



CONTROL AND MITIGATION OF DRINKING WATER LOSSES IN DISTRIBUTION SYSTEMS



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Acronyms and Abbreviations

AM	Asset Management	O&M	Operation and Maintenance
AMR	Automatic Meter Reading	PCCP	Prestressed Concrete Cylinder Pipe
ANSI	American National Standards Institute	PRV	Pressure Reducing Valve
ASCE	American Society of Civil Engineers	PVC	Polyvinyl Chloride
ASDWA....	Association of State Drinking Water Administrators	PWS.....	Public Water System
ASTM	American Society for Testing Materials	SCADA	Supervisory Control and Data Acquisition
AWWA	American Water Works Association	TILDE	Tools for Integrated Leak Detection
		WARN.....	Water & Wastewater Agency Response Network
BABE.....	Breaks and Burst Estimation	WRF.....	Water Research Foundation, formerly the American Water Works Association Research Foundation
CADD	Computer-Aided Design and Drafting	UARL	Unavoidable Annual Real Losses
CARL	Current Annual Volume of Real Losses	UFR	Unmeasured Flow Reducer
CUPSS	Check-Up Program for Small Systems	US.....	United States
DMA	District Metered Area		
DWSRF.....	Drinking Water State Revolving Fund		
ELL	Economic Level of Leakage		
EPA	United States Environmental Protection Agency		
FAVAD.....	Fixed and Variable Discharge Paths		
gpm	Gallons Per Minute		
GRP.....	Ground Penetrating Radar		
IWA.....	International Water Association		
ICCP.....	Impressed Current Cathodic Protection		
ILI	Infrastructure Leakage Index		
ISO	International Standards Organization		
MassDEP...	Massachusetts Department of Environmental Protection		
NRWA	National Rural Water Association		
NTNCWS .	Non-Transient Non-Community Water System		
NSF	NSF International (Formerly National Sanitation Foundation)		

Executive Summary

Maintaining system infrastructure to deliver clean and safe drinking water to customers is often a significant challenge for the operators of public water systems (PWSs). Much of the estimated 880,000 miles of drinking water infrastructure in the United States has been in service for decades and can be a significant source of water loss. In addition to physical loss of water from the distribution system, water can be “lost” through unauthorized consumption (theft), administrative errors, data handling errors, and metering inaccuracies or failure. Water is a commodity that is produced by a PWS; therefore, lost or unaccounted-for water can be equated to lost or unaccounted-for revenue. A water loss control program can help to locate and reduce these water losses and thus maintain or increase revenue.

A PWS must balance use of its resources to address the financial and personnel demands of economic restrictions, water availability, population and climate changes, regulatory requirements, operational costs, and public and environmental stewardship. A water loss control program can help identify and reduce actual water losses along with apparent losses resulting from metering, billing or accounting errors. Water loss control programs can potentially defer, reduce, or eliminate the need for a facility to expend resources on costly repairs, upgrades, or expansions. A water loss control program will also protect public health through reduction in potential entry points of disease-causing pathogens.

A water loss control program is an iterative process that must be flexible and customizable to the specific needs of a PWS. There are three major components of an effective water loss control program that must be repeated on a periodic basis to continually evaluate and improve the performance of a PWS. These three components are 1) the Water Audit, 2) Intervention, and 3) Evaluation.

Conducting a water audit is a critical first step in developing a water loss control program. A water audit quantifies the amount of water that is being lost. Most states have regulatory policies that set acceptable losses from PWS distribution systems at a maximum of between 10 and 15 percent of the water produced by the PWS. This percentage of unaccounted water provides estimated losses and does not adequately quantify how or why this water is categorized as “unaccounted-for.” Lack of standardized terminology has historically added to difficulties in comparing water losses from different PWSs. The International Water Association (IWA) and the American Water Works Association (AWWA) have developed standard methods and terminology to perform water audits and to assist water utilities in tracking their distribution system losses. The AWWA/IWA water audit methodology is based on the water balance table, which specifies different types of water consumption and losses. Through the water audit,

options will become apparent regarding how to proceed with further identifying where losses are occurring or where efforts to control or eliminate the losses should be concentrated.

The Intervention process begins to address the findings of the water audit and can include a variety of actions such as gathering of further information, implementing metering programs, adding or changing metering, and detecting and repairing leaks. The selected intervention option should provide the highest potential benefit value for the resources available that will help to alleviate a flaw or deficiency in the distribution system.

The Evaluation portion of the program consists of assessing the success of the audit and intervention actions. The evaluation of an intervention action can be as simple as answering a yes or no question – *Was the leak located and repaired?* – but more often provides detailed quantification of the implemented action through the use of performance indicators – *The pipe replacement resulted in a reduction of water losses of 1,000 gallons per customer per year.*

Performance indicators numerically evaluate different aspects of the distribution system and need to be consistent, repeatable, and presented in meaningful standardized units. A performance indicator (or collection of several) can be used to establish a benchmark. A benchmark allows a PWS to evaluate its performance over a period of time by repeating the performance indicating tests and comparing them with previous results. Performance indicators and benchmarks also allow comparisons between public water providers.

Accurate metering is crucial in a water loss control program. Metering establishes production and customer use volumes as well as provides historic demand and consumption data that is useful not only for auditing but for planning future needs. There is no single type of meter that will accurately measure flow for all applications, but there are a variety of meters that have been developed using different operating principles, designed to perform within required tolerances under different circumstances. The cost of meters typically ranges from a few hundred dollars to thousands of dollars per meter depending on size, complexity, and operating conditions. A PWS must select the meters they use carefully according to intended use, flow rates, and the environment where it will be installed. How the meters will be read is also a decision that a PWS has to decide when considering metering programs. Meters can be read manually but most PWSs are moving toward a variety of different Automatic Meter Reading (AMR) systems that reduce reading errors and allow labor to be reduced or reallocated.

While it is possible to spot losses through billing data discrepancies or abrupt changes in amounts of water that have been historically used, it is typically necessary to physically pinpoint the leak in the field. The location of a leak is not always obvious unless it is large. An array of

techniques and equipment are available to assess leakage from distribution lines within a geographic area or pinpoint a leak within a suspected segment of pipe. Flow monitoring of a District Meter Area (DMA) can be used to determine leakage within an area that can be isolated and may encompass 1,500 to 2,000 service connections. These techniques monitor flow to specific areas and compare water flowing into the area with known or estimated night usage to determine losses in the DMA or along a branch water line.

There are several different types of leak detection equipment that use different operating principles. Acoustic equipment detects a leak through noise made by water as it leaks from the pipe. Electromagnetic field detection is used on pre-stressed concrete pipe and locates defective reinforcing steel in the pipe. Thermal detection devices look for the temperature differences in the surrounding ground caused by saturation due to the leaked water. Chemical detection relies on locating substances added to the treated water such as chlorine or fluoride that do not occur naturally. A tracer gas may also be introduced into dewatered lines. If there is a leak, a special instrument can detect it at the surface. The different styles of leak detection equipment require varying levels of skill and experience to operate with accuracy. Capital costs for typical leak detection equipment range from less than one hundred to several thousand dollars depending on its complexity.

Once a leak is located it should be repaired. Some repair techniques include wrapping or using repair clamps. Replacement can be done by installing new pipe in an excavated trench or by use of a trenchless method, such as sliplining or pipe bursting, where a new pipe of the same size or larger is pulled through the existing pipe with special equipment. Micro tunneling and hydraulic jacking are other trenchless techniques where pipe is either pushed or pulled underground without the necessity of large amounts of excavation.

Operations and maintenance (O&M) procedures and standards should also be a part of any water loss control program. Along with ensuring proper design, and installation of new distribution components, maintenance and operation measures such as system flushing, valve exercising, meter assessment testing and replacement programs, system modeling, and pressure management all contribute to improved efficiency, reduction in water losses, and often cost savings.

Developing a complete water loss control program requires careful consideration of the water loss reduction goals a PWS wishes to achieve. The program should be customized for the unique features of the PWS and be flexible enough to update as the PWS conducts future water audits. Those assembling a water loss control program should also remember there is help available from the EPA, other PWSs, state drinking water primacy agencies, and other drinking water trade and conservation organizations.

1 WATER LOSS CONTROL PROGRAMS FOR PUBLIC WATER SYSTEMS

1.1 INTRODUCTION

Safe drinking water is a necessity for life. Every day billions of gallons of this precious commodity are delivered to millions of people across the United States (US). Thousands of independent water utilities around the nation are dedicated to producing, treating, and delivering safe water to the public. Significant resources are required to install, operate, and maintain the infrastructure of a public water system (PWS). PWSs are facing more obstacles and challenges today than they have in the past with more resource and funding constraints. The infrastructure of many of the drinking water systems in the US were built decades ago and are currently in need of attention. PWSs are not only expected to produce safe drinking water at a low cost but must also address current growing concerns such as limited water availability, increasing water demands, climate change, increasing regulatory requirements, and limited resources and funding.

The deterioration of the infrastructure of these drinking water systems has become a critical issue. There are approximately 880,000 miles of drinking water infrastructure in the US. In the American Society of Civil Engineers' (ASCE) 2005 *Report Card for America's Infrastructure* it was estimated that there will be at least an \$11 billion annual shortfall over the next 20 years in funds necessary to replace aging facilities and meet existing and future drinking water regulations. As the integrity of our aging infrastructure decreases, the loss of finished water in the distribution system increases. The loss of integrity in the distribution system is evident by the increasing amounts of reported breaches in distribution systems. The loss of finished water in the distribution system results in direct loss of revenue for the PWS. The American Water Works Association (AWWA) estimated in the *Distribution System Inventory, Integrity and Water Quality* publication that there are close to 237,600 breaks per year in the US leading to approximately \$2.8 billion lost in yearly revenue.

Water loss from a utility's distribution system is a growing management problem that is not only confined to lost revenue. Water losses in the distribution system require more water to be treated, which requires additional energy and chemical usage, resulting in wasted resources and lost revenues. With growing concerns about shrinking budgets, PWSs must look at how they can optimize their production and revenue. Water lost in the distribution system equals revenue lost. For these reasons more and more PWSs across the country are implementing water loss control programs. Not only can a well implemented water loss control program reduce revenue loss, but it can also protect public health by eliminating the threat of sanitary defects that may allow microbial or other contaminants to enter the finished water.

This guidance has been prepared for water management administrators, local government officials, system operators, and others who have an interest in developing programs to reduce losses from their drinking water distribution systems. The success of a water loss control program depends on the ability to tailor the program to the individual PWS. This guidance provides information on flexible tools and techniques that may help the PWS meet their water loss prevention needs.

1.2 GROWING CONCERNS PUBLIC WATER SYSTEMS FACE AND HOW A WATER LOSS CONTROL PROGRAM CAN HELP

A public drinking water system must provide enough water to meet demand at a reasonable cost while maintaining quality standards to protect public health. A PWS and its water management administrators must balance these goals at the same time they face growing concerns such as:

- Water availability.
- Economic restrictions.
- Population change: expanding and shifting populations.
- Climate change and drought.
- Operational and maintenance costs.
- Regulatory requirements.
- Public service responsibility.
- Social pressures and environmental stewardship.

Many of these issues are inter-related. A water loss control program can help to address each of these issues.

Water Availability

The complexity of PWSs varies with a community's size, composition, and location. All systems depend on quality and abundant water sources to meet increasing water demands. A PWS's source may be ground water, surface water, ground water under the influence of surface water, purchasing finished water from another PWS, or a combination of these sources. Each of these options requires resources and funds to locate, develop, treat, and maintain the source. When insufficient availability becomes an issue, a PWS has the option to find and develop another source or buy additional water from another PWS. However, finding a new reliable and adequate quality source may not always be easy or an option. Thus, the PWS may strive to reduce water demand. This can be accomplished by end-user conservation, or the PWS can investigate their processes and operations and determine if there is any way to save water. This is when developing and implementing a water loss control program at the PWS becomes essential. Through a water loss control program, water that was previously lost can now be sold

to the consumers, increasing revenue, meeting water demands, and reducing the need for other sources. Such a program may be able to defer development of new sources and reduce or eliminate the need to supplement supply from another PWS. The water loss control program is often the most economical solution.

