DETECTING LEAKS IN UTAH'S
MUNICIPAL WATER SYSTEMS

August 2013

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Utah Division of Water Resources

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PREFACE

One of the responsibilities of the Utah Division of Water Resources is comprehensive water planning. Over the past 20 years, the Division has prepared a series of documents under the title "Utah State Water Plan." This includes two statewide water plans, an individual water plan for each of the State's eleven major hydrologic river basins and "special studies" (such as this document). Preparing these documents involves major data collection, as well as extensive inter-agency and public outreach efforts. Much is learned through this process. State, local, and federal water planners and managers obtain valuable information for use in their programs and activities, and the public receives the opportunity to provide meaningful input in improving the state's water resources.

This document extends the "Utah State Water Plan" series by taking a look at a conservation measure recommended to all water utilities in the state: Water Audits and Leak Detection Programs. It does so by surveying leak detection efforts being undertaken by some of Utah's 150 municipal water suppliers that are required to submit conservation plans to the state every five years. It describes the International Water Association/American Water Works Association (IWA/AWWA) water audit method and leakage indexes and briefly looks at detection tools and programs currently being used successfully by water suppliers in Utah and elsewhere. Finally, it recommends the basic first-steps that water utilities should take when developing an effective leak detection program.

An Adobe Acrobat (pdf) version of this document is available for free download at: www.water.utah.gov. Reader comments regarding this publication are welcome. Please contact Russ Barrus at: russbarrus@utah.gov.

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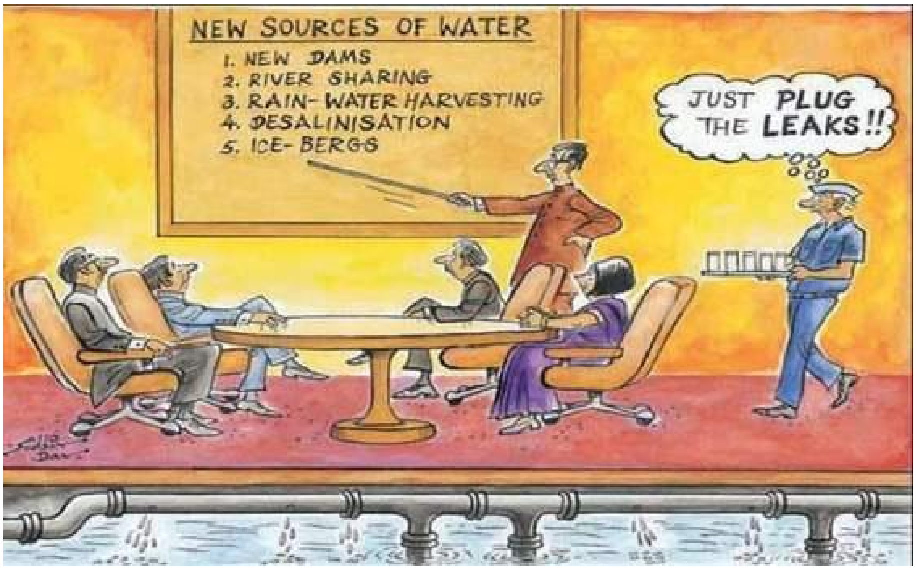
INTRODUCTION

Maintaining a water system to deliver clean and safe drinking water can be a challenge. Once the system's pipes are in the ground they begin to be worked on by physical stresses from the surrounding soil and the roadways and activities above them. Additionally, chemical interactions between pipes and soils begin corrosion. Pressures may also be increased as the system is stressed to deliver more water than it was designed for. Eventually small leaks may form and become larger over time. Small amounts of leakage from joints and valves, called "background leakage" exists in all systems and is often uneconomical to repair due to the costs incurred in finding and repairing them and the comparatively low value of the water lost. Other small leaks may go undetected for long periods of time while larger leaks are often repaired immediately because they surface quickly and pose a threat to property and infrastructure in addition to the greater monetary loss of system water. Eventually though, losses from the smaller leaks and the amounts lost through background leakage gradually increase to the point at which they become economical to reduce. That economic point can be determined by several factors: limits of the water supply, system capacity, ability of the system to maintain fire flows, cost of production as well as the costs to locate and find the leaks. Determining this point is an important part of running and maintaining a water system and a relatively easy way to do so is to conduct a system water audit, which accounts for all water entering and leaving the system.

Nationally, standards for leak detection have been evolving for the last 30 years and as of 2002, 33 states (including Utah) had adopted some form of policy regarding municipal water leakage.[1] Locally, the Utah Division of Water Resources (DWRe) has advocated water conservation and efficiency for all water users in its state water planning efforts since the early 1980s. More recently, with the passage of Utah's Water Conservation Plan Act (Act) in 1998, water conservation planning became law for municipal providers with more than 500 connections. The Act requires Utah water suppliers to submit a water conservation plan to the Utah DWRe every five years outlining the efforts they will use to conserve water within their systems. The methods used to achieve each system's goals are left up to the individual public water system and they choose those methods most suitable to their community and budgetary constraints. Wording of the act specifically mentions leak detection as an appropriate conservation measure. In addition, the DWRe is responsible for administering the Act and has provided a list of Best Management Practices (BMPs) that water providers can include in their water conservation planning. BMP #7, "System Water Audits, Leak Detection and Repair," recommends setting specific goals to reduce "unaccounted for water[2]" to an acceptable level and to set standards for annual water system accounting that would trigger repair and replacement programs within each system. Furthermore, Utah's, State Water Plan and individual river basin plans, (developed for each of the eleven hydrologic basins in the state) have encouraged water audits and leak detection since at least 1995.

The purpose of this study is to evaluate leak detection efforts being undertaken by Utah municipal water suppliers and to recommend further actions and best practices. This document will give a brief overview of why leak detection is important, will outline methods of quantifying the amount of leakage in a system, give a description of leak locating methods, and review some of the efforts conducted by Utah and other providers.



Fixing water leaks has not traditionally been part of future water planning. This is changing. (Image courtesy of World Bank Water and Sanitation 2002 Calendar.)

WHY ARE LEAKS AN ISSUE?

Water leakage is an issue that represents more than just lost water. Producing potable water requires energy to pump, treat, and distribute throughout the system. Clarification processes may also require the addition of chemicals to help remove particulate matter. Final polishing of the water also incurs costs from disinfection through the addition of chlorine or use of ultraviolet light or ozone. Fluoride may also be added to the finished water just before entering the system. All of these costs, once incurred, are lost with system leakage. High amounts of leakage can reduce the amount of water that can be delivered to customers, and the number of customers the system can supply. Leakage is also a liability. Roads and other infrastructure can be undermined by leak caused erosion (which causes sinkholes and instability issues), and structures can be flooded.

WATER LEAKAGE AND UTAH'S WATER CONSERVATION GOAL

To understand how leaks affect the calculations of water conservation, an understanding of how the Division of Water Resources (DWRe) calculates per capita water use is needed. Every five years DWRe calculates per capita water consumption (gpcd) for municipalities in each of the eleven river basins of the state. Municipalities must report their usage annually to the Division of Water Rights. This information is also used by the Department of Environmental Quality's Division of Drinking Water (DDW) and DWRe for their purposes. Metered potable water usage is determined by the amounts read from customer's meters (as opposed to source or "system" meters) and is reported in four categories; residential, industrial, institutional and commercial. The total from these four categories is divided by the population served to determine the gallons per capita per day (gpcd) value. Since most municipal leak detection and repair activities target the "system" side of customer's meters those leak reduction activities do not affect the amounts that the customer meters record and will not affect the calculated per capita use. Only leak detection and repair efforts on the customer side of their meters will directly reduce customer water use and the calculated gpcd.

While this study mentions some measures municipalities can employ to help customers identify leakage occurring on their property, it deals primarily with leakage in the municipal system. The aim of the state water conservation goal is to change the water use ethic of the general public (customer side use), however, municipal leak reduction will improve accountability and efficiency for system water supplies and instill public confidence in water utilities.

PASSIVE VS. ACTIVE LEAK DETECTION

Passive leak detection means waiting for visible signs of leakage to appear such as surfacing water or sinkholes in a road or other damage due to settlement and erosion from leaking water. Active leak detection goes beyond the readily visible signs of leakage to actively searching for leaks that might not otherwise appear until damage occurs or, in many cases, may never show visible signs. If a municipality repairs leaks only as their visual evidence appears, system demand would gradually increase as the system ages and unseen leakage gradually increases. With an active leak detection and repair program, leakage control activities are initiated when it becomes economic to find and repair them. The benefit of active leak detection is that leaks are usually found much sooner and less water is lost than when waiting for visible evidence.

TABLE 1
Reported Unaccounted for Water in Community Water Systems by Size

Size of System	No. of Connections	No. of Systems	Unaccounted for Water %
Very Small	500 or less	30,417	2.8
Small	501-3,300	14,394	9.1
Medium	3,301-10,000	4,686	11.4
Large	10,001-100,000	3,505	9.4
Very Large	>100,000	361	7.4
TOTAL	**-**	**53,363**	**8.4**

Source: *Onsite Wastewater Treatment Systems Manual,* United States Environmental Protection Agency, Office of Water, Washington D.C., February 2002, EPS/625/R-00/008.

Benefits of Early Leak Detection

Besides saving water, early leak detection can help delay the need to develop new supplies or the expansion of treatment facilities to purify more water by enabling existing system production capacity to serve more customers. It also helps protect public health by reducing the risk of system contamination. Leaked water carries away with it the costs associated with its production such as chemicals, filtration, pumping energy and equipment maintenance. These production costs result in revenue losses that are eventually passed on to customers. An active leak detection program is an iterative process that includes an audit, detection and repair and evaluation. An audit estimates the amount of leakage in the system and helps identify the point at which it is economical to actively search for and repair leaks. A simple cost / benefit ratio for example is one indicator that can be used, but other triggers could be based on the limits of the source or supply system to provide water to all customers. Industry guidelines, based on percent of leakage, previously estimated this economic break point at around 10 percent and later at 5 percent of system production.
Efforts to reduce leakage can improve public confidence in the utility because they are an active effort to maintain system integrity and water quality. Reducing system losses to an economically viable level should be an integral part of the stewardship of managers and operators of publicly owned treatment works.

National Leak Data / Trends

According to the EPA, in 2002 the national average municipal "unaccounted for" water was 8.4 percent, but, in general, varied by size of water system (see Table 1). Utah system operators and administrators that were contacted during the course of this study were asked to give an estimate of their system's leakage rate (very few systems had conducted a thorough audit so most of the responses were a "best guess.") The responses from the 36 systems that gave an answer, ranged from 2.5 to 35 percent with a median value of 8 percent.

According to DWRe, Utah's potable water deliveries in 2010 amounted to 557,600 acre-feet. Estimating the cost of water lost to leakage depends upon many factors; several of which are whether the losses are real (actual leakage) or apparent (retail meter inaccuracy, billing errors etc.) and if the utility is at the limits of its system or source capacity. If the system is at the limits of its source or system capacity, then the water loss is valued at the retail cost (DDW average cost of $1.62/1000 gallons[3]) or at the cost of procuring and delivering the next increment of water (which can be significantly higher). If a system has ample water with no shortages to its customers, then the value of the water loss is based on an average cost of production and delivery (a rough estimate of these costs is $0.50/1000 gallons[4]).

