplier water use and loss. Additionally, effective leakage management methods have been advanced with great success. This article advocates the use of the international water audit method and water and revenue loss control technologies that offer North American water utilities an outstanding water resource recovery opportunity and a great stride toward sustainability.—LH

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