Economic and Population Change

Population growth can put an additional strain on a water system. Economic, manufacturing, and industrial growth in a community can also affect the ability of a water system to provide sufficient water. Some industries rely heavily on water, such as food processing and beverage companies. These water demand increases must be met either by locating other sources, increasing the capacity of the existing water treatment facility, or investing in new capital improvement projects. A water loss control program can help find water that was previously lost in the system and potentially defer, reduce, or eliminate the need for more expensive alternatives. A reduction in population means less revenue for a PWS operating the distribution network, a portion of which may represent “stranded” capacity.

Climate Change and Drought

Droughts are naturally occurring phenomena. Periods of drought can contribute to increased water demand and add strain to the PWS’s source water supply. Drought effects can be especially critical in the more arid Southern and Western regions of the United States. Governmental agencies track drought data to predict water and resource needs. Drought maps like the one in Figure 1-1 for August of 2008 can be found at <http://drought.unl.edu/dm>. A water loss control program can help lessen the severity of the effects of drought and climate change on PWSs through retention of more water in their distribution system. This not only has the effect of retaining more water for the customers, but can lessen the amount withdrawn from the source.

U.S. Drought Monitor

August 5, 2008
Valid 8 a.m. EDT

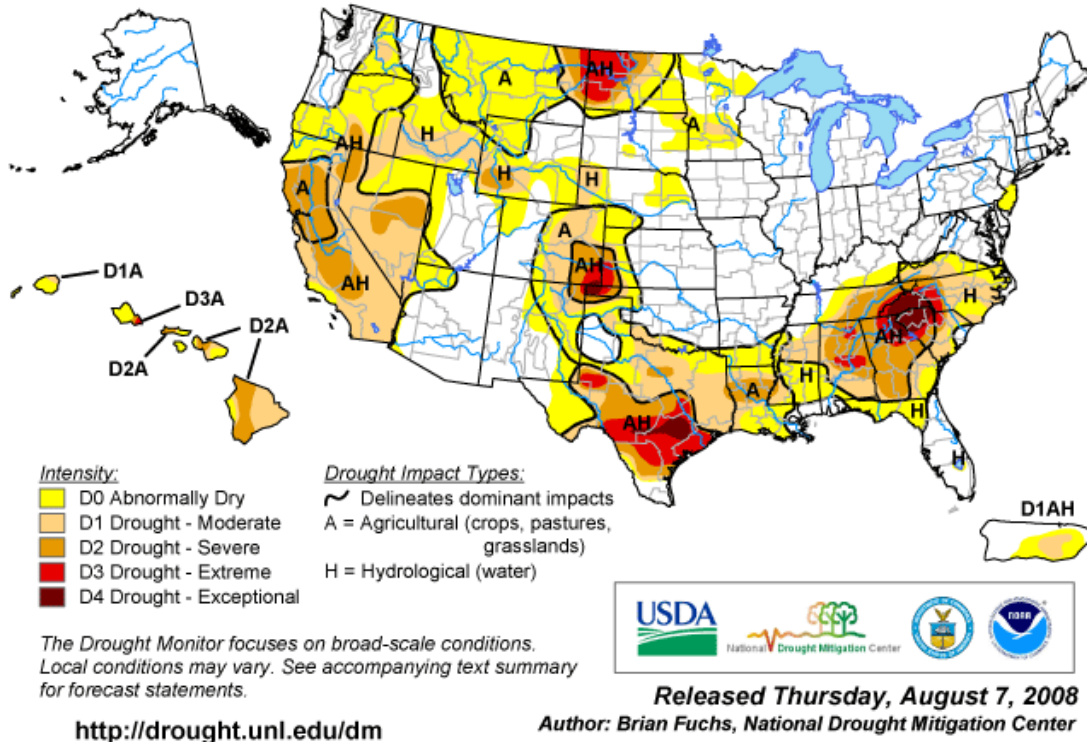


Figure 1-1. Drought Conditions During August 2008.

Source: National Drought Mitigation Center, August 2008.

Operational and Maintenance Costs

Water loss control programs can also benefit the bottom line of a PWS. Reduced water losses in the distribution system can translate to:

- Less electricity required to treat and pump the water,
- Reduced damage and liability costs from fewer disruptive piping failures,
- Potential reduction in the feed rates of treatment chemicals, and
- Potential reduction in disinfectant dose.

It can also mean deferred treatment facility upgrades. Savings may also be realized through reduced equipment maintenance and replacement. Along with fewer breaks and leaks to be repaired, the service life of distribution piping may be extended through pressure management and surge suppression schemes. Review of metering accuracy and other metering programs can recover lost revenues. Metering and pressure management will be discussed further in the following chapters.

Regulatory Requirements

Currently, there are no national requirements for auditing and reporting water loss from PWSs, but some states have taken it upon themselves to begin regulating and assessing water loss from systems in their jurisdictions. Texas, for example, became a leader in the push to control water loss with the passing of House Bill 3338, which required all Public Water Utilities to conduct water audits for 2005 operations and every five years thereafter. In 2009, the Pennsylvania Public Utility Commission, Delaware River Basin Commission, and California Urban Water Conservation Council enacted requirements for water utilities to submit annual water audits using the AWWA Free Water Audit Software®, which features the AWWA/IWA water audit methodology. The water audit report addresses four main points of water loss: real losses, largely distribution and customer service line leakage; and apparent losses occurring from customer metering inaccuracies, accounting errors in meter reading and billing practices, and unauthorized consumption. Many other states have existing rules regarding losses from PWSs and are continuing to tighten and enforce these requirements. A water loss control program can make complying with these existing and future regulations easier.

Public Service Responsibilities

A water loss control program can contribute significantly to a PWS's responsibility to provide its customers with safe water. Through a water loss control program, potential points of entry for microbial and other contaminants are reduced, increasing public health protection. Some facets of the program can reduce main breaks and the collateral damage associated with locating and repairing these breaks. For example, a water audit may identify sources of water loss in the distribution system. By addressing water leaks proactively, the PWS can prevent interruptions in service and reduce the cost of repair. Other potential benefits to the customers include: deferred rate increases, better distribution system reliability, and improved ability for the distribution system to meet the higher water pressure and flows required for firefighting. Combined, these benefits ultimately increase customer satisfaction and reputation of the PWS.

Social Responsibility and Conservation

In addition to the benefits to the PWS and its customers, a water loss control program can have further overarching benefits. Increasing social, government, and public pressures have changed the way society conserves water resources to ensure future sustainability. Not only will a water loss control program help conserve water, but it can directly impact the amount of electricity and treatment chemicals used. It may lead to conservation of materials and fuels used in maintenance and repairs. Combined, the reduction in use of these resources can help reduce greenhouse emissions.

1.3 WATER LOSS CONTROL PROGRAM COMPONENTS

A water loss control program must be flexible and tailored to the specific needs and characteristics of a PWS. There are three major components to an effective program:

1. The Water Audit.
2. Intervention.
3. Evaluation.

Each of these major components consists of additional steps and options.

The *Water Audit* is an assessment of the distribution, metering, and accounting operations of the water utility and uses accounting principles to determine how much water is being lost and where. The American Water Works Association (AWWA) recommends that an annual water audit be compiled by the water utility as a standard business process. Through the water audit process, options will become apparent as to how to proceed with further identifying where losses are occurring or where efforts to control or eliminate the losses should be concentrated. These options should be compared and evaluated not only economically but with consideration of all other issues and concerns the PWS faces. Typical steps in an audit include:

- Gathering information,
- Determining flows into and out of the distribution system based on estimates or metering,
- Calculating the standard performance indicator values and assessing water loss standing by comparing these values with ranges of values from audits from other water utilities,
- Assessing where water losses appear to be occurring based on available metering and estimates,
- Analyzing data gaps (e.g., determining if more information is necessary to make comparisons and an informed decision),
- Considering options and making economic and benefit comparisons of potential actions, and
- Selecting the appropriate interventions.

The *Intervention* process puts the options selected into action. More than one action may be selected as beneficial to a PWS and the public. For example, the water management administrator may decide that the PWS has three high priority items including adding additional metering in one neighborhood, precisely locating and repairing a leak in a specific section of main, and replacing a one-mile section of pipe. Selecting the order of these actions should be

based on budget constraints, public benefit, and priority of other scheduled capital improvements. Intervention can include:

- Gathering further information, if necessary,
- Metering assessment, testing, or a metering replacement program,
- Detecting and locating leaks,
- Repairing or replacing pipe,
- Operation and maintenance programs and changes,
- Administrative processes or policy changes, and
- No further action is necessary.

The *Evaluation* portion of the program consists of assessing the success of the audit and intervention actions. The evaluation will answer questions such as:

- Were the goals of the intervention met? If not, why not?
- Where do we need more information?
- How often should we repeat the Audit, Intervention, and Evaluation process?
- Is there another performance indicator we should consider?
- How did we compare to the last Audit, Intervention, and Evaluation process?
- How can we improve performance?

A major portion of evaluation is benchmarking. The audit establishes performance indicators, which serve as benchmarks. The intervention action should improve performance in some way. Evaluation is necessary to ensure that whatever the intervention was, it succeeded in its goal. If the goal of the intervention was not met, the evaluation process seeks to determine why and what can be done about it.

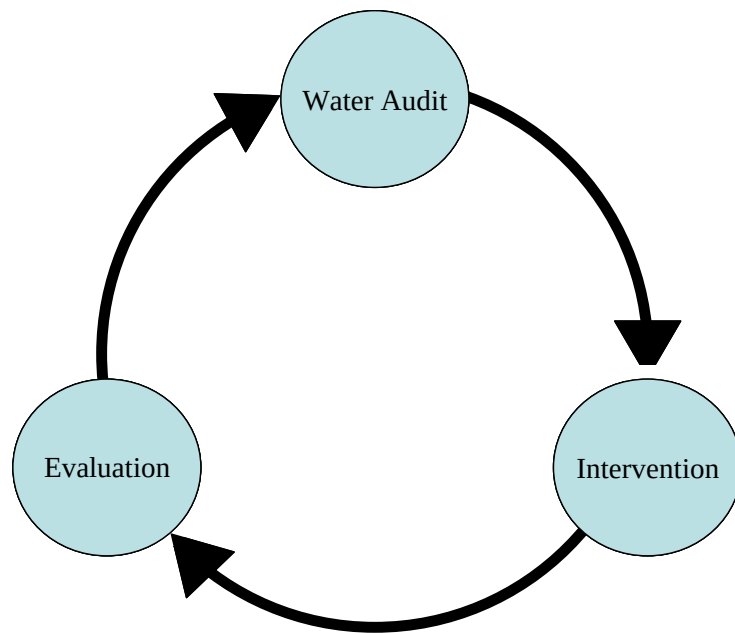


Figure 1-2. Water Loss Control Program Components.
A water loss control program as a continuous process.

2 WATER LOSS TERMS AND CONCEPTS

2.1 INTRODUCTION

There is no current comprehensive national regulatory policy that limits the amount of water loss from a public water supply's distribution system. Most states, however, do have policies and regulations that address excessive distribution system water losses. The policies vary among states, but most set limits that fall within the range of 10% to 15% as the maximum acceptable value for the amount of water that is lost or "unaccounted-for."

Neither the term "unaccounted-for-water" nor the use of percentages as measures of water loss is sufficient to completely describe the nature and extent of losses in water utility operations. Unaccounted-for-water is a term that has been historically used in the United States to quantify water utility losses. Unaccounted-for-water, expressed as a percentage, has generally been calculated as the amount of water produced by the PWS minus the metered customer use divided by the amount of water produced multiplied by 100, or,

$$\text{Unaccounted-for-Water \%} = \frac{(\text{Water Produced by PWS} - \text{Metered Water Used})}{\text{Water Produced by PWS}} \times 100$$

Although this percentage provides a rough idea of how much water fails to recover revenue, it does not help answer questions such as: Is the water really being lost? If so, where? Is water that is used for firefighting or by the city for street cleaning really lost? What about inaccurate meters, theft, or billing errors? These situations all can contribute to lost water but do not necessarily mean that there is excessive leakage in the distribution system. Determining how much water is being lost and where losses are occurring in a distribution system can be a difficult task. Without consistent and accurate measurement, water losses cannot be reliably and consistently managed. The confusion over inconsistent terms and calculations has led to the development of better tools and methods to track losses in water utility operations.