For comparison purposes Utah's leakage can be estimated at somewhere between these two unit costs. A well maintained system, maintained at a leakage rate as low as is economically prudent, is expected to have about 5 percent leakage. This would result in an annual loss of 27,900 acre-feet of municipal water for a cost between $4.5 and $14.7 million. At 8.4

percent leakage (the national average), 46,800 acre-feet would be lost annually for a cost between $7.6 and $24.7 million. Very few Utah water systems have performed an in-depth water audit so the actual state leakage rate is unknown, but if it is near the national average of 8.4 percent, there is a recoverable 18,900 acre-feet lost at a cost of $3.1 to $10 million dollars annually (the difference between the minimum leakage rate theoretically achievable of 5 percent, and the 8.4 percent rate).

Other States and Programs

Many other states are developing water loss reporting and leak detection and repair programs. A survey of state agencies sponsored by the AWWA, reviewed water loss reporting practices across the nation.[5] Completed in 2002, the study identified 43 states with developing or evolving water loss policies. Utah was listed as having a water loss policy in addition to standards and benchmarks. Utah's policy statements include "not wasting water" or "not allowing water waste" and a provision that water conservation plans may include leak detection to reduce leakage to an economic level.

Other states have taken audit and leak detection requirements much further. Washington and Texas both require a water audit along guidelines similar to those recommended by the AWWA. Washington is using a stepped approach, moving toward requiring audits for all municipal systems but has started with implementing a full metering program that requires the state's utilities to install meters on all customer service connections by 2014. The state requires an annual Water Use Efficiency (WUE) report that will include a water audit after 2014. Washington also has manuals online to help municipal water systems produce their WUE reports and plans. Texas' program requires both a Water Conservation Plan and a Water Audit every five years for municipal systems of a given size. However, if an entity has a loan from the Texas Water Development Board's (TWDB) revolving fund, an audit is required every year. Since implementing their program the TWDB has seen leakage rates as high as 50 percent in the audits turned in with loan applications. The Texas web site contains an interactive audit form in a portable document format (pdf) that municipalities can fill out and submit online. Their program also includes a confidence interval for each part of the audit and the state has requirements for each provider to improve the accuracy (confidence) of their water audits with each submission. Arizona requires reporting the percentage of lost and unaccounted for water and limits that amount to 10 percent of the total pumped. Other western states are also forming similar policies.

California was probably one of the first states in the nation to develop audit and leak detection standards. In 1985 California enacted its Urban Water Management Planning Act that required water suppliers that used 3,000 acre-feet of water or had more than 3,000 connections to submit an Urban Water Management Plan to the California Department of Water Resources that includes (among other measures) "system water audits, leak detection, and repair." A system could be excluded from any measure if they provided adequate proof through a cost/benefit analysis that the measure would not be economical. The fact that most systems include an audit in their plans suggests that leak detection and repair efforts are cost effective. Plans have to be submitted every five years. In 1986 the California Department of Water Resources released its Water Conservation Guidebook #5, Water Audit and Leak Detection Guidebook. Much of the information developed for that guidebook, made its way into the AWWA M36 manual, Water Audits and Loss Control Programs. In addition to California's state requirements for water audits, many California municipal water systems belong to the California Urban Water Conservation Council (CUWCC) and have signed a memorandum of understanding requiring them to perform a water audit every five years.

Tennessee is another state that enacted legislation to assess water loss in its municipal water systems. In 2007 the state passed legislation that required utility districts to audit their water systems and to take actions to reduce excessive losses. The state's initial audits required reporting "unaccounted-for" water as a percentage. Since 2010 the state has been promoting the IWA/AWWA audit methodology (described in this document, chapter 2) and is recommending moving away from the imprecise term "unaccounted-for" water and adopting performance indicators developed in the IWA/AWWA audits.

In addition to state programs for audits and leak detection, the United States Bureau of Reclamation

(USBR) is beginning to require water management planning for its customers who receive water from a Bureau project for either agriculture or urban use. Specifically, this requirement was enacted in 1992 for California entities receiving water from the Bureau's Central Valley Project. Similar to Utah's Conservation Planning Act requirements, these plans must include measurable objectives but additionally, require a water audit. Contracted entities must report their annual progress online and file an updated management plan with the USBR every five years.

SURVEY OF UTAH WATER PROVIDERS

In the fall of 2012, DWRe staff surveyed representatives of the 150 Utah municipal water suppliers that are required to submit water conservation plans to the state. Under the Plan Act, conservation plans are required to be updated and resubmitted every five years. Many of the conservation plans indicated that the system had a leak detection and audit program or would implement one as part of their efforts to conserve water during the next five years. Of the 93 systems responding to our survey, 73 had also graded the condition of their system according to the guidelines set forth by the Utah Division of Drinking Water, with the other 20 systems omitting a grade. The grading of the 73 systems was as follows:

A= All of system is in excellent shape. Very few leaks --39 systems.

B= Most of the system is in excellent shape. However, there are some areas of the system with excess leakage --17 systems.

C= The system is in fair shape. We regularly have leaks to repair but the situation is manageable --16 systems.

D= The system is in bad shape. We are kept busy repairing leaks and there is evidence of deterioration –1 system.

System age was one question asked of respondents in the DWRe survey. While many of the systems indicated they had small portions of water main over 100 years old still in service, most had much newer water pipe of less than 50 years age. Several systems indicated they still had water mains that included lead-jointed cast iron pipe from before the 1950s and many systems indicated they had or were in the process of installing pvc pipe. While it is impossible to determine the average age of Utah water mains from the information gathered, most of the systems

Laying new pipe in a residential area.

indicated that the bulk of their delivery pipe was less than 50 years old.

Audits were another item queried as part of the DWRe survey. Of the 93 systems that responded, 25 indicated they had performed an audit of their water system. Forty-one indicated that their audit consisted of metered inflow minus the amount billed to customer meters and the balance was "unaccounted for" water. Most respondents did not know what portion of the unaccounted for water was real leakage as opposed to billing errors, meter errors, system flushing, fire flows, theft or other unmetered uses. Although 36 of the system respondents had an estimate of their leakage rate, very few had performed a detailed audit that could accurately identify these components of unaccounted for water. Only one system was known to have completed an AWWA style audit (discussed in detail in chapter 2), the Salt Lake City Public Utilities Department.

Although many lacked a detailed audit to base it on, respondents were asked to at least estimate their system leakage rate. As mentioned previously, the median leakage rate of the 36 systems that gave one was 8 percent, which, if accurate, is very close to the estimated national average of 8.4 percent for unaccounted for water (which includes real leakage in addition to other system losses). Estimates of leakage ranged from 2.5 percent to 35 percent (this system knows the leakage source and is addressing the problem). Past AWWA reports suggest that the most efficient systems do not economically achieve leakage rates lower than 5 percent. The leakage estimates are most likely a conglomerate typical of the confusion created by many variations of the term "unaccounted-for" water. The varied definitions encountered during the course of our study also support the AWWA recommendation that the term "unaccounted for" water should be abandoned since its definition is not universal in the industry either nationally or in Utah and is a poor indicator of real leakage.

Leak detection efforts were also queried in the survey. Respondents were asked if they had an "active" leak detection program. Of the 93 system respondents, 17 indicated that they actively look for leaks rather than waiting for them to be reported. Leak detection efforts ranged from city personnel sounding their system with geophones (the most common method), to the installation of data loggers and leak correlators. Several systems hired consultants to do this work periodically or when losses seemed to be climbing, after which they would prioritize the leaks that were found and repair them as their budget allowed. A couple of systems indicated that they were isolating sections of their system to measure nighttime flows. Water tanks were also isolated and water levels watched to determine the integrity of their tanks. Many respondents indicated that their soils were so tight that even small leaks would surface quickly negating the need for active leak detection. Several systems look for leakage on the customer side of meters by analyzing meter readings and notify customers when anomalies are found that may indicate leaks. The surprise in the survey was that many systems are turning to water meters that support Automated Meter Reading (AMR) or Automated Meter Infrastructure (AMI) water metering, systems that can greatly aid in detecting customer-side leaks in addition to improving billing efforts and reducing labor costs. AMR meters send out meter readings by radio signal periodically or when queried by a transmitter/receiver mounted in a vehicle that canvases city streets every month. AMI systems typically use the same or similar meters but with fixed transmitter/receiver stations strategically placed around the city that can read meters every few minutes. These systems enable municipalities to read meters every month without the expense of meter reading personnel or vehicles, reducing liability and improving customer service by providing some leak detection capability on the customer side. Meters can be read even during the winter months and during winter morning hours (to establish baseline flows and detect in-house leaks). These systems can be expensive but enable much better accounting for system resources.

None of the respondents to the DWRe survey knew how much water they had saved from their leak detection efforts.

LEAK DETECTION PROGRAMS

The EPA has suggested an iterative three step approach to reducing system leakage.[6] The first step is a water audit. Knowing the amount of leakage from the audit is essential and will help determine the actions in the next step, intervention. Intervention in this case, is leak detection and repair. The amount and type of intervention can range from regular maintenance of system piping to replacement. The last step is evaluation of the intervention. What were the results? What additional actions are necessary? After evaluation, the process is repeated until leakage is down to the economic leakage level (ELL). This target point is different for each system. It is the point at which the sum of the costs of real (leakage) losses and the cost impact of the real loss reduction is at a minimum. Reducing leakage below this point is not cost effective as the return from leak reduction activities decrease.

Leak detection and repair (the second of the EPA's three steps) are only one of four main methods of controlling real leakage. The AWWA recommends that, "*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 the initial leakage reduction target and then assign the most appropriate combination of the four primary leakage control methods, which are:

1. <u>Active leakage control</u>: 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. <u>Optimized leak repair activities</u>: 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."[7]

The AWWA manual contains many suggestions for developing and using leakage indices, used to trigger differing levels of leakage management. The considerations depend upon the situation of each water utility and the limits of their water resources (supply), operational capacity and finances. One of the most often used is the Infrastructure Leakage Index (ILI). It is the measure of a systems real leakage (calculated by audit) divided by the Unavoidable Annual Real Losses (UARL) of the system (the UARL is the theoretical minimum amount of leakage the system could anticipate after utilizing all available technologies to control leakage). Most Utah systems have some form of water main rehabilitation schedule or program. However, budget restraints limit funds for such improvements and most utilities use leak repair to extend the useful life of system piping as long as possible. An audit and use of a leakage index could help justify needed expenditures.

SUMMARY

The national trend is toward more accountability for water utilities. Since funding for system repairs are projected to fall short of requirements nationwide, water utilities need to demonstrate their accountability and the need for limited monies. Most Utah water utilities are not-for-profit operations and thus operate under tight budgets. Performing a water audit can provide the information needed to demonstrate the economics of leak detection, system upgrades and repairs. Water system audits demonstrate accountability, not only for water use but also for minimizing the costs of running the system. Audits can also help establish the economic point at which an active leak detection program should be initiated. By reducing leakage to the lowest practical level and maintaining it there, system costs and resources are utilized most efficiently.

NOTES

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

[2] The term "unaccounted for water" has been defined as both all water that is not metered or billed to customer accounts, or as only water that can't be accounted for irrespective of whether it is measured or billed. Because both terms are typically very imprecise and not universal in their definition the AWWA recommends eliminating them completely. However, past water accounting studies frequently cite this term even though its definition is ambiguous.

[3] The Division of Drinking Water's cost per 1000 gallons includes all revenues collected in the state divided by the amount of metered deliveries. If leak detection and repair are undertaken, the same amount of operating revenue will still have to be collected for utilities to stay economically viable. However, reductions in production costs will eventually reduce the portion of revenue needed to pump, treat and deliver the lost water. Realistically, as systems approach the limits of their supply, water rights or treatment and delivery capacity, the incremental cost of procuring additional water would typically result in costs greater than $1.62/1000 gallons because of rising construction costs, water rights costs and the fact that most of the "cheap" water has already been developed.

[4] Lacking average costs of production for Utah, a current value was based on the 2003 production cost of $0.409/1000 gallons calculated in the SLCPUD water audit, $0.50 is a reasonable value for comparison.

[5] Ibid. Beecher 2002.

[6] Control And Mitigation Of Drinking Water Losses In Distribution System, November 2010, Environmental Protection Agency, EPA 816-R-10-019, pgs 1-6 to 1-8.

[7] Ibid; Water Audits and Loss Control Practices- M36, Third Edition, 2009, pgs. 109-110.

2

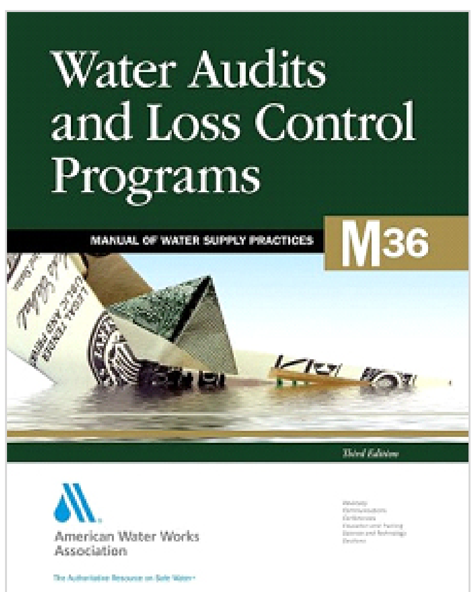
QUANTIFYING LEAKS

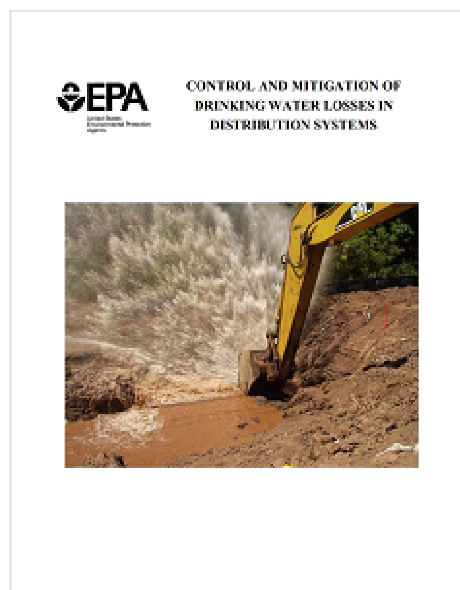
IDENTIFYING LEAKAGE WITHIN A MUNICIPAL WATER SYSTEM: THE WATER AUDIT METHOD

Introduction

Over the years, various water utilities and water professionals have developed water auditing procedures and processes to account for the water flowing into and out of a municipal water system, including leaks. Although these processes were useful for the individual systems and professionals performing the audits, they lacked a common terminology and consistent methodology, and as a result were not widely adopted by water utilities. Recognizing the lack of industry-wide standards for water loss accounting, the International Water Association (IWA) developed a standardized water audit method. Later, with the participation of the American Water Works Association (AWWA), this method was refined and published as the industry standard for water audits worldwide. In recent years, this method has been adopted by many water utilities in the United States and has even been used as the standard by several states for audits required by statute.

The Utah Division of Water Resources (DWRe) encourages all drinking water systems in Utah to adopt the IWA/AWWA Water Audit Method. Water audits should be conducted annually in conjunction with regular financial auditing cycles in order to have the greatest impact on system efficiency. To help facilitate the adoption of the Water Audit Method in Utah, this chapter summarizes its key features and benefits. For a detailed description of the method, along with useful worksheets and step-by-step instructions on how to perform an audit and improve system efficiency and performance over time, DWRe recommends that the reader obtain a copy of AWWA's manual: *Water Audits and Loss Control Programs* (M36).[1] Several other excellent free water audit resources that follow the Water Audit Method are also available from the EPA[2] and Texas Water Development Board.[3]





The American Water Works Association and the U.S.Environmental Protection Agency have prepared two documents dealing with leak detection and control.

The Water Balance

The Water Audit Method uses a water balance approach. This intuitive approach provides a detailed accounting of all the water that enters or exits the water system. Under this approach, no water is labeled “unaccounted for” and use of this flawed, yet commonly used term, is done away. Figure 1 shows all the components of the Water Audit Method’s water balance.

Audit Terminology

The Water Audit Method employs precise and standardized terminology that may be foreign to some water system operators. Some of the new terms used by this method include, “authorized consumption,” “apparent losses,” “real losses,” as well as “revenue” and “non-revenue” water. Table 3 contains the definitions of these and other important terms.

Because of their importance to quantifying leakage, the terms “apparent losses” and “real losses” are discussed in particular detail here. As noted in Table 3, apparent losses are “paper” losses that occur when water reaches a customer, but the volume is not accurately measured and/or recorded because it is unauthorized, the customer meter is inaccurate, or the data is susceptible to systemic handling errors. Apparent losses represent water that has been consumed but not paid for due to error in quantifying the volume of water. These losses cost water utilities revenue and result in understating the collective measure of customer consumption. Valued at the customer retail (revenue) rate, these losses are often very cost effective to recover.

Real losses are the “physical” losses from the water system infrastructure and primarily represent leakage from mains, valves, service lines and tanks. Real losses are categorized as leaks and overflows from storage tanks, leaks on transmission or distributions

FIGURE 1
The Water Audit Method – Water Balance

<table>
<tr><td rowspan="10">System Input Volume (corrected for known errors)</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption (including water exported)</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="8">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="6">Water Losses</td><td rowspan="3">Apparent Losses</td><td>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 and Overflows at Storage Tanks</td></tr>
<tr><td>Leakage on Mains and Lateral Pipes</td></tr>
<tr><td>Leakage on Service Connection Lines</td></tr>
</table>

Source: Adapted from, American Water Works Association, "IWA/AWWA Water Audit Method," Table 1, 2. Retrieved from AWWA's web page: http://www.awwa.org/Portals/0/files/resources/water knowledge/water loss control/ iwa-awwa method_awwa.pdf, on December 18, 2012.

TABLE 2
Standard Definitions Used in the Water Audit Method

Definitions
System Input Volume: The total water supplied to the water distribution system, corrected for any error in the production meters. It includes the sum total of purchased surface or groundwater, water obtained through the utility's own wells, water purchased through contracted interconnections with other water suppliers, or water obtained from other sources. This is the total of all production meter readings for the entire audit year from all sources. • **Production Meter Accuracy**—All production and bulk purchase volumes should be metered. Meters should be well maintained and calibrated to ensure a high degree of accuracy. For any given water utility, one or more production meters may incur a degree of inaccuracy due to wear, malfunction, or improper installation. • **Corrected System Input Volume**—The level of production meter accuracy is usually a percentage. To calculate corrected system input volume, divide the system input volume by the percentage of accuracy to achieve the corrected system input volume—the volume actually placed into the distribution system. Since inaccurate meters often under-register, this number will usually be larger than the reported system input volume.
Authorized Consumption: This category consists of all water that has been authorized for use by the utility and its customers. Authorized consumption includes, but is not limited to, water used for residential and commercial uses, fire fighting, public fountains, golf courses, municipal landscape watering, line flushing, city offices, water treatment facility use, dust control, and construction practices. Authorized consumption is all the water the utility gave permission to a business, individual, or itself to use. It may be billed or unbilled, metered or unmetered. • **Billed Metered**—Water that is appropriately metered and billed. • **Billed Unmetered**—Estimated water that has been sold but not metered; for example, dust-control trucks and types of businesses using authorized water drawn from fire hydrants or other unmetered uses. • **Unbilled Metered**—Water that is metered but not billed, such as city/government offices, city park irrigation, water treatment facility use, some fire department use, and line flushing. • **Unbilled Unmetered**— Estimated water that is not billed or metered, such as most line flushing. Estimations may also be entered for this category. Installing meters on any of the sources of significant unmetered water represents bottom-up activity to improve the accuracy of the top-down water audit and better manage these water uses.
Water Losses: This is derived by subtracting authorized consumption from corrected system input volume. Water losses exist in two major classifications: apparent losses and real losses. Both are considered types of water loss. Apparent loss is valued at the customer retail rate because it had the opportunity to be sold. Real loss, however, is calculated at the variable production cost of water. • **Apparent Losses**—These are "paper" losses that occur when water reaches a customer, but the volume is not accurately measured and/or recorded because it is unauthorized, the customer meter is inaccurate, or because of systematic data handling errors. Apparent loss is water that has been consumed but not paid for due to error in quantifying the volume of water. These losses cost water utilities revenue and understate the collective measure of customer consumption in the water utility's service area. Valued at the customer retail (revenue) rate, these losses are often very cost effective to recover. • **Real Losses**—These are the "physical" losses, largely leakage, from the water system infrastructure. Real losses are categorized as leaks and overflows from storage tanks, leaks on transmission or distributions mains, or leaks on individual customer connection lines up to the point of the customer meter. Real losses can be alternatively categorized as "reported" (visible) events or "unreported" (nonvisible—found only by active leak detection) events. Real losses occur prior to reaching customers and effectively force the water utility to treat and deliver more water than its customer population actually requires. These losses are typically valued at the variable production rate (costs for water treatment, pumping, or bulk water purchase); however, if the utility is experiencing a water shortage, then real losses may be valued at the customer retail rate because recovered leakage could be viewed as water that can be sold to customers.
Revenue Water: Revenue water consists of billed wholesale water exported and billed metered and unmetered water. These are usually the primary categories through which the utility can generate revenue.
Non-revenue Water: This term is the sum of apparent loss, real loss, and unbilled authorized consumption. Non-revenue water is clearly defined as all water for which no revenue is received.

Source: Adapted from, Texas Water Development Board, *Water Loss Audit Manual for Texas Utilities,* Report 367, (Austin, Texas: March 2008), Table 3-1, 6.

mains, or leaks on individual customer connection lines up to the point of the customer meter. Real losses can be alternatively categorized as “reported” (visible) events or “unreported” (nonvisible—found only by active leak detection) events. Real losses occur prior to reaching customers and effectively force the water utility to treat and deliver more water than is required. These losses are typically valued at the variable production rate (costs for water treatment, pumping, or bulk water purchase); however, if the utility is experiencing a water shortage, then real losses may be valued at the customer retail rate because recovered leakage could be viewed as water that can be sold to customers.

The Audit[4]

Figure 2 shows a sample form outlining all the data required and produced by the AWWA/IWA Water Audit Method. The clear cells require data entry while the shaded cells are calculated. The numbers to the left of each data entry item or calculation are referred to in the following paragraphs as necessary to describe specific items in more detail. *(Note: The free water audit software or interactive spreadsheet provided by AWWA automatically calculates the shaded entries shown in the sample form and provides further details regarding what is required for each data entry field.)*

Water Supplied (Lines 1-5)

The “Water Supplied” section of the audit requires an estimate of the volume of water entering the water system as measured by source meters (line 1). It also provides a means to account for any water imported into the system from external sources, or, conversely, exported to other water system(s) (lines 3 & 4). The form also requires an estimate of the under- or over-registration of water entering the system due to source meter errors (line 2). Unless source meters are regularly calibrated to ensure maximum accuracy, a value should be entered estimating the total volume associated with this error. This must be entered as a positive number, so it is important to indicate whether the adjustment is because the master meters under-registered (did not capture all the flow) or over-registered (overstated the actual flow). The net value of this section is the “Water Supplied” shown in line 5.