The International Water Association (IWA) and the American Water Works Association (AWWA) began to finalize standard methods to assist water utilities in tracking their distribution system losses in the last several years. These methods are the foundation of water auditing and conservation strategies that are now being used successfully

worldwide. In order to understand how to apply the AWWA/IWA methodology, several concepts and terms must be defined and explained. The AWWA/IWA Water Balance Table (Figure 2-1) is the foundation of the methodology and defines the terms used in water auditing. The water audit determines the type and quantity of water loss. Performance indicators can then be calculated to measure the level and volume of water losses in the PWS. These performance indicators then serve as benchmarks to gauge improvement during the next scheduled audit. Performance indicators and benchmarks are discussed in more detail in Section 2.4.

2.2 THE WATER BALANCE

System Input Volume	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
			Billed Un-metered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non Revenue Water (NRW)
			Unbilled Un-metered Consumption	
	Water Losses	Apparent Losses (Commercial Losses)	Unauthorized Consumption	
			Customer Meter Inaccuracies	
			Systematic Data Handling Errors	
		Real Losses (Physical losses)	Leakage in Transmission and Distribution Mains	
			Storage Leaks and Overflows from Water Storage Tanks	
			Service Connections Leaks up to the Meter	

Figure 2-1. The AWWA/IWA Water Balance Table.

Standardized terminology and definitions are crucial to consistent measurement. These standards are needed to accurately track performance and improvements. In the AWWA/IWA methodology, all water that enters and leaves the distribution system can be classified as belonging to one of the categories in the water balance table shown in Figure 2-1; each of these terms is defined below. The table is balanced because it accounts for all of the water in the distribution system, and the sum of any of the columns should also total the *System Input Volume*.

System Input Volume is defined as the amount of water that is produced and added to a distribution system by a PWS. It also includes water that may have been purchased from

another water supplier to supplement the needs of the PWS. It is important that this value be well validated as it is the first, and largest, number included in the water audit.

Authorized Consumption is water that is used by known customers of the PWS. Authorized consumption is the sum of billed authorized consumption and unbilled authorized consumption and is a known quantity. It also includes water supplied to other PWSs.

Billed Metered Consumption is an authorized consumption that is directly measured. It is the quantity of water that is metered and generates revenues through the periodic billing of the consumer.

Billed Un-metered Consumption is an authorized consumption that is based on an estimate or flat fee. This billing method is used for customers that do not have meters. Estimated use is often based on historical or average use data. The fee may vary for different types of customers such as residential or industrial.

Unbilled Authorized Consumption consists of known uses, condoned by the utility, for which no revenue is received. Unbilled authorized consumption can be either **metered** or **un-metered**. Unbilled authorized consumption is shown in yellow in Figure 2-1. Some examples might include filling city street cleaner trucks or a city swimming pool, flushing water lines or sewers, or water used by the fire department. All are legitimate water uses, with the full cognizance of the utility.

Unbilled Metered Consumption is that quantity of water that does not generate revenues but which is accounted and not lost from the system. Water used in the treatment process or water provided without charges are examples of these quantities. The PWS does not bill a charge for this water.

Revenue Water is water that is consumed and for which the utility receives payment. Revenue water consumption volume is measured or estimated. Revenue water includes metered and un-metered billed authorized consumption. Revenue water is shown in green in Figure 2-1.

Non-Revenue Water (NRW) is water that is not billed and no payment is received. It can be either authorized, or result from apparent and real losses. Unbilled Authorized

Consumption is a component of NRW and consists of unbilled metered consumption and unbilled un-metered consumption.

Unbilled Un-metered Consumption is the quantity of water that is authorized for use by the PWS but is not directly measured and creates no revenues. Water main flushing and firefighting are often examples of this category.

Some PWSs either meter or estimate use by the city or public services such as fire departments even though no fee is charged. These systems have an advantage when preparing a water audit since this information can be input into the water audit with a high degree of validation.

Unauthorized Consumption is that quantity of water which is removed from the system without authorization and presumably without the PWS's knowledge. Unauthorized consumption includes theft by illegal meter by-passes, vandalism, or un-metered hydrant use for construction or recreation. This water quantity is very difficult to estimate but must be accounted for and is amenable to reduction through administrative action. Figure 2-2 shows a fire hydrant with a garden hose attached as an illustrative example of an un-metered and possibly unauthorized connection. Unauthorized consumption as in this example can also be a potential source of contamination because there is no backflow prevention device in use.



Figure 2-2. Hydrant With Un-metered and Possibly Unauthorized Use.

The lower part of the Water Balance Table consists of **Water Losses**. Water losses are categorized as either real or apparent. **Real Losses**, also referred to as physical losses, are actual losses of water from the system. When performing financial calculations related to real losses, leakage volumes are often valued at the cost of production since this water is not available for a consumer to use and costs only what it takes to produce. In many cases, reducing real losses results in lower operating cost through reduced production requirements and reduced water process chemical and electrical use. In cases of PWSs operating in regions of limited water resources, real loss reductions may be

valuated at the customer retail rate (same as apparent losses) based upon the premise that any water saved via leakage reduction can be sold to meet growing customer demand.

Real Losses are the physical leaks shown in grey in Figure 2-1 and consist of leakage from transmission and distribution mains, leakage and overflows from the utilities' storage tanks, and leakage from service connections up to and including the meter. Preventing or repairing real losses usually requires an investment in the utility loss control program and/or PWS's infrastructure. Such investment can reduce losses such as:

- **Distribution and transmission main leaks**, which represent the quantity of water that is lost from the system, generates no revenue, can severely damage system reliability if not corrected, and may result in water quality problems.
- **Storage leaks and overflows from water storage tanks**, which consist of the quantity of water that is lost from the storage facilities within the system.
- **Service connection piping leaks**, which consist of the quantity of water that is lost from leaks from the main to the customer's point of use. Even though a leak after a customer's meter can generate revenues for the PWS and is often the responsibility of the customer, it is wasteful and can strain customer and PWS relations. Service connection leaks represent real losses from the system and may be easy to detect or very challenging to identify. In the AWWA/IWA water audit methodology only service connection leaks up to the meter are included.

Apparent losses, also referred to as commercial losses, occur when water that should be included as revenue generating water appears as a loss due to unauthorized actions or calculation error. Apparent losses consist of unauthorized consumption, customer metering inaccuracies, and systematic data handling errors in the meter reading and billing processes. Apparent losses are shown in orange in Figure 2-1.

Customer Metering inaccuracies and systematic data handling error losses can be thought of as accounting losses. This quantity of water flows through the water distribution systems and reaches the customer endpoint, with under-stated or no revenue generated. These apparent losses arise from customer metering inaccuracies caused by a variety of means, meter reading errors, data handling and billing errors, and billing period variances. Some of the quantities lost via systematic data handling error may be reduced through administrative action.

When performing financial calculations related to apparent losses, the water is priced at the retail rate since it should have been charged at that rate. Recovering apparent losses will not reduce physical system leakage, but it will recover lost revenue. Repairing or

replacing inaccurate meters or enforcing policies against unauthorized use can substantially reduce apparent losses.

These water balance terms help classify and standardize the methods used in the water audit. The water audit is the starting point for the utility to understand its water loss. The audit is a methodical approach to account for all water that is placed into the distribution system and accounts for its ultimate disposition.

2.3 THE WATER AUDIT

The water audit is the foundation and critical first step in the establishment of an effective water loss management program. With the successful completion of a system water audit, the PWS will have gained a quantified understanding of the integrity of the distribution system, which provides the basis to formulate an economically sound plan to address losses. Water loss in a public water system can be a major operational issue. Non-revenue generating water can significantly affect the financial stability of the PWS. The interventions needed to identify and abate water loss may carry its own substantial costs. The economic trade-offs between value of lost water given it generates no revenue and the investment to reduce this loss requires careful planning and economic judgment. The PWS needs to clearly understand the type of loss as well as its magnitude. Water resource, financial, and operational consequences must be weighed when considering the system's water loss control strategy. This decision is unique to every system.

There are several published water auditing software packages available for free or at a low cost. Several can be downloaded from internet Web sites. Care should be taken in selecting and applying water loss auditing software since many of these tools are based on European models and use metric units.

A blank water audit worksheet is included in Appendix C from the Texas Water Development Boards' *Water Loss Audit Manual* (2008). The manual along with the form can be downloaded from:

http://www.twdb.state.tx.us/assistance/conservation/Municipal/Water_Audit/wald.asp.

Appendix C also contains The Massachusetts Department of Environmental Protection's (MassDEP) Water Audit Forms, worksheets, and guidance instructions. These can also be found the MassDEP Web site at:

<http://www.mass.gov/dep/water/approvals/wmgforms.htm#audit>.

AWWA also provides Free Water Audit Software© that can be downloaded from: <http://www.awwa.org/Resources/WaterLossControl.cfm?ItemNumber=47846&navItemNumber=48155>. Version 4.2 (2010) of this software added data grading capability. This grading can be used to assess validity and reliability of the audit and determine the status of the utility's data quality. Utilities with a lower composite grading should focus program efforts on data collection and validation until the overall data quality becomes more reliable. Utilities with higher composite grades can trust their data to serve as the basis for budgetary decisions on major loss control initiatives such as leakage management controls or wholesale customer meter replacement. Screen images of some of the software pages are included in Appendix C.

A summary of steps to compile a preliminary water audit is as follows.

1. Determine the amount of water added to the distribution system, adjusted to correct for errors at source/production meters.
2. Determine authorized consumption (billed + unbilled).
3. Calculate water losses (water losses = system input – authorized consumption).
 - a. Estimate apparent losses (unauthorized use + customer metering inaccuracies + systematic data handling errors).
 - b. Calculate real losses (real losses = water losses – apparent losses).

These steps are an example of a **top down audit**, which starts at the “top” with existing information and records. It may also be known as a desktop audit or paper audit since no additional field work is required. Distribution systems are dynamic. The water audit process and calculation of the water balance has to be periodically performed to be meaningful to a utility's water loss control program.

After performing an initial top down audit it may become evident that some of the numbers are rough estimates and inspire little confidence in their accuracy. The next action in the audit process is to refine and hone the quantities that may have been initially estimated and begin reducing non-revenue water losses. A **bottom up audit** is often implemented after several top down audits have been completed and can better quantify loss volumes that were not revealed by the top down audit. A bottom up audit will help find apparent and real losses and begins by looking at components or discrete areas in the utility's operations. A bottom up audit assesses and verifies the accuracy of the water loss data associated with individual components of the distribution system.

Bottom up audits are more costly since they are more labor and staff intensive. The top down audit can help to identify areas where bottom up audit efforts should be concentrated. There are several techniques and methods used to perform a bottom up analysis. These including:

- District metered area analysis, discussed below;
- Calculation of performance indicators such as Current Annual Volume of Real Losses and Unavoidable Annual Real Losses which helps to isolate system components that may need closer attention (discussed in Section 2.4 below);
- Use of operational data and policies such as pressure management and active leakage control techniques (discussed in Section 2.5 and 4.2);
- Meter testing and replacement activities (discussed in Section 3), and
- Leakage rate analytical and predictive methodologies such as Background and Bursts Estimates and Fixed and Variable Area Discharges pressure-leakage relationship (discussed in Section 4.2.5).

District Metered Areas (DMA) and night flow analysis are two major tools used in bottom up assessments of distribution system leakage. A DMA is a specific area of a water distribution system that can be isolated by closing valves so that water inputs and outputs can be monitored. The water flowing into the DMA is metered and compared with metered customer use. The difference is the water loss for the DMA. DMA flow data for minimum consumption hours (often nighttime hours) is analyzed to best distinguish leakage volumes from customer consumption. This **night flow analysis** minimizes errors in the loss calculations by reducing potential customer meter error and by reducing pressure and use variations.