Authorized Consumption (Lines 6-10)

This section of the audit estimates the volume of water that is authorized. Authorized consumption (line 10) represents metered and unmetered water taken by registered customers (the water supplier itself and others who are authorized to do so by the water supplier, for residential, commercial, industrial or institutional purposes). This does NOT include water sold to neighboring utilities (water exported), which was registered previously as part of the “Water Supplied” section of the audit. Authorized consumption may include items such as fire fighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water and others. These are categorized as either billed (lines 6 & 7) or unbilled (lines 8 & 9), metered (line 6 & 8) or unmetered (line 7 & 9). The default value for unbilled and unmetered consumption (line 9) is calculated as 1.25% of the volume from own sources (line 1), but can be overridden if a more accurate estimate is available. While the unmetered uses will typically require rough estimates initially, they can be refined in future audits as accounting practices are improved. *(Note: An estimate of data errors in customer meters is not included in this section of the audit; these are accounted for in the following “Water Losses” section.)*

Water Losses (Lines 11-16)

This section of the audit estimates the apparent losses (line 15) and real losses (line 16) within the water system. It includes an estimate of unauthorized consumption (line 12), which includes water illegally withdrawn from hydrants, connections that bypass the meter, or meters that do not register correctly because they have been tampered with. While this component has a direct impact on revenue, in most water utilities the volume is low and it is recommended that the auditor apply a default value of 0.25% of the volume from own sources. If the auditor has well validated data that indicates the volume from unauthorized consumption is substantially higher or lower than that generated by the default value, then this value can be entered. Although a value of zero can be entered on the paper form, it will not be accepted by the free audit software since all water utilities usually have some volume of unauthorized consumption occurring in their system.

FIGURE 2
The Water Audit Method – Sample Form

Water Audit Report for:

Reporting Year:

Notes: Please enter data in the white spaces below. Where available, metered values should be used; if metered values are unavailable please estimate a value. All volumes should use the same unit: acre-feet per year (or other unit of preference). Indicate the confidence in the accuracy of the input data by grading each component (1-10) where 1 indicate very poor confidence and 10 very high confidence.

	WATER SUPPLIED	<< Enter grading in this column (1-10)			
1	Volume from own sources:			ac-ft/yr	
2	Master meter error adjustment (enter positive value):			under- or over-registered (specify) ac-ft/yr	
3	Water imported:			ac-ft/yr	
4	Water exported:			ac-ft/yr	
5	**WATER SUPPLIED:**			ac-ft/yr	
	AUTHORIZED CONSUMPTION				
6	Billed metered:			ac-ft/yr	
7	Billed unmetered:			ac-ft/yr	
8	Unbilled metered:			ac-ft/yr	Percent: Value:
9	Unbilled unmetered:			ac-ft/yr	1.25% or ____ ac-ft/yr
10	**AUTHORIZED CONSUMPTION:**			ac-ft/yr	
11	**WATER LOSSES (Water Supplied - Authorized Consumption)**				
	Apparent Losses				Percent: Value:
12	Unauthorized consumption:			ac-ft/yr	0.25% or ____ ac-ft/yr
13	Customer metering inaccuracies:			ac-ft/yr	<10% or ____ ac-ft/yr
14	Systematic data handling errors:			ac-ft/yr	
15	**Apparent Losses:**			ac-ft/yr	
	Real Losses (Current Annual Real Losses or CARL)				
16	**Real Losses** = Water Losses - Apparent Losses:			ac-ft/yr	
	NON-REVENUE WATER				
17	**NON-REVENUE WATER:**			ac-ft/yr	
	= Total Water Loss + Unbilled Meterd = Unbilled Unmetered				
	SYSTEM DATA				
18	Length of mains:			miles	
19	Number of active AND inactive service connections:				
20	Connection density:			conn./mile main	
21	Average length of customer service line:			ft	(pipe length between curb and
22	Average operating pressure:			psi	customer or property boundary)
	COST DATA				
23	Total annual cost of operating water system:			$/yr	
24	Customer retail unit cost (applied to Apparent Losses):			$/1000 gallons	
25	Variable production cost (applied to Real Losses):			$/ac-ft	
	PERFORMANCE INDICATORS				
	Financial Indicators				
26	Non-revenue water as percent of volume of Water Supplied:			%	
27	Non-revenue water as percent of cost of operating system:			%	
28	Annual cost of Apparent Losses:			$/yr	
29	Annual cost of Real Losses:			$/yr	
	Operational Efficiency Indicators				
30	Apparent Losses per service connection per day:			gallons/connection/day	
31	Real Losses per service connection per day*:			gallons/connection/day	
32	Real Losses per length of main per day*:			gallons/mile/day	
33	Real Losses per service connection per day per psi pressure:			gallons/connection/day/psi	
34	Unavoidable Annual Real Losses (UARL):			ac-ft/yr	
35	From Above, Real Losses = Current Annual Real Losses (CARL):			ac-ft/yr	
36	Infrastructure Leakage Index (ILI) [CARL/UARL]:				

* only the most applicable of these two indicators will be calculated

Source: Adapted from AWWA Water Loss Control Committee, "Free Water Audit Software: Determining Water Loss Standing," WASv4.2.

Line 13 is where apparent water losses caused by the under-registration of customer water meters can be entered. Just like source meters, customer meters are prone to error, and collectively this error can be just as significant as source meter errors. "Many customer water meters will wear as large cumulative volumes of water are passed through them over time and this causes the meters to under-register. The auditor has two options for entering data for this component of the audit. The auditor can enter a percentage under-registration (typically an estimated value), this will apply the selected percentage to the two categories of metered consumption to determine the volume of water not recorded due to customer meter inaccuracy. Alternatively, if the auditor has substantial data from meter testing to arrive at their own volumes of such losses, this volume may be entered directly. Since all metered systems have some degree of inaccuracy, a positive value should be entered. A value of zero in this component is valid only if the water utility does not meter its customer population."[5]

Line 14 is where systemic data handling errors can be accounted for. These are errors caused by various processes that are used to transmit, archive, and report customer consumption totals for billing purposes. Every effort should be made to eliminate manipulation or adjustment of this data to satisfy common billing practices or procedures; however, if this cannot be avoided, an estimate of the volume of water associated with these data handling errors should be provided.

The sum of lines 12-14 represents the apparent losses in the water system (line 15). Once this value is calculated, the volume of real losses can be determined (line 16). An alternate name for real losses is "Current Annual Real Losses" or CARL. This value is used later in the audit to estimate the Infrastructure Leakage Index (ILI)

Non-Revenue Water (Line 17)

The Water Audit Method makes it easy to estimate the costs of leakage to the water system. By breaking down the water in the system into revenue and non-revenue components, the method allows system auditors to easily identify the portion of total system input that is producing revenue and the portion that is not—and is ultimately costing the system money.

Line 17 represents the volume of water that is not producing revenue for the water utility. Non-revenue water is essentially any unbilled and unmetered water identified in the system. This is calculated in the audit by adding the amount of any unbilled metered water (line 9) to the water losses (line 11).

System and Cost Data (Lines 18-25)

Lines 18, 19 and 21 of the audit require the auditor to enter various physical attributes of the water system. This includes the length of mains, number of service connections, average length of customer service lines, and average operating pressure. Although much of this data should be readily available, some will require estimates or approximations. Lines 23-25 require the auditor to enter actual costs of operating the system for the period covered by the audit. This includes total operating costs, retail costs per unit of water, and variable production costs. Because utilities often use rate structures with different rates for different customer classes (residential, commercial and industrial, for example), it is recommended that a composite rate for all customer classes be used as the unit retail cost. The variable production cost is usually a little easier to calculate. One common way to calculate this is to divide the sum of the raw water, energy, and chemical costs by the corrected input volume.

System and cost data are critical components of the water audit and help the water utility assess the cost of water losses and whether leakage control programs would be cost effective. They also allow the utility to measure the performance of the utility over time and set short- and long-term goals to improve system efficiency. These performance indicators are discussed in more detail in the following section.

Performance Indicators (Lines 26-36)

The last component of the Water Audit Method uses the system and cost data entered to produce some financial and operational efficiency indicators that auditors can use to evaluate the performance of the water system. These indicators are valuable because they help the utility identify baseline values and set goals for system improvements over time.

Financial Indicators[6]

All water losses represent a cost to the water utility and the communities they serve. By conducting regular water audits, the utility can accurately assess the quantity of water being lost and the costs associated with that loss. These costs can then be compared to the cost of implementing leak detection and repair programs and are essential to designing a water loss reduction program that is successful and cost effective.

The first two financial indicators relate to non-revenue water. The first is non-revenue water as a percentage of the total volume of water supplied by the system (line 26). The second is non-revenue water as a percentage of the total cost to operate the system (line 27). Both of these indicators give auditors an idea of how significant apparent and real losses are to the system.

The last two financial indicators estimate the annual cost of apparent and real losses. Using the retail unit cost and variable production cost entered in the previous section, the audit form calculates the annual cost of apparent and real losses, respectively (lines 28 & 29). With the exception of the costs associated with water lost due to tank overflows, the annual cost of real losses represents the estimated cost of leakage from the water system.

Operational Efficiency Indicators

Much like the financial indicators, operational efficiency indicators provide means to compare and analyze the extent of apparent and real losses within the system. In essence, these indicators are metrics to measure performance and are only useful if they are used over time to compare performance and improve overall system efficiency.

Perhaps the most useful of all the indicators is the Infrastructure Leak Index (ILI). This index focuses only on real losses and provides a very useful way to compare the leakage within the water system to other systems throughout the world. Table 4 contains some basic guidelines as to how ILI can be used to set infrastructure improvement goals, etc.