2.4 PERFORMANCE INDICATORS AND BENCHMARKS

Conducting the water audit – ideally on an annual basis – allows a PWS to monitor its water loss performance over time or compare itself to other PWSs. This is called **benchmarking**. Benchmarking uses a collection of **performance indicators** to numerically evaluate different aspects of the distribution system. Performance indicators need to be consistent, repeatable, and presented in meaningful standardized units. Examples of performance indicators include: breaks per mile of distribution main per year, gallons of water lost per service connection, gallons lost per mile of distribution

main, gallons lost per customer, real losses in gallons per year, and dollars of apparent losses per year. The AWWA/IWA Water Audit Methodology has a standard array of performance indicators that the PWS can track annually when compiling the water audit.

PWSs may use benchmarking to record the values of one or more performance indicators. This data is then used to compare previously recorded values evaluated with the same units. Benchmarking can be done at any increment of time: daily, monthly, yearly or every few years. By benchmarking, a system can:

- Evaluate its performance;
- Identify areas where improvement is necessary;
- Compare itself to other water systems;
- Evaluate financial options;
- Gauge itself competitively; and
- Provide data for reports to the public, regulators, and ultimate water users.

Although reductions of water theft and meter validation and replacement programs have their physical aspects, correction of apparent losses is largely an administrative effort. There is no physical defect in the distribution system that is allowing water to escape. This is not the case with real losses.

The **Operational Performance Indicator for Apparent Losses** is the annual volume of apparent losses from the water audit divided by the number of customer service connections. The indicator exists with the units of gallons per service connection per day. The Operational Performance Indicator serves as a useful tool for performance tracking and target-setting of efforts to control apparent losses.

The AWWA/IWA audit methodology relies on four performance indicators to help characterize real losses from distribution systems. These performance indicators are the Current Annual Volume of Real Losses (CARL), Operational Performance Indicator for Real Losses, the Unavoidable Annual Real Losses (UARL), and the Infrastructure Leak Index (ILI).

The **Current Annual Volume of Real Losses (CARL)** is the volume of water that is lost from the system due to leaks in the transmission and distribution systems, losses at the utility's storage tanks and leaks in the service lines from the main to the point of customer usage. The CARL is given in volume per the audit period year. This total

volume is largely straightforward and derived from the top-down water audit. It should be recognized that this volume contains water losses that can be identified, located and repaired as well as background leakage that occurs to some extent in most systems.

$$\text{CARL (gallons/year)} = \text{Transmission Losses} + \text{Distribution Losses} + \text{Storage Losses} + \text{Service Line losses} \quad (\text{Eq. 2-1})$$

The **Operational Performance Indicator for Real Losses** is the annual volume of real losses from the water audit divided by the number of customer service connections. The indicator exists with the units of gallons per service connection per day for water utilities with a customer service connection density greater than 32 per mile. If the customer service connection density is less than 32 per mile, then the form of the indicator is gallons per mile of pipeline per day. The Operational Performance Indicator serves as a useful tool for performance tracking and target-setting of efforts to control real losses.

The **Unavoidable Annual Real Losses (UARL)** is a reference value that represents the theoretical low level of leakage that would exist in a distribution system if all of the best leakage management techniques were successfully employed. The UARL is also given in gallons per year for the reference water audit period. By defining and then calculating the reference volume of the UARL in the system, an indication of the **Potentially Recoverable Real Losses** can be calculated as the difference between the CARL and the UARL. However, AWWA/IWA research across a large number of systems, together with actual operating data from many countries has resulted in the development of a relationship between various system parameters and the UARL with statistically good accuracy. A system's UARL is a function of the length of the distribution system, the number of service connections, the length of the service lines, and the average system operating pressure.

$$\text{UARL (gallons)} = (5.41 \times L_m + 0.15 \times N_c + 7.5 L_c) \times P \quad (\text{Eq. 2-2})$$

Where: L_m = Length of transmission and distribution system (miles).

N_c = Number of service connections.

L_p = Total length of private pipe (miles).

L_c = $N_c \times L_p$, miles.

P = Average pressure in the zone (psi).

Care must be exercised when calculating the UARL for systems where N_c is less than 5,000, P is less than 35 psi, or N_c/L_m is less than 32. Field testing of these systems should be undertaken to verify and validate the calculated results. The value of L_p in metered systems is the number of service connections multiplied by the average distance between the curb stop and the customer's meter. In un-metered situations this is the first point of use within the property. In most US systems, this pipe is typically not considered to be “private” pipe but rather is the responsibility of the utility. However, for consistency, the IWA terminology has been used in these definitions.

The **Infrastructure Leak Index (ILI)** is a ratio indicator recommended by the IWA to perform benchmarking of utility leakage status. The ILI was developed to address the lack of an objective benchmarking indicator. The ILI is defined as the ratio between the Current Volume of Real Losses and the volume of Unavoidable Annual Real Losses.

$$ILI = \frac{CARL}{UARL} \quad (\text{Eq. 2-3})$$

The ILI is substantially different and more meaningful than the frequently used simplistic “unaccounted-for water” percentage for comparing system efficiencies.

This latter percentage (unaccounted for water divided by plant production) provides only limited information about the real water loss characteristics of the system. The percentage is unduly affected by varying levels of aggregate customer consumption. In fact it can even appear to improve when actual water losses are increasing. For example, a new subdivision goes on line, and the total production increases to meet the additional demand with little if any change in actual loss volumes. However, the unaccounted-for water percentage actually decreases as the plant production (the denominator of the ratio) increases even though the total quantity of water loss from the system has not decreased. The system may appear to be more effective than it was the day before the new portion of the distribution system went on line, but in reality, just as much product is being lost as before the addition. Such insensitivity makes the output/input structure of the unaccounted-for water percentage an ineffective metric for economic or operations planning and is virtually meaningless as a comparison between systems (benchmarking). The ILI calculation includes pipe length and other parameters that adjust for changes to the distribution system and make it more useful as a comparison between different audit periods or PWSs.

An ILI index of 1.0 indicates that current annual real losses (CARL) are equal to unavoidable annual real losses (UARL) and the PWS is operating at the technically low level of leakage possible, a virtual rarity in actual practice. Limited data from water utilities who were the early adopters of the AWWA/IWA water audit methodology indicates that find ILI values typically fall in the range of 1.5 to 2.5.

If the water audit quantifies real losses as excessive, a targeted level of leakage reduction should be established by the PWS, or may be established by regulatory authorities. The Operational Performance Indicator for Real Losses (gallons per connection per day or gallons per mile per day, depending upon system size) is best to use for target-setting and performance tracking. The ILI is useful as a benchmarking indicator. In setting a targeted level of leakage reduction, the PWS should carefully assess the economic justification of the leakage management effort.

2.5 ECONOMIC CONSIDERATIONS OF REAL LOSS CONTROL

The objective of a water loss control program is to apply appropriate and effective techniques to recover as much leakage as economically justified. There are limits to what a well-run water loss management program can achieve. Ideally, no water would be lost; however, this not achievable in the field. There is a point at which it costs more to control leakage than is economically justifiable. A balance must be maintained between water loss reduction and costs associated with water loss reducing measures. A PWS can directly affect real water losses by controlling:

- Pressure management;
- Speed and quality of repairs;
- Active leakage control; and
- Pipeline and assets management through selection, installation, maintenance, renewal, or replacement.

Figure 2-3 is a graphical representation of the component parts of lost water and the actions that an active water loss management program can use to address these losses.

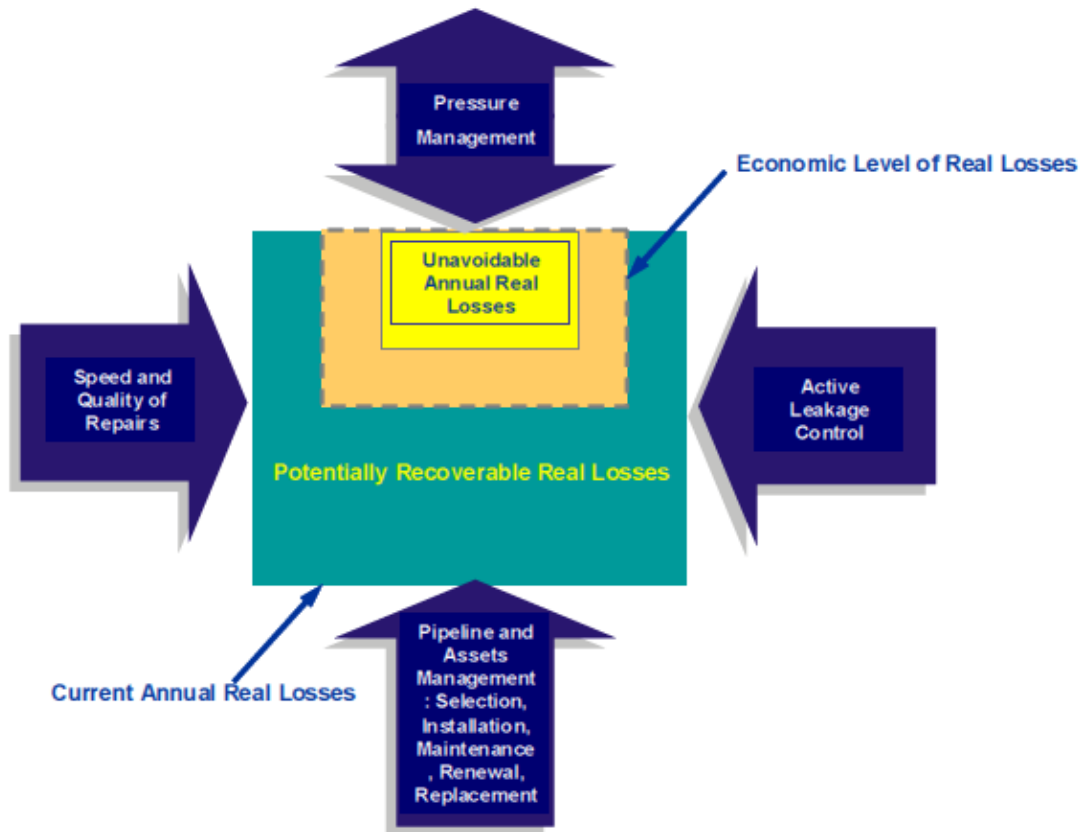


Figure 2-3. Forces Controlling Leakage and Costs.

Source: (Sjøvold et al. 2005) IWA/AWWA and European Commission TILDE, D20 Benchmarking Tools.

The cost of water lost to a leak projected over a specified period of time can easily surpass the initial cost to identify and abate the leak. The magnitude of the water lost from a leak is a direct function of the time it takes to identify, locate, and repair the leak. The amount of water lost from a leak or break is equal to the leakage rate multiplied by the length of time until the leak is stopped and repaired. In Figure 2-4 the boxes represent different stages in the life cycle of a leak. The individual boxes in the figure represent the volume of water lost during each phase in the life of the leak. A large leak running for 10 days at 1,000 gallons a day represents a loss of 10,000 gallons. A smaller 10 gallons per day leak for 1,000 days (around 2 years and 9 months) has the same loss.