Data Validation

Grading the Accuracy of the Data

Much of the data required by the audit necessitates that an approximation be made or is otherwise subject to physical limitations and/or systemic error. A reasonable effort should be made to eliminate these errors. It will be more effective to deal with most errors over a period of time. The Water Audit Method acknowledges the challenges associated with collecting accurate data and thus requires that the auditor assign a grading value on a scale from 1-10 to all manually entered data. This provides a realistic way to validate the accuracy of the data entered. "Validation is defined as the process by which water audit data is confirmed to reflect the actual operating conditions of the water utility within a reasonable degree of accuracy."[7] A grade of 1 indicates data that it is very rough and likely inaccurate. A grade of 10 indicates the highest level of accuracy. The auditor should not overstate the accuracy of any data, as this could undermine the conclusions of the audit and encourage premature adoption of leakage control measures, or, conversely, a false sense of security that all is well and no further action is necessary. *(Note: The free water audit software or interactive spreadsheet provided by AWWA provides some qualitative descriptions that will help the auditor determine the appropriate grade to enter for each item.)*

Improving Data Accuracy

The Water Audit Method is primarily a top-down exercise that can be performed on a computer with little to no field work required. However, this exercise is only a starting point and water system managers will want to increase the validity and usefulness of the audit over time by complimenting it with meaningful and targeted bottom-up activities. "If many of the water audit quantities are derived from estimates, new data collection procedures and/or bottom-up field activities should ultimately be instituted over the course of time to generate more accurate and realistic data that better validate the water audit results and lead to better loss control program decisions ."[8]

TABLE 3
General Guidelines for Setting a Target Infrastructure Leak Index (ILI)

Target ILI Range	Financial Considerations	Operational Considerations	Water Resources Considerations
Less than 1.0	If the calculated Infrastructure Leakage Index (ILI) value for a water system is 1.0 or less, two possibilities exist: (1) the system is maintaining leakage in a class with the top worldwide performers, or (2) a portion of the system data is flawed, causing losses to be greatly understated. The second possibility is likely if the system does not employ extensive leakage control practices. If so, system auditors should perform field measurements to confirm the accuracy of production and customer meters, or to identify other potential errors in the data.		
>1.0 - 3.0	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.	Operating with system leakage above this level would require expansion of existing infrastructure and/or additional water resources to meet the demand.	Available resources are greatly limited and are very difficult and/or environmentally unsound to develop.
>3.0 - 5.0	Water resources can be developed or purchased at reasonable cost; periodic water rate increases can be feasibly imposed and are tolerated by customers.	Existing water supply infrastructure capability is sufficient to meet long-term demand as long as reasonable leakage management controls are in place.	Water resources are believed to be sufficient to meet long-term needs, but demand management interventions (leakage management, water conservation) are included in long-term planning.
>5.0 - 8.0	Cost to purchase or obtain/treat water is low, as are rates charged to customers.	Superior reliability, capacity and integrity of the water supply infrastructure makes it relatively immune to supply shortages.	Water resources are plentiful, reliable, and easily extracted.
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 resources. Setting a target level greater than 8.0 is discouraged.		

Source: AWWA Water Loss Control Committee, “Free Water Audit Software: Determining Water Loss Standing,” WASv4.2.

Table 5 contains a matrix of recommended actions to improve data accuracy across five core focus areas. The first two areas (audit data collection and short-term loss control) contain recommendations for any level of data accuracy. The other three focus areas (long-term loss control, target-setting, and benchmarking) only contain recommendations when a certain level of accuracy is obtained. Following this planning guide will help the water utility ensure that the validity of water audit data is improved before undertaking potentially costly leakage control measures. Ideally, each water utility should seek to achieve a data validity level of IV or V and implement as many of the recommended measures that can be justified financially.

Identifying Leakage Beyond the Customer Meter

While a water utility’s responsibility to identify and correct leaks typically ends at the customer meter, leakage continues to have an impact on a municipal water system beyond the meter. Leaks in the homes, businesses, and various other entities serviced by the water utility create a greater demand on the system than would otherwise be necessary. This increases production costs and ultimately forces the system to make capital investments to acquire and develop additional water supplies sooner than would otherwise be necessary. While most water utilities that meter customers are able to cover the increased production costs associated with this leakage, they do not structure their water rates to cover the cost of large capital investments that will be necessary in the future. Thus, helping customers to identify and reduce leaks beyond the meter is beneficial to all.

AWWA Residential Indoor Water Use Survey

Leakage beyond the customer meter is not a trivial matter. In a detailed study of residential water use published by AWWA Research Foundation, researchers estimated that leaks accounted for approximately 14 percent of the average residential demand.[9] The study also found that a relatively few homes were responsible for the majority of leakage;

specifically, 10 percent of the homes in a typical water system accounted for approximately 58 percent of the overall residential leakage.[10]

Identifying Customer Leaks Using Water Use Data

The results of the AWWA study suggest that if a water utility could identify which customers are responsible for most of the leakage, they could contact these customers and offer them assistance or incentives to fix the leaks. One simple way to identify customer leaks is to analyze water use during the winter months when no outdoor irrigation is required. It is likely that the customers with the highest water use during the winter have significant leakage. This method of identifying customer leaks appears to be fairly common in Utah and should be adopted by all water utilities that would benefit from reducing customer leaks.

Identifying Leaks Using Automatic Meter Reading Technology

Another common method used to identify customer leaks is the installation of automatic meter reading technology. This technology makes it easy to read customer meters frequently and identify customers with unusual meter readings that may indicate they

TABLE 4
Water Loss Control Planning Guide

Focus Area	Water Audit Data Validity Level (Score)				
	Level I (0-25)	**Level II** (26-50)	**Level III** (51-70)	**Level IV** (71-90)	**Level V** (91-100)
Audit Data Collection	Launch auditing and loss control team; address production metering deficiencies.	Analyze business process for customer metering and billing functions and water supply operations. Identify data gaps.	Establish/revise policies and procedures for data collection.	Refine data collection practices and establish as a 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.	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.

Note: The crossed-out cells in this table indicate focus areas that are not justified and should not be pursued until a higher validity level is achieved.
Source: AWWA Water Loss Control Committee, “Free Water Audit Software: Determining Water Loss Standing,” WASv4.2.

have a leakage problem. When advanced automatic meter reading data is made available to the customer on a timely basis it makes it possible for customers to view their water usage data online, in real time, and potentially even identify and correct leakage problems on their own.

NOTES

[1] For more information about this manual, as well as free water audit software (interactive spreadsheet), see AWWA's Water Loss Control web page: www.awwa.org/resources-tools/water-knowledge/water-loss-control.aspx.

[2] See U.S. Environmental Protection Agency, *Control and Mitigation of Drinking Water Losses in Distribution Systems,* EPA 816-R-10-019, (Office of Water: November 2010).

[3] See Mathis, Mark et. al., *Water Loss Audit Manual for Texas Utilities,* (Texas Water Development Board, Austin, Texas: March 2008).

[4] The text describing certain audit categories in this section comes directly from AWWA's free water audit software mentioned in note 1 above (Water Audit Software Program ©American Water Works Association). Because the text refers to this valuable tool frequently, it was not deemed necessary to place quotation marks around every instance of direct quotation.

[5] Explanation of "customer metering inaccuracies" from Water Audit Software Program ©American Water Works Association.

[6] Mathis, Mark et. al., *Water Loss Audit Manual for Texas Utilities,* (Texas Water Development Board, Austin, Texas: March 2008), 5&7. This section is derived in part from Section 3.1, "How Much Are Losses Costing the Utility?"

[7] Mathis, Mark et. al., *Water Loss Audit Manual for Texas Utilities,* (Texas Water Development Board, Austin, Texas: March 2008), 10.

[8] Ibid.

[9] Mayer, Peter W. et. al., *Residential End Uses of Water,* a study sponsored and published by the AWWA Research Foundation (Denver, Colorado: 1999), xxvi.

[10] Ibid, xxvii.

3

LOCATING LEAKS

Large leaks tend to surface even in porous soils where water can drain away rapidly, and they are repaired quickly. Smaller leaks, occurring in pipes buried in tight, fine-grained soils such as clays, may also surface because the water follows the path of least resistance which is generally toward the surface. But many leaks never surface if an adequate conduit, such as bedding gravels or sand are present, allowing the leakage to migrate elsewhere, going undetected without an audit or an active search. This is especially true about leaks located in areas of underlying loose gravelly soils or under roadways bedded (by specification) with readily drainable soils.

With any leak detection program, detectable leaks can form at any time between surveys. The AWWA M36 manual suggests that the average awareness time for a leak is half the time period between leak surveys[1] (that is if all detectable leaks are discovered with each survey). The total run time of a leak depends additionally upon the response time, which is determined by the priority of leak repairs, scheduling the repair and the time it takes to pinpoint and repair the leak. Large leaks are repaired quickly due to the damage they can cause, the loss of system pressure and the attention they garner. Small leaks can run much longer even once they are detected because the value of the water loss may not offset the cost of digging up and repairing the leakage and subsequent roadway repair. In well maintained systems many small to medium size leaks may form the bulk of water losses.[2]

Water utilities can locate leaks through one or a combination of any of three primary methods: visual, acoustic or flow measurement. Which of these methods utilities choose to employ and their rate of success depend upon the specific requirements of each method and matching conditions in the utilities system. All of these three methods are important in controlling leaks, however, active leak detection and reduction programs go beyond repairing the leaks discovered through visual evidence. It also requires accounting accurately for system water and diligently searching for and repairing as much leakage as makes sense economically. Besides measuring water flow and conducting a water audit, an active leak control program uses acoustic devices that can amplify, record and analyze noise generated by leaking water. Using modern water meters and acoustic devices, leaks can be detected and located accurately and quickly.

LEAK DETECTION METHODS

Visual Detection

While visual detection is typically a passive method of discovering leaks (since finding a leak is dependent upon evidence of the leak appearing and being reported) it is still important to any leak detection program. An active leak detection program requires that managers and operators have a good knowledge of their water system. Meter reading personnel are often trained to look for leaks as they read individual service meters. They can discover leaks by looking for water seeping through pavement cracks and flowing along street edges as well as slumping pavement. However, city residents often report leaks before they are discovered by city personnel.

With the advent of automated meter reading (AMR) and automated meter infrastructure (AMI) technology, meters are now being read more frequently by radio to vehicle or by direct signals. This has elimi-

Ground Microphone or Geophone. (Photos courtesy of Sewerin Technologies for Leak Detection.)

nated the periodic visual inspection of mainline routes and system meters. Previously, water system meter readers would walk the entire system to read meters one, two or more times each year. Personnel were taught what to look for and listen for at each meter and visually along their reading routes. Leaks in the meter box could be detected by sound or visually. During the course of the Utah DWRe system survey, several operators mentioned that before the installation of AMR meters, meter reading personnel would find several leaks each year. However, AMR meters often find leaks much more quickly, especially on the customer side of the meter. To replace the visual detection that has been lost by the replacement of meter reading personnel, cities frequently train staff to look for evidence of leaks and periodically have them walk their system. As they walk the system, they may also listen with acoustic devices at each meter, hydrant and exposed system valve, for leakage sounds.

Acoustic Devices

Most of the leak detection technology that has been developed over the past 60 years or so has been based on acoustic leak detection. Water leaking from pressurized pipes imparts energy to the piping and appliances such as valves, meters, and hydrants producing audible sound that can travel considerable distances in a distribution system, especially in metal pipe. Water escaping under pressure emits two distinct sounds: low frequency sounds that come from pressurized water impacting soil, and higher frequency sounds coming from the leak in the pipe. Trained listeners can distinguish between the two sounds. Lower frequency sounds travel only a short distance, while the higher frequency sounds can travel considerable distances along pipes. Metal pipes transmit sound much further than poly, asbestos cement, or pvc pipe.

Acoustic listening devices have been used since the 1950s. The first devices (still in use today) were comprised simply of an ear cup attached to a metal rod. The metal rod would be placed on the pipe or appliance and the sound would travel to the cup, against which the technician would place his or her ear. The cup isolated the ear from ambient noise and amplified sounds transmitted through the pipe. Later devices electronically amplified the sound to which the technician listened to through headphones, greatly enhancing the sensitivity. The strength of the sound received would indicate the distance to the leak as the device is moved closer or further away.

Ironically, small leaks tend to produce more noise and are thus easier to detect with all acoustic equipment.

Another listening device is a ground microphone that can be placed directly on the ground to listen for sounds generated by escaping water. This equipment is still widely used today, often to verify the leak locations indicated by leak correlators.