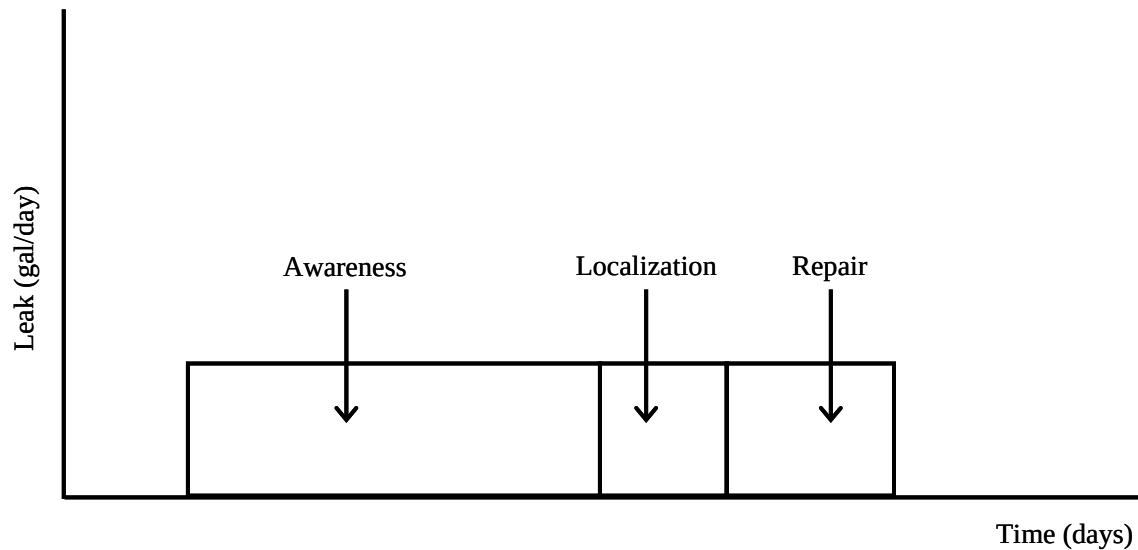


Figure 2-4. Time to Repair a Leak.

Source: Based on IWA/AWWA diagrams and IWA Leak Location and Repair Guidance Notes, (2007).

Repairing or replacing a leak includes not only the logistics and operations of manually replacing the pipe, but it also may involve customer notifications, arrangements for temporary water bypassing, or contracting an outside repair source.

Active leakage control (ALC) is the process of proactively searching for hidden but detectable leaks and repairing them. Acoustic leak detection surveys are the most common form of ALC employed by water utilities; however, District Metered Areas (DMAs) provide enhanced monitoring capabilities to alert the emergence of new leakage base upon flow measurement principles. ALC attempts to identify leaks while they exist in the “unreported” state and abate them before they reach the “reported” state, whereby they are identified by customer complaints after they have created a disruption.

Speed and Quality of Repairs: Repairing a leak, or rehabilitating a habitually leaky pipeline, includes not only the logistics and operations of manually conducting the pipework, but also involves customer notifications, arrangements for temporary water bypassing, or contracting an outside repair source. For most PWSs, customers own at least a portion of the water service connection piping supplying their premises. PWSs often have in place a policy that requires the customer to arrange for repairs of leaks on their service connection piping. Customer-arranged repairs often lengthen the time to

address known leaks as customers are often reluctant to pay the cost of such repairs and are stymied by the administrative requirements of the process.

Pipeline and asset management (AM) are discussed throughout this guidance document. Asset management involves documenting and evaluating the components of a water utility to determine when the optimal time is to replace or rehabilitate a component or pipeline. Evaluation of whether to replace or rehabilitate a component not only depends on economics but also on impacts to the community served, such as potential health effects, inconvenience, or public opinion and perception of the utility.

The level of **Pressure management** employed by a PWS affects water leakage rates. Also, poor pressure management has been correlated with increased pipe failure rates. These are relatively intuitive ideas since more pressure means greater flow whether it is through the pipe or through a crack or hole in the side of the pipe. Higher pressures mean higher stresses on the pipe. These higher values often translate into increased failure rates. The management goal is to meet customer pressure expectations, fire flow requirements, and adequate pressures to operate the system at as low a pressure as is reasonable. Pressure stabilization or pressure reduction are effective techniques in controlling “background” leakage, which is the acoustically undetectable weeps and seeps at pipe joints that cannot be economically repaired on an individual basis.

Each of the methods that a PWS has to address real losses also has an associated cost. In Figure 2-1 the CARL sets the existing losses and associated costs, and the UARL represents the theoretical technical low leakage level a PWS can achieve. The area between is potentially recoverable real losses. The balance of what makes economic sense for a water loss reduction program for the water system lies between these two and is called the **economic level of leakage (ELL)**.

By establishing the ELL, the PWS can compare its costs for making decisions whether a leak detection program will pay for itself or when to repair a pipe versus replacing it. The ELL is the point at which the cost of reducing leakage is equal to the benefit gained from leakage reductions. The method to determine the ELL can be an involved process that compares different scenarios. Figure 2-5 illustrates the general approach. The cost of the volume of water that is lost is proportional to the time that the leak starts until it is repaired. If the leakage management program calls for minimal field inspections, the probability of a leak going undetected for an extended amount of time increases. A

program with frequent field visits minimizes the time to detect leaks and hence reduces lost revenue and volume of finished water.

The cost to detect and pinpoint a leak should also be accounted for in the analysis. A program with infrequent leak detections will have a very low detection cost per year. Conversely, a program with a frequent detection cycle will experience high annual costs. It is important to point out that this cost does not include the cost of repair since these costs would be very similar regardless of the time it took to detect the leak. The cost per year to conduct a field investigation diminishes exponentially as the number of detection cycles decreases. A parabolic cost curve is formed, rapidly falling from many cycles per year to achieve very low water loss to relatively low total cost per year for programs that are willing to have greater leak loss but only detect infrequently. However, even though a utility may elect to have a frequent detection cycle, there will be a minimum at which no amount of additional detection effort will find the leaks. At this point, the cost of detection line (green in Figure 2-5) becomes asymptotic to the “*background*” leakage levels.

The total cost of leak detection is therefore the sum of these two opposing cost curves. The resultant saddle-curve provides a minimum program range at which the detection frequency is balanced with the amount of water loss from the system. This is known as the ELL range.

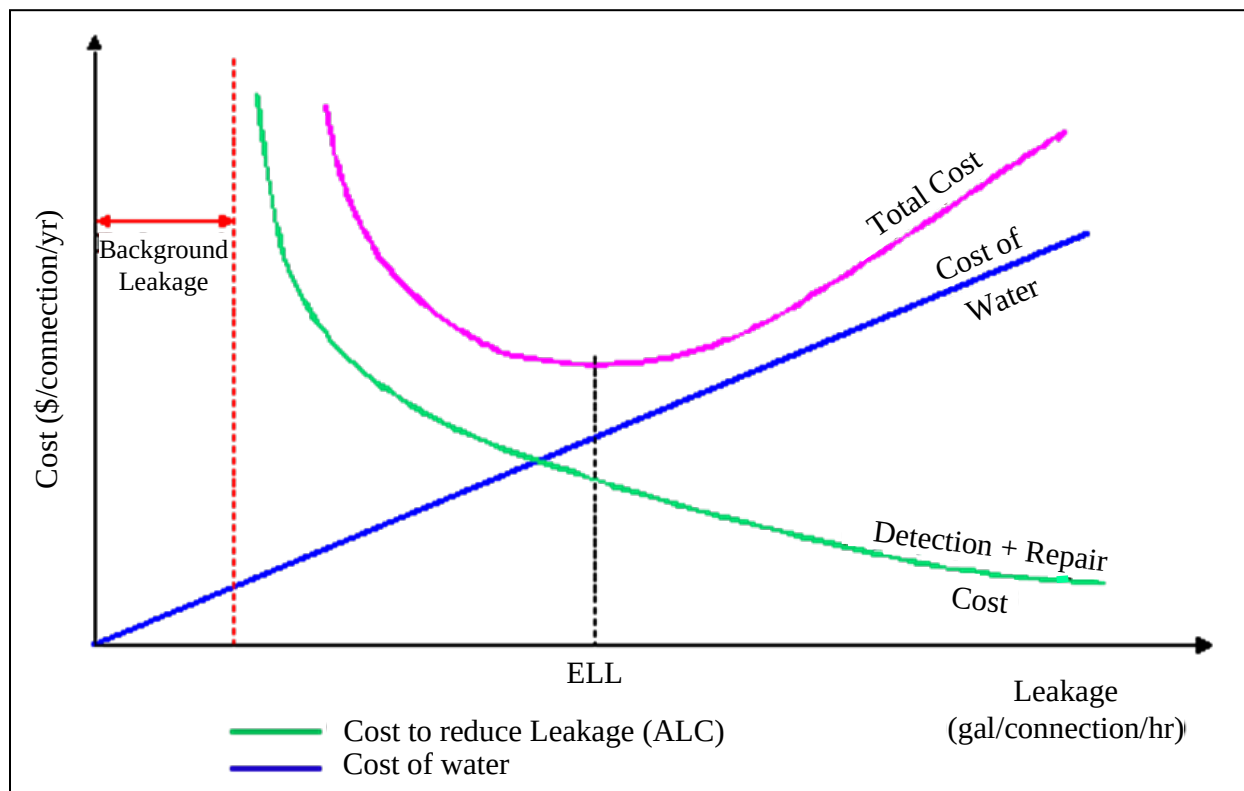


Figure 2-5. An Example of an ELL Curve

3 METERING

3.1 INTRODUCTION

Meters are very important for all aspects of the water supply operations. They make it possible to charge customers based upon the quantities of water that they consume. They record usage and therefore make billing fair for all customers. They can encourage conservation by making customers aware of their usage. They help detect leaks and establish accountability. Production Meters are used by PWSs to monitor treated water output and demand. Meter records provide historic demand and customer use data that is used for planning purposes to determine future needs. In short, metered water data makes accurate water auditing possible.

A hierarchy of metering applications exists in most PWSs. Production meters measure the bulk flow from the supply sources or water treatment plants. Customer meters measure end-user consumption. Other meters can exist intermediate to these two extremes, such as meters to measure water in pressure districts or District Metered Areas (DMAs). Selection of a meter for a given application depends on many factors including:

- Meter operating principles.
- Required accuracy.
- Convenience and ease of use.
- Volume of flow and flow rate.
- Types of flow (laminar vs. turbulent).
- Range of flow.
- Installation location and orientation.
- Required power.
- Data logging requirements.
- Durability.
- Debris and particle tolerance.
- Temporary vs. permanent installation.
- Calibration and required maintenance.
- Size of pipe.
- Type of pipe.
- Pressure drop.
- Meter orientation.
- Flow obstruction tolerance.
- Meter reading methods.
- Temperature and environment.

There is no single type of meter that will accurately measure flow for all applications. A meter has to be selected to meet the location requirements and the conditions where it will be installed. Several types of meters have been developed to meet different requirements, and metering technology is always advancing. Each of the meter types has advantages and disadvantages. Proper meter selection can be complicated, and there are several references that can provide in-depth direction for metering choices and selection including: AWWAs M6 manual *Water Meters-Selection, Installation, Testing and*

Maintenance and the Bureau of Reclamations' Water Measurement Manual available at http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm.

Metering is important to all aspects of a water loss control program. Meters provide the data to audit a PWS for water loss, assess leakage levels, guide intervention strategies, and validate performance indicators to reveal the status of water loss within a PWS.

3.2 METER TYPES

There are several ways water meters can be classified, but meters encountered in water distribution systems either operate based on principles of positive displacement or the velocity of flowing water. These operating principles, as well as some examples of these types of meters, are briefly described below. Meters used in water treatment and distribution systems can be further classified in one of five major categories based on the operating principle or use: The five major categories of meters are as follows:

- 1) **Velocity Meters** operate based on measuring the velocity of flowing water through a known cross-sectional area to obtain a flow rate. The volume of water passing through the meter can then be calculated by multiplying the flow rate by the period of time being considered. There are several sub-categories of velocity meters that measure the flow by different methods. These types of meters are often used to measure large, bulk flows from water production sources: water treatment plants, reservoirs, etc. They include the following:

- **Propeller, turbine, paddlewheel, and multijet** meters measure the velocity of water by placing an impeller in the water flow. The force of the water on the impeller causes it to rotate at a speed proportional to the velocity of the water. The impeller is connected to gears or an electronic device that computes the flow based on the velocity of the water and the area of the pipe. The method of operation for these meters is mechanical in nature so their accuracy can be subject to wear, interference from debris in the water, and mineral or scale buildup on the operating mechanisms. Some of these types of meters are designed for insertion into the pipe, which also requires a pipe tap. They operate more accurately at higher steady flow rates because there can be a slight lag in impeller rotation when starting and stopping that can reduce accuracy. These meters are best suited for use in larger water mains where flow rates do not change quickly. Some models are smaller and can be used as insertion meters to temporarily monitor flow. Propeller, turbine, and paddlewheel meters are sensitive to turbulence in the pipe (especially smaller meters) and require a straight length of pipe before and after the meter so that the flow becomes steady and non-turbulent. The distance measured before and after the meter is often specified as some number multiplied by the

diameter of the pipe so that the specified distances are dependent only on the pipe diameter that is being metered. The length of straight pipe before and after the meter can range from 10 to 30 pipe diameters.