Newer equipment uses listening technology that can detect noise from leaks that often produce sounds at too low of a frequency for the human ear. Computer technology has also been employed to help calculate the distances from listening points to the point of leakage. These devices are called “Leak Correlators” and are placed on valves or pipes to listen for and record leak noises. The devices are usually magnetically attached at two points of the distribution system with a suspected leak located somewhere on the pipe between them. The distance to the leak between each of the two locations can be calculated by computer algorithms that compare sound volume and frequency between the points and through different pipe materials.
Other listening devices called “Leak Noise Loggers” (loggers) can be placed at multiple valves, meters, or pipe locations to listen and record leak sounds. Both Provo City (40 loggers), and Salt Lake City (16 loggers) use these devices, which they move around their respective systems to detect leaks. The loggers can be programmed to turn on and record late at night when background noise from traffic and normal water uses are minimal. The reduction in noise at these times allows greater sensitivity for the listening devices and the reduced water use helps ensure that leakage noise is not overshadowed by normal turbulence through the pipe. After retrieval, the sound file for each location is recorded and stored on a computer to compare with subsequent recordings of the same location. Some devices can transmit the data to a receiver where it can be transferred immediately to a computer for analysis. Data loggers can be deployed permanently or moved around to survey different parts of a system. After they are recorded, leak noises can be compared to expose anomalies. Computer programs can compare noise at one location with subsequent recordings or with a database of typical leakage sounds to detect leakage. With the use of a data logger system, once a leak has been detected it is typically pinpointed between two listening points using a correlator or geophone.

Flow Measurement

Automated Meter Technology

One newer technology that is helping municipalities track consumption and can detect water leaks is radio-read meters. Automated meter readings can be used to identify leaks on the customer side of the meter. For older systems that are read only a couple of times each year, leak detection through meter reading is difficult. When meters are read more frequently the likelihood of detecting anomalous flows increases, although only the largest of leaks may still

Leak Correlators pinpoint leakage between two points. (Photo courtesy of Fluid Conservation System.)

be detectable due to differences in the period in which meters are read. Meters read each month may not be read exactly the same number of days apart even for the same month each year and the difference in consumption may hide small leaks. Newer meters are often read on a monthly or daily frequency and large changes in daily flows or comparisons with previous year's flows for the same period can point out potential leaks

The first meters that municipalities installed in Utah were simple[3] and required city personnel to walk to each meter and read the indicated use. Over time, a system could become comprised of different models of meters from the same manufacturer or from different manufacturers. Misreading the meter dials often occurs because the dials can be arranged differently or the hands can turn opposite to others. Technicians had to look out for these differences, but errors sometimes happened. This was partially rectified by touch read meters where the technician would carry a device that could electronically retrieve meter data simply by touching a probe to a point on the top of the meter. This still required someone to walk to each meter. In Utah, many cities only read their meters biannually or monthly in the warmer months due to snow limiting access to the meters and other weather related hazards and access issues. In addition, the labor costs of having monthly readings could entail having several meter readers out at the same time in order to cover a municipal system in a timely manner. The advent of Automatic Meter Reading (AMR) technology introduced a transmitter to the meters. The meter sends out a short-range radio signal that can be picked up by a receiver installed in a passing vehicle. AMR meters send out information every 30 seconds to one minute, so a whole area could be read by a slow moving vehicle fairly quickly. Many cities can read their meters in one day with this system. The data would then be downloaded into a computer for archiving and billing purposes. The AMR system reduces errors in reads, eliminates the need for many hours of meter reading labor and allows meters to be read year round.

AMR technology has now moved to the next generation systems with the introduction of a fixed network to receive meter signals, called Automatic Meter Infrastructure (AMI). With this system, receivers

Correlating noise loggers attach with strong magnets and record pipe sounds at each location. (Photos courtesy of Fluid Conservation System.)

are installed permanently throughout the city that can retrieve signals from the AMR meters. All meters within a city can often be read in 15 minutes depending on the size of the system and the type of infrastructure installed.

With AMI comes quick monthly billing, the ability to resolve customer inquires into billing and use, the reduction in "truck rolls" to read meters for disconnects, and the ability to provide web-based "customer engagement," where the utility can post detailed daily usage on a personalized web portal. When combined with information such as lot size and number of people in residence, the billing can show how their usage compares with other customers with a similar profile, or with past years' usage. In addition, the utility can detect leakage on the customer side of the meter through comparative water flows. This is where metered flows are typical of hoses left on, or continuous meter flows during the nighttime when water use should stop even if for a short period. The utility can also set alarms for extreme flows that can indicate line breakage. This is especially helpful in areas with seasonal homes which are frequently unattended and breaks can go undetected for long periods. The meters need to be properly sized and accurate enough to record small flows in order to detect leaking toilets and large drips (1/8 to ¼ gpm is typical of toilet leaks). One study performed in California revealed that some meters in the system were too large to record flows below 1/8 gallons per minute and thus unable to detect smaller leaks.[4] Some AMR system managers have implemented biweekly or weekly reading of their meters to emulate some of the advantages of AMI systems without upgrading. By reading meters more often, smaller anomalous flows such as are created by smaller leaks can be detected. While still not having all the capabilities of AMI systems such as nearly instantaneous leak detection, the ability to detect small leaks and reduced truck rolls for shut off and meter checks etc., the improvements may well be worth the extra effort.

The meters are not without problems. Each meter can cost more than four times that of a simple mechanical meter, and battery life, while greatly improved and often under warranty for up to 20 years, still produce headaches for system operators. Additionally, the technology is still evolving and system managers worry that today's software and meter technology could quickly be outdated and not continue to be supported by the manufacturer. There are also issues of compatibility between older and newer models. Another issue pointed out in a recent article in the magazine "Water Efficiency,"[5] is that customers are not utilizing the full potential of AMI technology due mostly to the fact that the municipal systems themselves need to produce the web portals and reports that allow viewing and analysis of the large amounts of data AMI can provide. "Each operation runs a bit differently, and sophisticated AMI customization must necessarily occur in-house."[6] Adding interactive customer access to customer records for example would require setting up a web portal and usually a computer system operator.

In addition to serving water utilities, AMI systems can also be used to read electric and gas meters when they are properly equipped. An impediment to shared AMI systems though, is that water utilities in Utah are more commonly owned by the municipalities they serve, while gas and electric utilities operate separately and supply many municipalities. Cooperation between these entities cold provide cost sharing for all as well as greater flexibility in control and speed and ease of reading meters.

When AMI is used in a system equipped with a supervisory control and data acquisition system (SCADA) the utility can often perform monthly water audits. SCADA systems place gauges on many of the larger system valves and pipelines which gives a utility the ability to monitor not just customer connections, but also system inflow, tank volumes, pressures and mainline flows and other parameters from a central computer or location. This enables system accounting on a continual basis. SCADA also provides the ability to control valves and gates when they are equipped with actuators, enabling easier management of the system. New software, designed to analyze system pressures, can detect leakage in the system despite daily changes in system flows and pressures. The software uses historical patterns and trends to compare with current pressures to detect anomalous patterns and alert system operators to potential problems.[7]

<u>Zone Audits / System Isolation</u>

Zone or District Metered Area (DMA) testing segregates the system into smaller areas for flow and pressure testing. It requires that a segment of the distribution system can be isolated from the main system by valves at each end and the area must also have either a permanent or temporary meter installed to measure flow into the DMA. Flow into the DMA is measured and cataloged. Changes in flow during the same or similar time periods may indicate increased leakage. DMA audits cannot pinpoint leakage but can identify problem areas and indicate when area piping may need replacement. Flow characteristics for each DMA may change as connections are added and retired, or uses change. It is essential to keep accurate records of these changes in order to discern increases in leakage. With a system divided into DMAs, a mini audit on each area can be performed even if the larger system has difficulty calibrating source meters or other challenges which make conducting an accurate system audit difficult. In systems with very large intakes, measuring flows may be difficult due to the importance and difficulty of calibrating large meters. Small errors in the calibration of large meters can mean large inaccuracies in measurement. DMAs offer the ability to measure flows with smaller meters that are more easily calibrated and often times, better sized for flow rates incurred in the pipe. A leak detection search is implemented when a target loss value is reached for each DMA. This method can be effective for small and medium DMAs but in larger areas small leaks can be hidden by system background leakage. The AWWA manual contains detailed instructions for using DMAs to determine leakage. Once leakage has been determined for a DMA, other means are needed to precisely pinpoint the leakage, generally acoustic devices.

Other Detection Methods

Trace Gas Sampling

Trace gas tests typically use helium or hydrogen gases. In both tests the gas is introduced into the water line suspected of leaking and the gas or gas-mixture escaping through leak is detected. If helium is used the line is dewatered and then filled with gas by opening one end and filling at the other end of the water line to be tested. Helium is detectable in very small amounts and once the water line is filled with pressurized gas, “sniffing” equipment (mass spectrometer) is passed along the surface to detect escaping helium. Helium is an inert gas which means it will not react readily with the water or other chemicals present in the water system and it is not flammable. When hydrogen is used, it is first mixed as a hydrogen/nitrogen solution at a 5 percent concentration of hydrogen (below 5.7 percent hydrogen is not flammable) in nitrogen, and the mixture is then be added directly to the water system without dewatering. After the gas has been added to the water supply it escapes with the leaking water into the soil and then fairly quickly to the surface of the ground. Since hydrogen molecules are small they easily move through moderately porous soils but less quickly through tight soils such as clays. As with helium, a sniffer is then moved across the ground above the suspected leaking pipeline to detect the gas. The Kane County Water Conservancy District had good success using this method to find leaks in their Duck Creek Fork area where porous soils had allowed small leaks to previously go undetected.

Storage Tanks

Leaks occurring in storage tanks can go undetected until the tanks are drained for cleaning. The base material under many tanks is composed of course soils often covered over with gravel for leveling and support. Leaks in the tank can often find their way into and through the course material and remain unseen for years. To test for leaks, tanks need to be isolated from the system for several hours and the water level watched to see if it remains constant. Many communities in Utah have tanks that are gravity fed from mountainside springs and once full they simply overflow. Without meters on both the inflow and both the outflow and overflow of these tanks, leakage goes undetected. Water tanks fed by pumped water automatically shut off the pump when full so leakage can be calculated if the outflow is metered or can be shut off. Periodic testing by isolating the tank and outlet can reveal leaks. The most effective leak detection programs will regularly monitor storage tanks for leaks.

OTHER CONSIDERATIONS

Geographical Information System (GIS) Mapping

Over the past two decades the mapping of city utilities has improved dramatically. City maps can now be entered digitally into a computer data base with the coordinates and important information about the water system detailed. The physical characteristics of the pipe such as age, material, pressure and leak locations, as well as the location of each bend of pipe, valve, hydrant and connection can aid in system management. This makes it much easier for system personnel to be familiar with and trouble-shoot their system. Records of leak repairs and leakage can be valuable in predicting when pipe sections need replacing or where leaks may likely be. The location of retired services and their valves can often be lost. With GIS, the location of service line connections and meters can be documented on maps as well as other pertinent data. With newer AMR and AMI meters, visits to valve locations are eliminated and vegetation can obscure them. Accurate mapping preserves their locations, saving time and effort in finding leaks.

Consultant or In-house

Many of Utah's utilities surveyed by DWRe indicated that they use consultants to find leaks and to audit their system. Simple internet searches can locate many consultants nearby that have equipment and trained personnel to acousticly survey municipal water systems. Leakage consultants can have a wide range of equipment including data loggers, which can be expensive for a small utility or municipality to purchase, and they will contract to survey all or a portion of each system. Having a consultant periodically look for leaks can aid systems even when the leakage rate is unknown. The results of small area surveys can often be extrapolated to indicate the condition of other portions of the system of similar construction and time frame.