- **Ultrasonic meters**, also called acoustic meters, transmit an ultrasonic signal into a pipe at a diagonal angle. The signal frequency that returns to the meter's receiver is altered by the flowing fluid or particles in it. The frequency shift is proportional to the velocity of the water. The flow can then be calculated based on the measured velocity and the cross-sectional area of the pipe. Ultrasonic simply means that the acoustic signal is above audible human detection. There are basically two types of ultrasonic meters, Doppler effect ultrasonic flow meters and time-of-transit ultrasonic flow meters. **Doppler effect flow meters** have one probe that contains both a transmitter and receiver. Doppler meters rely on suspended particles or air bubbles in the water to reflect the signal. Treated drinking water does not typically contain enough suspended particles for Doppler meters to operate properly, and they are not often used for clean water applications. **Transit-time flow meters** transmit an acoustic signal from an upstream transmitter/receiver diagonally through the pipe to a downstream transmitter/receiver. The downstream transmitter/receiver also transmits a signal along the same path to the upstream transmitter/receiver. The difference in the travel times in the signals transmitted from the upstream versus the downstream time is related to the velocity of the water in the pipe. The velocity and pipe size are then used to calculate flow rate. This type of meter may also be referred to as time of flight, time of flow, or time of transit meters. Advantages of this type of meter are: there is no obstruction to flow; they are portable and can be clamped on; there are no moving parts to wear out; they can be used with different pipe sizes; and they can measure flow in either direction. Disadvantages include their sensitivity to bubbles and turbulence in the flow and the precise alignment and set up requirements. The pipe material itself, along with the internal and external surface conditions, can affect the signal and therefore accuracy of transit flow meters. These meters work best on cast and ductile iron pipe. Most transit flow meters require an external power source of 90 to 250 volts AC. There are some models that operate on lower DC voltages that can be powered by step down transformer or rechargeable batteries.
- **Electromagnetic flow meters**, often called magmeters, operate based on the principle that water flowing through a magnetic field will produce a voltage that is proportional to the velocity of the water. The measured voltage is then converted into a flow rate. There are two general types of these meters: in-line magmeters and insertion magmeters. **In-line magmeters** are constructed so that the magnetic field is created around the diameter of the pipe. The coils that create the magnetic field and sensing probe are arranged so there is no change in diameter in the pipe and no obstruction to the flow. This type of meter is installed in the pipeline as a permanent short length of pipe.

Insertion magmeters are inserted into the flow and require a pipe tap. Insertion magmeters form the magnetic field around the probe inside of the pipe. Insertion meters are often used for temporary metering. They have the advantage of being sealed and have no moving parts to foul or wear. In-line magmeters typically require a line voltage power source of 90 to 250 volts AC, while the insertion meters can operate on DC currents that range from a few volts to 30 volts.

- **Differential pressure gauges** use a pressure drop that occurs when the water flows through a restriction or around an obstruction in the pipe. The pressure drop is related to the water velocity, and from this relationship, the flow rates and volumes can be determined. There are several types of meters that operate on this principal; they include: pitot rods, flow tubes, venturi tubes, and orifice plates. **Pitot rods** are relatively inexpensive insertion meters that are often used for temporary flow measurements. The pitot rod itself forms the obstruction that creates the pressure differential that is used to measure the flow rate. Although pitot rods are often used as temporary meters, they do require a pipe tap for installation. **Flow tubes** consist of a funnel shaped obstruction placed in the pipe that creates a pressure differential between the large and small opening of the funnel shape. The funnel forms the restriction that creates the pressure differential used to measure the flow rate. The pressure differential in **venturi tubes** is created by a gradual narrowing of the pipe diameter followed by a short section of a smaller diameter pipe. The pipe then increases gradually to the original diameter. The pressure differential used to measure the flow rate is measured at the original pipe diameter and the reduced diameter section. **Orifice plates** are round plates with a hole of a specific size bored in them. The plate is placed in the pipe such that the flow has to pass through the restricting hole. Pressures upstream and downstream of the plate are compared to determine the flow rate. By nature of their measurement method, differential pressure gauges restrict the flow in some way and require pipe taps to measure the pressure differential, but they are simple devices with no moving parts and can maintain accuracy over long periods of time.

- 2) **Positive Displacement Meters** are the most common type of meter for measuring customer consumption and separate the flow into known volumes, keeping a running count of these volumes to measure the accumulated flow. The meters use some form of vane, gear, piston, diaphragm, or disk to separate the measured volumes. These meters are sensitive to low flow rates and are accurate over a fairly wide range of flows. There are typically two types of positive displacement meters used in the drinking water industry, nutating disk, and piston meters. These types of meters are used in homes, small businesses, hotels, and apartment complexes. They are available for pipe sizes from 5/8 inch to 2 inches. **Nutating disk meters** have a round disk that wobbles or “nutates” around a spindle in a cylindrical chamber. The wobble of the disk in the chamber is caused by the flow of the water. Each rotation represents a specific volume that is registered. **Piston meters**, also known as rotating piston or oscillating piston meters, have a piston that oscillates back and forth as it

rotates. The piston is forced to rotate as water flows through the meter. Each rotation represents a specific volume that is registered. Other types of positive displacement meters include reciprocating piston, rotary vane or sliding vane, rotary gear, rotary oval, or rotary lobe, but these are not common in drinking water distribution systems.

- 3) **Compound Meters** measure over a wide range of flows. The metering unit contains separate velocity and positive displacement meters. The positive displacement meter measures the lower flows and the velocity meter (usually a turbine meter) measures the high flows. A valve regulates which meter is measuring the quantity of water used based on the rate of flow required. These meters can be used in factory settings where demand during production hours is much higher than off hours. The accuracy of compound meters can be compromised if the typical flow level occurs within the transition flow range between the high flow and low flow meter.
- 4) **Proportional Meters** measure a small portion of the flow in a pipe. Differential pressure techniques are used to divert a small portion of the flow from the main pipe through a meter. After passing through the meter the flow is returned to the main pipe. The flow through the meter is multiplied by a factor based on the pipe size to determine the flow through the pipe. These meters may also be known as fire-line meters, bypass meter, or shunt meters and are most often used in larger diameter pipes. The advantage of this metering method is high flow rates can be achieved with little obstruction or pressure loss due to a meter.
- 5) **Open-Channel Meters**, as their name implies, measure flow in open channels. There are two major types of open channel meters: weirs and flumes. There are different styles of weirs and flumes, but each uses the same principal for measurement. **Weirs** measure the depth of water flowing over a rectangular or notched wall of a known size. The depth of water is related to the flow rate. **Flumes** are a specially designed section of channel. All of the water flow in the channel is directed through it. The depth of flow in the flume is related to the flow rate. Flumes and weirs are designed to be used for open channel flow and are not typically used in distribution systems.

3.3 METERING POINTS

Meters can also be classified by their placement and usage. Meter placement is critical for water audits and leak detection. Six types of meter usage based on placement in the distribution system are described below: master meters, submeters, district meters, component meters, service meters, and temporary meters.

- **Master Meters** or **Production Meters** record the output of finished water flowing into the distribution system. A master meter can also be used to measure water being sold from the plant or a take-off point in the distribution system to another system.

- **Submeters** are typically installed by a company or private entity other than the PWS to track or bill water use by an individual process or housing unit. Submeters are installed after the utility owned service meter. A landlord, property management firm, condominium association, homeowners association, or other multi-tenant property might use submeters to bill tenants for individual measured water usage. A PWS does not typically submeter but might encourage submetering programs to promote water conservation. A PWS may also be interested in submetering if a municipality bills for both water and wastewater treatment based on the volume of water that is supplied to the customer. In this billing system, the wastewater is billed on the metered volume delivered based on the assumption that a sizeable percent of the water being metered into the premise is going to be returned as wastewater to be treated. For a user with a large percentage of the delivered water not returned as wastewater, the assessed fee may be reduced based on a submeter reading. The submeter determines the amount of water that is not returned to the system and will not have to be treated as wastewater. A soda beverage bottling plant is one example, since a large portion of the water is bottled and shipped off site.
- **District Meters** or **Zone Meters** measure the water used by a large group of users within a defined area such as a residential or business district. District meters are used to determine if leaks or losses are occurring within the metered area.
- **Process Meters** or **Component Meters** are frequently used to carefully measure chemicals or water used in a process or through specific piece of equipment. Meters at a pumping station could also be considered to fit in this category.
- **Service Meters** or **End User Meters** measure the consumption by water users in the system at the service line (where the line goes from the distribution line to the household). Typically, one service meter is positioned on the service line just past its connection with the distribution main.
- **Temporary Meters** or **Portable Meters** can be used wherever it is necessary to determine a flow, confirm meter accuracy, help locate losses, perform field testing, or determine a user's consumption profile. These are typically some form of an insertion meter.

3.4 METER REGISTERS, METER READING AND AUTOMATIC METER READING

Meter Registers. The register is the part of the meter that records the volume of water that has flowed through the meter. The register is either mechanically or magnetically linked to the metering mechanism. Most registers display an accumulated total of all water that has passed through the meter after its installation. Many meter manufacturers provide different registers to meet the requirements of their customers. Different registers can record the water volume in units of cubic feet, cubic meters, US gallons,

Imperial gallons, or liters. In the United States, US gallons or cubic feet are the most common. Registers can also be arranged to record detailed information over a period of time using a device called a data logger. The register can also send the data to a remote data reading device for billing purposes.

Meter Reading. Residential and service meters have a mechanical or digital display for monitoring and recording the volume. Direct read or straight reading meters are the most common meters and have a numerical display similar to the odometer on an automobile and the volume can be read directly. Many of these will also have a hand that sweeps around the dial showing the instantaneous water flow. They often will have a small triangle or star shaped indicator that rotates even at extremely low flows. This indicator is used to determine if there is a leak occurring downstream from the meter. If all of the water in a metered facility has been turned off and the triangle is still spinning, then there is likely a leak in the building plumbing system. Some meter models, especially older ones, might have an arrangement of six or seven circular dials on the meter face. These are round-reading meters. Each of the smaller dials represents a multiplier for the number shown on the individual smaller dial face. The multipliers are 100,000, 10,000, 1,000, 100, 10, and 1. Some models may have a large sweep indicator that represents a 0.1 multiplier. The indicators show the number to multiply by. If the arrow is between numbers, use the smaller of the two. The flow through the meter is simply the sum of all of the individual smaller dials. When reading these types of meters, you must pay attention to the direction of the scale numbers on the individual dials. Some of the scales increase in a clockwise direction and some of them decrease in a clockwise direction. See Figure 3-1.

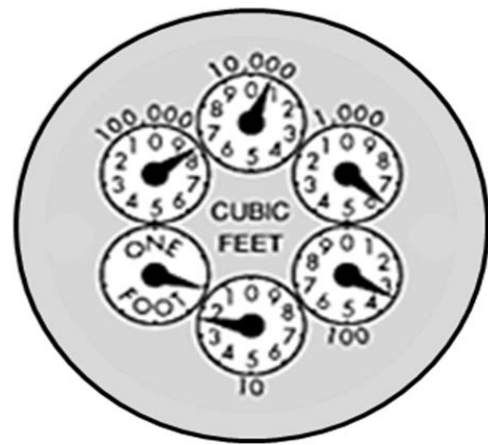


Figure 3-1. This Round-Reading Meter Registers 806323 Cubic Feet

Meter reading occurs on a set schedule based on the billing cycle. Meters are either read manually by a utility worker or read automatically by an Automatic Meter Reading (AMR) system.