Hiring an engineering firm to conduct an audit is also an option for municipalities. Most frequently, an audit can be conducted by the municipality if they have kept fairly detailed records and have maintained their system meters well enough that they have confidence in their data. They can utilize the IWA/AWWA audit resources to calculate system balances and performance indicators. Large, complex systems may desire to hire a consultant due to a myriad of problems they have to tackle. The large Salt Lake City Public Utilities System hired a consultant in 2004 to conduct an audit of their system. Some of the challenges they faced in performing the audit were accurately determining flows at five water treatment plants and calibrating the respective source meters. In addition to conducting an audit of the system, the consultant came up with several recommendations that will enable easier and more accurate audits in the future. Most of the less-complex systems in Utah should be able to perform a rudimentary "top-down" audit using their own resources and estimates. Increasing confidence levels may require outside help in some cases.

The Rural Water Association of Utah

The Rural Water Association of Utah (RWAU) is an organization that works with water and wastewater entities across the state. The RWAU is funded by the Environmental Protection Agency, US Department of Agriculture, the State of Utah, and by membership dues. RWAU technicians can help water users find leaks and perform audits of their systems. The association has limited leak detection equipment but its technicians have a wealth of experience with water delivery systems and can help find leaks, calibrate meters and solve a myriad of other problems when requested.

NOTES

[1] Manual of Water Supply Practices: Water Audits and Loss Control Programs -M36 third edition, 2009, American Water Works Association, pg. 144.

[2] Brown, T.G., D. Huntington, and A. Lambert, 2000. *Water Loss Management in North America –Just How Good Is It?* Proceedings , Technical Session on Progressive Developments in Leakage and Water Loss Management, Distribution System Symposium. Denver, Colo.: American Water Works Association.

[3] With 3 or 4 rotating dials that rotate and read similar to a clock's face.

[4] “Pressure Zone Audits Pinpoint Water Loss,” *Opflow*, David Wallenstein and Andrew Chastain-Howley, May 2008, pgs. 18-20.

[5] “Data: Where to Start,” *Water Efficiency*, David Engle, January/February 2013, pgs. 10-15.

[6] Ibid. pg.14

[7] “Pressure Monitoring Software Helps Identify Distribution System Problems,” *Waterworld*, January 2013, pg. 48. Online magazine found on the web at: www.waterworld.com

4

CASE STUDIES

UTAH

Centerville Culinary Water System

Centerville Culinary Water serves approximately 17,000 people through 4,511 service connections. This system conducted an audit in 2009 and more recently, an audit in 2012. The 2012 audit was much more detailed and had many similar components to the AWWA water audit. In addition to a water balance accounting, the second audit included many of the "bottom up" activities recommended by the AWWA. These activities included calibration of production and customer water meters, checking for zero read meters and billing discrepancies, and breaking the system into District Metered Areas (DMAs) utilizing the five pressure zones of the system.

To produce the DMAs, city personnel installed bypass lines around their system's pressure reducing valves (PRVs). Low-flow meters were installed on each bypass to accurately record the low nighttime flows that they anticipated into each DMA. Early morning flows were measured because the lowest flow rates measured could indicate leakage in the DMA. By increasing system pressure to 90 psi the PRV valves closed and the low demand flows were met by the bypass line without the PRV opening. In three of the pressure zones an average leakage rate of 0.02 gpm per connection was calculated. City personnel believe this rate represents leaks on the customer side of the service meters because water main leaks surface quickly due to the fine-grained soils distributed through most of the city. In one of the other two zones, excessive leakage was tracked to one of the city's storage tanks. The tank was drained, cleaned and repaired, then retested. Leakage from the tank dropped from 18 gpm to 1.49 gpm after repair. Future plans are to replace all tank caulking to drop leakage even further. The other line with high flows included some industrial connections. Once the tank was repaired and the industrial connections were isolated and accounted for, these two zones were retested and showed the same amount of leakage per connection as the first three lines.

City personnel bench tested several of their residential meters and discovered that flows below ¼ gpm were not detected by the meters and that amount, if universal throughout the city, could easily account for the 12% city-wide leakage. City staff calculated the cost of the leakage at their production cost with a value of approximately $6,000 per year. However, losses on the customer side of the meters should be valued at the retail cost since those are billing losses. The theoretical minimal background leakage for this system has not been calculated, but would be useful for comparison purposes.

Provo City (Acoustic Correlators and AMI)

The Provo City water system serves approximately 120,000 people through 18,573 retail service connections. City water official determined that unaccounted for water was around 18 percent in 2009 which was unacceptable to them. The city bought correlating leak noise loggers to help them identify where some of the water was leaking. Twenty Gutermann loggers were installed in an area that was prone to earth movement (possibly from underground springs) which they wanted to monitor to make sure leaks weren't contributing to the problem. The city also used 40 additional loggers they could move to listen for leak sounds throughout the system. The loggers are placed on valves and hydrants overnight to record sound, they are then retrieved the next day and the data is analyzed to identify pipe segments with suspected leaks. Two real-time leak correlators are then placed on two points on the pipe segment with leak noises to pinpoint the location of the leak. Information such as pipe length and size, composition, and pressure are all entered and used by the computer program to help locate the leak on the pipe segment. Finally, a geophone is used to verify leakage sounds at the pinpointed location and the leak is then repaired or marked for later repair. The 40 loggers are moved throughout the city in the same manner, listening for leaks. City staff indicated that several leaks were found in very porous soils that exceeded 100 gallons per minute. These leaks had produced no visible evidence of their presence. Although it is not known how much water was lost through all the leaks that were repaired, production meter readings dropped between 15 and 18 percent over the same months of a ten year average. Successive surveys of the distribution system have only found minor leaks.

The city is also changing its meters to a complete AMI system using Neptune brand meters. So far, 3,000 of the 18,573 meters have been changed out. The city expects the complete change out to take 4 to 6 years. The new meters log all meter flows and software supplied for the system can analyze and graph each account to look for anomalies. The program can flag suspicious readings such as constant reads overnight (indicating a continuous leak) or intermittent meter readings of the same volume (possibly a leaky toilet flapper). So far, nearly 50 percent of the new meters have flagged suspicious flows. The city is adjusting the parameters the system uses to identify flow anomalies as they learn the capabilities of the system and software. Among other things, the new system will help identify tampering, backflow, leakage and excessive use and will help both the customer and utility better manage their water consumption.

Salt Lake City (Comprehensive Water Audit and Acoustic Monitoring)[1]

The Salt Lake City Public Utilities Department (SLCPUD) serves over 326,000 customers through 92,000 connections. Seventy-eight percent of those connections serve single residences which use 44.5 percent of the drinking water delivered. Inflow to the system is about 110,000 acre-feet per year. In response to increasing water loss records, the SLCPUD conducted an audit of its water system in 2003 using the IWA/AWWA water audit methodology. At the time, the city was only the fifth major utility in the United States to perform a complete IWA/AWWA water audit.

A consultant was hired to help coordinate and gather all the information required for the audit and to make calculations and estimates as needed. The consultant also worked on the meter calibration issues and made corrections as best they could. The biggest obstacle auditors faced was the calibration of the large source meters, flumes, and weirs at the water treatment facilities. Much of the water coming into the system is from surface water sources (72 percent) by way of the Jordan Valley Aqueduct and from mountain creeks with under a third (28 percent) coming from groundwater. Therefore, small errors in measuring the large incoming surface water sources can easily throw off the balance calculations of the audit, so their calibration was critical. The SLCPUD attempted to rectify all calibration issues but was unable to, owing to budget, issues dealing with construction, and space limitations to add calibration points, tapping locations, rebuilding of a weir and pipeline ownership. As a consequence, the confidence level in the results of the water audit was low.

To measure how the utility compares to other similar utilities, the IWA/AWWA performance index[2] was used. This calculation uses the audited leakage rate to compare with the amount of leakage that would still be present in an ideal system where every leak reduction action was taken. The background leakage calculation is based on the number of connections, miles of main, length of pipe between mainline and meter, and average system pressure. Based on the best estimates auditors could produce, the audit placed system Current Annual Real Losses (CARL) at 4,364,000 gallons/day and Unavoidable Annual Real Losses (UARL) at 2,174,000 gallons/day, producing the system Infrastructure Leakage Index (ILI) at 2.01 (4,364,000/2,174,000 = 2.01), “which is a very creditable performance for a utility that does not have an active leakage control programme.”[3] The audit estimated real leakage losses at $650,000 per year based on $0.409/1000 gallons for non-revenue water, while apparent losses were valued at $1.178 million per year based on the 2003 retail rate of $1.3763/1000 gallons for total loss valued at $1.829 million[4]. The city is planning to perform another audit when it has addressed more of its master meter issues and billing discrepancies.

Since the audit, the department has implemented an active leak detection program with a dedicated full-time employee. The city has had good success with leak correlators and other acoustic devices. Department personnel use 16 leak correlating loggers that are moved around the city water system weekly to listen during the night for leakage sounds. They have found that the loggers do not work with their PVC pipe sections or in areas with high constant flows, such as near hospitals and factories. Personnel find leaks almost daily and some are fixed immediately while others are marked for later repair. Until their next audit (planned for 2018) city managers can only guess at how effective their leak detection program has been.

Vernal (Consultant Services, Acoustic Leak Survey)

The Vernal Municipal Water System serves approximately 9,000 citizens through 4,315 retail connections. The city hires a consultant service to acoustically survey a quadrant of the city each year for a cost of about $5,000 per year. The consultant is required to listen at every valve, meter, and hydrant in the quadrant (which typically amounts to over 900 points and about 13 miles of pipe). Much of the system is PVC pipe which does not transmit sound as well as metal pipe. If no access is available to the pipe or appliances a geophone is used over hard surfaces such as concrete or asphalt. Over bare soils, a plate may be used, or a listening rod driven into the ground to collect leak sounds from nearby pipes.

The survey frequently identifies leaks on the customer side of the meter as well as leaks in the water mains and appliances. The consultant produces a report detailing the location and size of the leaks it finds and submits a report to the city. If the sound profile indicates a leak is large enough, it is often repaired immediately by the city. Although the city repairs 25 to 30 leaks annually, the 2012 consultant survey only revealed three leaks (a service connection 12 gpm, a hydrant leak estimated at about 0.5 gpm, and a customer side leak of unknown volume). Over the course of a year 12.5 gpm would equate to 20 acre-feet of water.

NATIONAL

Philadelphia[5]

Philadelphia began to analyze its water losses in 1980 when an unaccounted-for Water Committee identified sources of water loss and proposed loss reduction actions. Improvements proposed for their system at that time included master meter calibration, leak detection crews and customer meter replacement. Even after these efforts were initiated non-revenue water remained well above 100 mgd in the decade following this work.

In 1993 a water rate increase of 30 percent was proposed and rejected, but prompted further loss reduction measures. The city formed a standing “Water Accountability Committee” which began participating with the AWWA’s Water Loss Control Committee in the early 1990s. As recommended by the city’s committee, expansion of the water mains replacement program and water meter replacement program, were also undertaken. Between 1997 and 1999, the city replaced over 400,000 meters with new AMR meters.

The city became the first U.S. system to perform a water loss audit using the AWWA method in 2000. By using the AWWA method, the city was able to calculate the performance indicators recommended in it. An infrastructure leakage index (ILI) of 12.3 was calculated for the city. The ILI is a measure of the cities leakage rate compared against the unavoidable annual real losses (UARL) that the city could achieve with background leakage at a minimum. That means that the city has leakage 12.3 times the amount of unavoidable annual real losses it could expect under ideal conditions.