Manual Meter Reading requires the reader to correctly read and record the metered value. The raw recorded values are then entered into a billing system. Manual read

systems are more labor intensive and have higher potential for human error. Errors in manually read meters can allow data errors to affect billing and water audit accuracy. Because manual meter reading is labor intensive, it works best for smaller water systems. Advantages of manual meter reading can include lower initial meter costs and billing system simplicity. Another advantage of manual meter reading includes the fact that the utility's meter reader may spot potential problems before they become serious or locate unauthorized use since they have to visit each meter.

Automatic Meter Reading systems can provide many advantages over manually read meters. AMR is a technology that automatically collects data from the meter and transfers it to a central database for analyzing and billing. Depending on the AMR system used, fewer employees might be necessary for meter reading, less gasoline might be used for the meter reading route, and the data can be processed quicker. Some systems can even provide real time trend analysis. Some of the more popular AMR technologies include:

- Handheld data collection where the reader has a data logger that needs to be brought into the proximity of the meter. The meter or a device mounted outside of an exterior wall of the building is touched or “swiped” to download the information to the portable unit that collects the data from the route and is then later downloaded to the utility billing software. This type of system still requires a meter reader to access each meter but reduces recording errors and increases efficiency since meter readers usually don't need to enter a building to obtain a meter reading.
- Mobile data collection is similar to the handheld version but requires the reader to only drive by the general location of the meter that automatically uploads its stored information to the mobile unit. A data logger in the vehicle collects the information via a short-range radio signal. Many more meter readings can be collected in a day using mobile data collection compared to handheld data collection.
- Other systems use network technologies based on telephony platforms (wired and wireless) or radio frequency (RF) including WiFi, (a computer protocol), to transmit the data to the central data collection location. These “Fixed Network” systems can collect meter reading data more frequently – as often as every 15 minutes – and can assist leakage management, hydraulic modeling, and water conservation efforts.

3.5 METERING PROGRAMS

Well-managed customer metering programs are critical to the revenue stream of a PWS. Metered water consumption data serves as the basis for equitable billing and revenue

generation. Metering and accounting systems can also help detect leaks and other losses. The upkeep of the meter population requires expenditures for installation, maintenance, calibration, testing, and replacement.

The Meter - Billing Relationship. Meters and metering programs are an integral part of billing systems. Many small utilities charge a flat monthly rate for water and might meter only for some large-use customers, if at all. Flat rates may be based on type of use such as residential, commercial, industrial, or agricultural, or they might be based on occupancy. Systems that use flat rates alone with no metering are usually smaller and might not have the resources to maintain equipment and accounting systems that are necessary for metered billing. A decision by a small PWS to add metering will also involve extra effort to maintain the meters and billing systems.

Larger systems usually meter customer consumption which serves as the basis for billing. Water rates can be based on customer type or quantity of water used. Rates may increase as proportionally more water is used or decrease with increased use. Metered water data is also used to determine performance and system efficiencies by monitoring specific equipment or areas. While a basic water audit can be compiled using estimated water data, accurate metering is crucial in compiling a well-validated water audit.

Establishing a metering program is a good step if you are a small or medium water system and do not have a metering program. While individual customer metering may be out of the financial reach for your system, zone metering may be a way to achieve more accurate billing and gain system operating information at a reduced cost. Metering also becomes more compelling if the PWS is facing water shortages and must implement a water conservation program. A PWS must consider available funds for a program and answer questions such as:

- Where do we want metering?
- How many meters will we need?
- What type of meter is appropriate?
- What method of meter reading will we use?
- How do we integrate the new meters into our billing system?
- Is a new billing system required?
- Are the meters upgradeable?
- Does our PWS staff install them or should we have them installed by a contractor?

- Who will test, calibrate, maintain and replace them?
- How do we pay for the program?
- Have we quantified all of the expected benefits of the metering system?

Initial capital costs required to purchase and install the meters may come from the operating budget of the PWS, a grant, a tax levy, a water rate increase, or municipal bond. Low interest loans may also be available from a state's drinking water revolving fund. More information about the Drinking Water State Revolving Fund (DWSRF) can be found at the DWSRF Web site: http://water.epa.gov/grants_funding/dwsrf/index.cfm. Ideally, the newly installed meters will at least partially pay for themselves in new and recovered revenue and/or reduced operating costs.

Installation. Following the manufacturer's installation instructions for a meter is also crucial to proper operation. A properly calibrated meter can register incorrectly if installed improperly. Meter sizing is very important since the accuracy of the meter is dependent on its design type and design flow. Some meter locations require compound meters with dual registers to properly record widely varying flow rates. In some cases, an authorized meter bypass is necessary because the meter restricts flow at higher rates. A bypass might be necessary in emergency situations at industrial, commercial or multi-residential facilities to allow unrestricted flow around the meter for fire control systems.

Calibration and Testing. Over time, most water meters fail to register an increasing proportion of the water flow through them. Under-registration results in lower billing and loss of potential revenue, while at the same time erroneously indicating an increased level of water lost from the system which will also skew water audit results.

Just as with any mechanical or electrical system, meters are subject to inaccuracy or failure if not installed or maintained properly. Some of the common problems that necessitate calibration and testing of meters include:

- Incorrect installation or sizing,
- Higher or lower flows than designed for,
- Debris in the water,
- Scale build up due to minerals in the water,
- Tampering,
- Environmental extremes including high or low temperature or vibration, and
- Wear.

Meters should be calibrated according to manufacturers' instructions. A PWS should first concentrate on testing accuracy of customers who consume more and have larger meters since errors in the larger meters will result in higher revenue losses. Maintenance and calibration of these commercial meters can be accomplished in larger utilities that operate their own meter-shop with trained technicians. However, many utilities contract this work from outside providers.

For many systems, residential meters can account for 80% or more of the water sold by the system. Depending on installation methods, residential meters can be tested in place or might have to be removed. Meter testing can be done with portable testing and calibrating equipment, or the meters can be sent to a company that tests, calibrates, and refurbishes them.

Many water systems test only a representative sample of residential meters and base their decisions to replace or repair meters in a selected area on the results of the tested sample. In their M-36 publication, *Water Audits and Loss Control Programs*, the AWWA suggests 50 to 100 meters is a good number to test. The number of meters tested may need to be larger and depends on the number of meters in the PWS and the statistical confidence levels with which the PWS is comfortable. The more meters that are tested, the more accurate the results will be. State public service commissions often require periodic testing of water meters. For residential meters (5/8 inch) the required testing period can range from 5 to 20 years depending on the state. Larger meters may require more frequent testing. Many PWSs have found that calibration or repair of small residential meters is not cost-effective since most meter models retain accuracy over a long life, and the cost of a new meter is less than the cost of calibration or repair. Calibration and repair is still common for most models of large commercial and industrial meters.

Replacing. If the PWS has older meters in its distribution system, it might be a good idea to test or replace them. Residential meters are relatively inexpensive to replace and therefore are seldom rebuilt as would be done with a commercial meter. There is, however, no single, agreed-upon standard as to when these meters should be replaced. Thumb-rules abound in the industry, but a careful analysis of the system can save substantial time and money for the operator.

The larger issue is determining when the most cost-effective time is to undertake meter replacement. The rate at which these smaller meters lose accuracy and the amount of

their degradation is very site specific and depends on the meter, water quality, frequency of meter use, type of flow through the meter, and a wealth of other, not-so-quantifiable factors.

An analysis similar to the ELL (see Section 2.5) can be undertaken to find the point where a meter replacement program provides the most economic benefit. The optimum point is based on the cost of installation versus the value of recoverable losses. In the past it was recommended that residential water service meters be replaced on a rotating schedule of anywhere from 10 to 20 years, but current strategies are more complicated. These strategies are based on: the number of meters in the system, results of meter testing, types and sizes of meters, period of service, water quality, available staff to perform the work, and cumulative volume that has passed through the meter.

AWWA's manual M6, *Water Meters-Selection, Installation, Testing, and Maintenance*, provides detailed descriptions of meter calibration testing and maintenance programs. Another straightforward approach by Dr. Hans D. Allender¹ is instructive for its comprehensive approach to establishing meter replacement targets. The analysis contains the following steps:

Step 1 – Meter Accuracy. The initial step is to measure the degree of under-registration of meters in the system being studied. This can be accomplished in the meter shop using 4-6 meters from each age group of in-service meters (e.g., 15 years, 20 years, 25 years, 30 years). These meters should be tested at three flow rates: low, medium, and high. The results of this testing will provide a small database of accuracy as a function of meter age and flow rates.

Step 2 – Proportion of Total Flow. From the above testing, it is apparent that meter accuracy is not constant across the flow spectrum. Most meters are inaccurate at very low flows, and some lose accuracy at very high flows. It is important for a system to understand where its meters “typically” operate to understand the degree of under-registration taking place. The utility can select 4-6 typical residential units and measure the flow rates and durations over a period of several days. From this analysis, the utility should be able to determine the percent of total water used in 24 hours that was provided at low flow rates, the percent at medium, and the percent of the total at high flow rates.

¹ Dr. Hans D. Allender, President. “The ProducBox TM Institute,” from an article in *Water Engineering & Management*, September 1996. <http://www.wqpmag.com/Determining-the-Economical-Optimum-Life-of-Residential-Water-Meters-article493>.

While the demarcation of low, medium, and high is somewhat arbitrary, the analysis will typically indicate practical break-points (e.g., 0-0.25 gpm for low, 0.25-2 gpm for medium, >2 gpm for high).

Step 3 – Meter Reading Accuracy. Thus armed with information on the meters in the system and the typical usage patterns, age-based accuracy can be developed as the weighted sum of the accuracies in each meter age group.

Step 4 – Calculate Annual Unregistered Water. Most utilities have a good sense of the average water production quantity per household in their service area. Armed with this annual average production and the meter accuracy, the quantity of unregistered (and hence unpaid) water per household per year can be calculated for each meter age group. The last calculation is to value the unpaid water, based on the commodity charges for water in effect. This calculation provides the operator with the lost revenues per household to continue to use the meter.

Step 5 – Optimization of Replacement. As the meter ages, the lost revenues continue to increase. Replacing the meter too early or too late is not cost effective. Using the information developed above, the operator can now calculate the real cost (cumulative cost to replace the meter + lost revenues each year) to the utility over a 30-year life of the meter. Finally, this total cost can be annualized by dividing it by the number of years that the meter has been in operation. A general U-shaped curve will result by plotting the annualized cost as a function of the meter age. The minimum point on this curve represents the least cost. The meter age when this minimum cost occurs represents the optimum meter replacement age for a particular utility.

4 WATER LOSS CONTROL PROGRAM ELEMENTS

4.1 CONDUCTING A WATER AUDIT

Regardless of whether you are in the initial stages of developing a water loss control program or already have a well-established program, collecting and maintaining information on the elements and condition of components in your distribution system will lead to more accurate water audits. Information collected for a water audit is only the first step and only a portion of the data necessary for a complete water loss control program. The knowledge base of potential weaknesses of your distribution system and locations where the most benefit per dollar invested can be achieved will increase as water audits are performed over successive years. When the water audit is updated with more detailed distribution system data, the PWS management can become more proactive in its operations planning. Chapter 2 provided the definitions and basics to understand the water audit and conduct an initial water audit. This chapter is intended to help a PWS add accuracy to their water audits and devise effective loss control strategies. It should also be helpful to provide for a more robust and extensive water loss control program beyond the basic requirements.

4.1.1 Gathering System Information

The effectiveness of a PWS loss control program increases with the type, amount, and detail of information that is collected. Table 4-1 shows some of the distribution system details that should be collected and maintained. In addition to piping information, data should be maintained for other components within the water system including: meters, valves, storage tanks, fire hydrants, pumping and pressure boosting stations, and distribution system controls and monitoring equipment. Additional data such as average system pressure and the number of customer service connection pipes – needed for the UARL calculation in Section 2.4 – should also be collected. While all of the data maintained for a distribution system can provide valuable information, maps showing the locations of the assets are critical.