As of June 2006, the city had reduced its losses from the level of 120 to 130 mgd they had before 1994, to 76.9 mgd, reducing its ILI to 9.9. These reductions came from measures enabled by the AMR meter installation and other leak control measures to control real and apparent losses. Real losses have been reduced through a combination of stepped-up leak detection efforts, improved leak repair job routing, introduction of District Metered Areas (DMAs) and pipeline replacement. Based on a recommendation in the report *Applying Worldwide Best Management*

Practices in Water Loss Control[6] the city has set a goal to reduce the ILI to under 8.0 within five years.

Apparent losses have been reduced by the residential meter replacement (with AMR meters), large meter right-sizing, billing error corrections, thwarted unauthorized consumption, and creation of billing accounts for city-owned properties. The city is also continuing to work on reducing its still excessive, non-revenue water.

Reducing apparent losses has a high value for the city because they are billed at the retail rate. Even though real losses (59.3 mgd) are four times that of apparent losses (15.1 mgd) in volume, apparent losses represent water that could be billed at the retail rate. The cost of real losses (actual loss) are valued at the cost of production and equals $4 million annually. Apparent losses (meter and billing losses) are valued at the retail rate and are over $20 million annually.

NOTES

[1] Experience of Using the IWA/AWWA Water Audit Methodology in Salt Lake City Public Utilities Public Utilities Department, J. M. Lewis Salt Lake Public Utilities Department, 153 South West Temple, Salt Lake City, Utah 84115, USA Jim.Lewis@ci.slc.ut.us, and P. V. Fanner, Fanner and Associates Ltd. 7 Brunswick Hill, Reading, RG1 7YT, UK, Paul@FannerAssociates.com .

[2] Manual of Water Supply Practices: Water Audits and Loss Control Programs -M36 third edition, 2009, American Water Works Association, pgs. 52-61.

[3] The ILI most suitable for the SLCPUD as taken from the AWWA –M36 manual on page 112, is 1.0-3.0.

[4] An error was entered into the "LEAKS" spreadsheet model the consultant used to calculate audit values. The culinary water production cost of $0.409 was entered as $0.0409 in error, causing real losses to be calculated at 1/10th their actual value. Total annual losses as stated on page 75 of the report should have been reported as $1.829 million, coming from apparent losses of $1.178 million and real losses of $651,000.

[5] Manual of Water Supply Practices: Water Audits and Loss Control Programs -M36 third edition, 2009, American Water Works Association, pgs. 259-265.

[6] Kunkle G. 2003. Applying Worldwide Best Management Practices in Water Loss Control. Committee Report -- AWWA Water Loss Control Committee. *Journal AWWA*, 95(8): 65. (This guideline has been added to the AWWA Manual of Water Supply Practices: Water Audits and Loss Control Programs -M36 third edition on pg. 112).

5

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The purpose of this study was to determine the nature and extent of water auditing and leak detection efforts being utilized by Utah's municipal water suppliers, review current standards and practices, and to make recommendations that could be undertaken by them.

The survey conducted during the course of this study revealed that most Utah municipal water systems do not accurately account for water use and that most do not have an "active" leak detection program. The very common and rudimentary accounting that many system officials (in Utah and nationwide) refer to as an audit, compares customer's metered billing with source or production meters and the difference between them is termed "unaccounted for" water, but this definition is not universal. Some systems may estimate in whole or in part, the amounts used for firefighting, dust control, system flushing, leakage, authorized un-metered uses theft or other amounts. These quantities of water may or may not be included in either of the production or billed categories. So even if one system's make-up and size are similar to others, their unaccounted for water volumes may not be comprised of the same components, making it useless as a comparative index.

RECOMMENDATIONS

Utah's municipal water suppliers should eliminate the term "unaccounted-for" water from their vocabulary and universally adopt the AWWA/IWA terminology as the standard for water auditing. Replacing "unaccounted-for" water with very distinct terms and categories will enable accurate accounting of municipal water supplies and provide understandable and useful divisions of water use that can be better understood and managed.

The second recommendation is that all of the 150 municipal water suppliers that are currently required to submit an updated conservation plan to the DWRe every five years, should also include an AWWA/IWA "top down" water audit or thereafter, an updated water audit with their plans also every five years. The results of the audit will improve system accountability and indicate the general condition of the system better than the ABCD rating system currently used by the DDW (or it can help determine the leakage conditions for this rating). Further, the results of the audit can be used to calculate other AWWA/IWA indices that can be used to compare their system's performance with previous year's audits and with other systems, and can also be used to trigger leak detection and repair activities. The audit should include calculation of the AWWA infrastructure leakage index (ILI) in order to compare their system with others and to measure the municipality's progress with each successive audit. With these indices calculated, a more accurate estimate of the value of lost water and revenues can be made and the economic level of leakage (ELL) determined. Additionally, the confidence level for each component of the audit should be determined and included, and the municipality should strive to improve the overall confidence with each audit turned in.

After the initial submission of audits, a minimum confidence level could be set by the DWRe as a target for successive audits. A minimum ILI of 8 (recommended by the AWWA/IWA audit methodology see chapt. 2) could be set as a target for initiating leak detection and repair activities. In addition to the DWRe, the Division of Drinking Water and Division of Water Rights could also utilize water audit information in their planning efforts. The Board of Water Resources and Drinking Water Board could consider the water audit as a requirement for grants and loans.

The last recommendation comes from the AWWA/IWA manual, that all supply systems should be engaging in at least one of the four pillar activities of leakage control.

1. Active leakage control
2. Optimize leak repair activities
3. Pressure management
4. System rehabilitation and repair

An investigation into the particulars of these four activities and their application is up to the individual water systems. Leak detection activities can be undertaken even without an audit and, as indicated by the DWRe survey, most systems engage in the last activity, system rehabilitation and repair on a regular basis.

Better accounting of water resources should be a key component of efficiently running a water supply utility. Leakage control activities to keep losses at the ELL will ensure fiscal responsibility and give customers greater confidence in system administrators.

APPENDIX A

SURVEY FORM:

LEAK DETECTION SURVEY OF

UTAH MUNICIPAL WATER SYSTEMS

LEAK DETECTION SURVEY OF UTAH MUNICIPAL WATER SYSTEMS

Surveyor Name:____ Date:____________________________

System Name: ____ Phone Number:__________________

Contact & Position:______________________________________ Email Address:___________________

Hello, my name is ________________ with the Utah Division of Water Resources. We are currently studying leak detection efforts throughout the state. Our study will identify those systems that are **actively** searching for leaks and highlight the detection methods that may be more practical and effective for other Utah systems.

Do you have time to answer a few questions for me?

If no: When would be a good time for me to call you back?

If they still seem reluctant or extra busy: Would it be easier for me to send you the questions via email?

1. To Start with, do you know the age of the oldest sections of your delivery system?

2. Have you ever conducted a Water Loss Audit of your water system? (By audit, I mean a budget or mass balance of all inflows and outflows to and from your system.)

3. Do you have an estimate of your current leakage?

    a. Does this amount include other unaccounted-for water, such as unmetered water (fire flows, system flushing, dust control or irrigation of public grounds, schools etc.)?

4. At what point or what percentage of leakage do you believe it would be advantageous to try to locate and eliminate leaks?

5. Do you have an **active** leak detection program?
(To clarify, an active leak detection program is one that attempts to identify and/or locate~~s~~ leaks through one or more of the following methods: system audits, customer billing comparisons, utilizing acoustic listening equipment, zonal pressure testing etc. Many suppliers wait for water to surface or for reports of leaks from the public and call that leak detection; this is not an active program.

If yes;

a. What are the specifics of your program?

b. How long have you been doing it?

c. What have been the results (water/cost savings)?

d. Do you have any other thoughts regarding your program that you would like to share with us?

6. Would you be interested in receiving a copy of our report when it is completed?

If yes, what is your email address?

APPENDIX B

THE WATER AUDIT METHOD-SAMPLE FORM

Water Audit Report for:

Reporting Year:

Notes: Please enter data in the white spaces below. Where available, metered values should be used; if metered values are unavailable please estimate a value. All volumes should use the same unit: acre-feet per year (or other unit of preference). Indicate the confidence in the accuracy of the input data by grading each component (1-10) where 1 indicate very poor confidence and 10 very high confidence.

	WATER SUPPLIED	<< Enter grading in this column (1-10)			
1	Volume from own sources:			ac-ft/yr	
2	Master meter error adjustment (enter positive value):			under- or over-registered (specify) ac-ft/yr	
3	Water imported:			ac-ft/yr	
4	Water exported:			ac-ft/yr	
5	**WATER SUPPLIED:**			ac-ft/yr	
	AUTHORIZED CONSUMPTION				
6	Billed metered:			ac-ft/yr	
7	Billed unmetered:			ac-ft/yr	
8	Unbilled metered:			ac-ft/yr	Percent: Value:
9	Unbilled unmetered:			ac-ft/yr	1.25% or ac-ft/yr
10	**AUTHORIZED CONSUMPTION:**			ac-ft/yr	
11	**WATER LOSSES (Water Supplied - Authorized Consumption)**				
	<u>Apparent Losses</u>				Percent: Value:
12	Unauthorized consumption:			ac-ft/yr	0.25% or ac-ft/yr
13	Customer metering inaccuracies:			ac-ft/yr	<10% or ac-ft/yr
14	Systematic data handling errors:			ac-ft/yr	
15	**<u>Apparent Losses:</u>**			ac-ft/yr	
	<u>Real Losses (Current Annual Real Losses or CARL)</u>				
16	**<u>Real Losses</u>** = Water Losses - Apparent Losses:			ac-ft/yr	
	NON-REVENUE WATER				
17	**NON-REVENUE WATER:**			ac-ft/yr	
	= Total Water Loss + Unbilled Meterd = Unbilled Unmetered				
	SYSTEM DATA				
18	Length of mains:			miles	
19	Number of <u>active AND inactive</u> service connections:				
20	Connection density:			conn./mile main	
21	<u>Average</u> length of customer service line:			ft	(pipe length between curb and
22	Average operating pressure:			psi	customer or property boundary)
	COST DATA				
23	Total annual cost of operating water system:			$/yr	
24	Customer retail unit cost (applied to Apparent Losses):			$/1000 gallons	
25	Variable production cost (applied to Real Losses):			$/ac-ft	
	PERFORMANCE INDICATORS				
	<u>Financial Indicators</u>				
26	Non-revenue water as percent of volume of Water Supplied:			%	
27	Non-revenue water as percent of cost of operating system:			%	
28	Annual cost of Apparent Losses:			$/yr	
29	Annual cost of Real Losses:			$/yr	
	<u>Operational Efficiency Indicators</u>				
30	Apparent Losses per service connection per day:			gallons/connection/day	
31	Real Losses per service connection per day*:			gallons/connection/day	
32	Real Losses per length of main per day*:			gallons/mile/day	
33	Real Losses per service connection per day per psi pressure:			gallons/connection/day/psi	
34	Unavoidable Annual Real Losses (UARL):			ac-ft/yr	
35	From Above, Real Losses = Current Annual Real Losses (CARL):			ac-ft/yr	
36	Infrastructure Leakage Index (ILI) [CARL/UARL]:				

* only the most applicable of these two indicators will be calculated