Data storage and organization can be as simple as a log book or spreadsheet. EPA has developed the *Check-Up Program for Small Systems (CUPSS)* to assist with water system component inventory as well as with system asset management activities. CUPSS is a free, easy-to-use asset management tool for small drinking water and wastewater utilities. CUPSS provides a simple, comprehensive approach based on EPA's highly successful *Simple Tools for Effective Performance (STEP) Guide* series. More information on CUPSS can be found at <http://water.epa.gov/infrastructure/drinkingwater/pws/cupss/index.cfm>. A brief description of the CUPSS software and some screen captures from the program can be found in Appendix D.

Table 4-1. Data Requirements for a Detailed Management Plan								
Physical	Exist	New	Performance	Exist	New	Commercial/Service	Exist	New
Year of Installation	Y	Y	Complaint Frequency	A	Y	Critical Customer	Y	Y
Diameter	Y	Y	Type of Complaint	A	Y	Affect on Community	Y	Y
Material	Y	Y	Break Frequency	A	Y	No. of People Served	A	A
Length	Y	Y	Type of Break	A	Y	Length of Shutdown	A	A
Location	Y	Y	Reason for Break	A	Y	Coordination w/Others	A	A
Interior Lining	A	Y	Service (hydraulic) Adequacy	Y	Y			
Exterior Protection	A	Y	Fire Flow Adequacy	Y	Y			
Joint	A	Y						
Wall Thickness	A	Y						
Soil conditions	A	A						
Internal Condition	A							
External Condition	A							
Y = yes, in all cases A = as needed, or as available								

Source: Based on (USEPA, 2002) Deteriorating Buried Infrastructure Management Challenges and Strategies.

4.1.1.1 Mapping – CADD & GIS

Determining size and location of a water system's piping and other assets is the first step in data gathering. Most PWSs have an existing map(s) of their pipelines and water supply assets. Some systems use hardcopy maps, while others use their own Computer Aided Drafting and Design (CADD) system or Geographic Information System (GIS) packages to update the distribution system inventory. Mapping software packages range in price from a few hundred dollars to several thousand dollars. CADD and GIS software can help keep necessary information current and easily accessible. The ideal tracking tool will depend on the complexity of the distribution system and the sophistication of the tracking that a PWS needs. Low cost and free CADD and GIS software packages are available for water system managers who want to begin electronic mapping with minimal expense.

4.1.2 Employing Performance Indicators

A proactive water loss control program requires that a water audit is completed and the standard performance indicators are calculated. This guidance document concentrates on performance indicators related to control and mitigation of water loss in the drinking water distribution system. Section 2.4 of this guidance document defined performance indicators and benchmarking and discussed the CARL, UARL, and ILI as indicators of the leakage status of the distribution system. The CARL, UARL, and ILI are operational performance based indicators and would be recorded as performance indicators in the *water system performance* benchmark category.

4.1.2.1 Assessing Losses and Data Gap Analysis

Once baselines have been established, undertake an analysis to determine where water loss control improvements can and should be made. Start with the obvious problems that can be remedied within budget then examine larger issues that may involve further analysis or a large financial investment. Review and compare your options through economic level of water loss and other financial analyses then prioritize needs. Once a course of action has been selected, the PWS should arrange financing and set schedules to complete the task.

4.1.3 Comparing Loss Control Options

In addition to the economic level of water loss as a tool to assist in assessing losses, a cost/benefit analysis between options is extremely useful. A cost/benefit analysis allows for direct comparison by converting all aspects of competing options to present dollar values so they can be compared on an equivalent dollar for dollar basis. An option that should be included in nearly all cost/benefit analysis comparisons is the option of “taking no action.” When discussing a leak control program, the “take no action” option compares the cost of a leak over a period of time to other optional interventions and loss control options. This comparison is useful for illustrative purposes only to compare costs; PWSs should maintain some level of water loss control in order to contain losses that inevitably occur in PWS operations.

4.2 INTERVENTION

4.2.1 Further Information Gathering

Both water audits and calculated performance indicator values will identify operational areas where more data should be collected. Periodic water audits and tracking of performance indicator values identify the most significant components in terms of loss volume and cost impact. In many cases it may be necessary to install additional meters, establish DMAs, or review records in greater detail (the “bottom-up” auditing process) to further narrow the physical search effort for losses.

4.2.2 Leak Detection and Locating

4.2.2.1 Locating Leaks and Losses Through Records

In the “top-down” or preliminary water audit process, apparent losses are frequently quantified first and the real losses are taken as the remaining loss volume after apparent losses and unbilled authorized consumption are subtracted from the total Non-revenue Water Volume. In such cases, errors in under-stating the volume of apparent loss results in real losses being over-stated. It is possible to identify apparent losses through billing data discrepancies or abrupt changes in amounts of water that have been historically used. Some existing billing software packages have

built in functionality to flag historical water use changes. Desktop spreadsheet software can also be programmed to flag water use changes with minimal effort. AMR systems that can track and show usage profiles at more than monthly or quarterly billing intervals may also be instrumental in finding either real or apparent losses. Sudden increases in meter readings may be a sign of leakage, unauthorized use, or an open valve that should be closed.

Accounts that have been estimated but not read for several billing periods should also be reviewed since the estimated usage may be quite different from the actual usage. It is prudent to re-calculate the apparent loss volumes annually to ensure that water usage patterns in the area have not changed unduly, causing a distortion of the real loss (leakage) volume.

4.2.2.2 Physically Locating Leaks and Leak Detection Approaches

Identifying system leaks can pose a challenge. While operating personnel might identify some leaks in the distribution system during routine field inspections, not all leaks are visible, and targeted leak detection efforts are needed to detect hidden leaks in the water distribution system. Planned maintenance will help identify leak occurrences. To better understand how water leaks are detected, water managers should look at three major water loss leak detection categories: (1) leak detection through appearance, (2) leak quantification through flow monitoring, and, (3) locating hidden leaks with leak detection equipment (acoustic, thermal, electromagnetic, tracer, etc.).

Leak Appearance

Estimates of the average lifetime of a slowly developing leak, from its inception until its repair can be up to two years (AWWA M36, 1999). Development of a leak depends on many variables and not every leak is immediately detected. In the absence of an active leakage control program, the presence of a leak in the distribution system is identified only when it appears on the road surface, in utility chambers, building basements, etc. and is reported by a utility employee or customer (i.e., reported leaks). It is best if a PWS can locate leaks in the hidden (unreported) phase via active leakage control; however, reporting from customers is very valuable. An educated and motivated customer, as well as a trained field inspector, is an indispensable resource for this mode of detection. Appearance of a leak may take a variety of forms from the subtle to the spectacular. The ways that leaks may be recognized and reported in the field include:

- **Suspect Areas** - This is perhaps the subtlest of appearances and may go unnoticed for some time. Educating customers on what to look for sensitizes them to consider unanticipated moisture as a possible leak and report it. The leak may manifest itself as a moist or discolored area, especially if it is in the vicinity of the water main, service line,

or meter. In some climates, this indicator may not be standing water but rather may be an unusually green patch of landscape especially during dry summer months.

- **Surface Flows** - Water appearing on the surface of roadways or the ground in quantities sufficient to cause a flow may portend a leak that has become large enough to make it to the surface in such a quantity that it is not being absorbed by the surrounding soil or evaporating. Flows around hydrants can often signal an improperly seated foot-valve or a damaged connection. While such flows may be from naturally occurring ground water flows, they may also need special attention from the water provider to identify their sources. Typically, a simple chlorine (or fluoride) residual test can determine if the flow is potable water. Flows in culverts or entering streambeds may not be immediately recognized as leaks from the public water system as one expects to see flowing water in these locations.
- **Reduced Water Pressure** – Some customers are highly sensitive to changes in their service and expect their water utility to provide excellent water quality and reliable flow. If a leak has grown large enough, the system might experience a notable loss of pressure. While a very gradual loss of pressure over time is hard to recognize, increased reports of “unacceptable” pressures within an area should be a signal the leak may have reached actionable levels.
- **Flow Disruption** - Probably the most dramatic form of water loss detection is due to the sudden failure of the main and loss of service. The provider is typically notified of such occurrences as they tend to be highly visible and may become a public safety issue. This water loss has moved from the category of a leak to being a true system rupture that has the potential to impair both the water quality and flows. System operators are often aware of such failures, even if its exact location is unknown, through loss of system pressure or storage tank level. If not located in a visible area, larger water main failures may be reported through user complaints of low pressure and/or discolored water.

Active Leakage Control for Unreported (Hidden) Leakage Occurrences

PWSs should operate an active leakage control program in order to detect hidden leakage, which is always growing in water distribution systems. Two primary approaches exist to identify hidden leakage: flow monitoring and direct leak detection.

Flow Monitoring of Bulk Leakage

One of the major methods to trend bulk leakage quantities in a portion of a water distribution system is through system flow measurement. Leaks within customer building premises' may be detected by high water meter readings and billing computations by the customer service department. Household leaks may be recognized by the customer when higher than expected water bills are received if the leak is on the service line on the customer's side of the water meter. On an area wide basis – such as a District Metered Area (DMA) – bulk leakage variations are identified by observing supply flows during the minimum customer consumption hours of the day. Customer consumption can be reliably quantified via estimates or data-logging of samples of customer accounts, or taken from the collective customers' meters over a specific period of time using AMR systems. With the advent of advanced AMR systems and Automated Metering Infrastructure (AMI), the utility manager can compare the water volumes discharged from the treatment facilities or the volume passing through system zone meters with the collective customer meter readings over the same period of time. Such comparisons require training, communication, and management attention. Customer service billing activities and system flow monitoring operations have not historically been compared in many utilities as each set of data usually serves a unique and different purpose, although AMR/AMI are providing improved capabilities in this regard. Management must provide the leadership and incentive for flow monitoring to be utilized successfully as an effective tool in water loss identification.

Continuously monitoring flows in isolated portions of the system, such as DMAs, is an effective means to actively seek out real water losses. Such an approach entails monitoring flows at close intervals to discern flow components reflecting valid customer consumption from leakage components. The size of a DMA is a function of the system configuration, hydraulics, customer demand patterns, and geography. Typically a DMA will serve 500-3,000 customer connections. Once a DMA has been configured, the flow is metered with an installed or portable water meter to measure the total volume of water supplied to the area. Data recorded by the DMA master meter during minimum consumption hours, often late night periods (2:00 am – 5:00 am), can provide indications of higher flows than would be expected during this early morning period. DMAs with suspiciously high flows during minimum consumption hours are candidates for detailed acoustic leak detection to better characterize the water loss in this area.

Leakage quantification from flow measurement can be achieved using either permanent or temporary metering. Permanent meters have the advantage of continuous data collection with archived data available to help their calibration. Key points in the distribution system, which will be needed for routine analysis of system flows, are good locations for permanent meter installation. Permanent meters can be routinely read either via a Supervisory Control and Data Acquisition (SCADA) system, or a separate data-logger. Frequently these meters are used to

monitor flows throughout the system but can double as meters measuring flow in DMAs as part of a water loss management program. Permanent water meters require an investment to install and maintain. Unless it can serve dual and repetitive functions, permanent DMA meters may be financially infeasible for some systems.

Alternatives to fixed meters are temporary portable meters. Many of these meters are available as “clamp-ons” that measure the volume flow rate through a water main by being attached to the outside of the main, or as insertion meters that enter the stream of the flow through a standard ferrule connection tapped into a pipeline. The advantages of these types of temporary meters are that the integrity of the pipeline system remains intact, and the meter can be placed and then relocated to another location when measurements are completed. Furthermore, if the water main is readily accessible (e.g., meter vault, pressure reducing valve (PRV) site, air release valve vault), the need to excavate the line is avoided. Care must be taken to understand the accuracy of clamp-on and insertion meters and their sensitivity to the flow rate thresholds when used in water loss assessments.

Several general categories of temporary flow meters are shown in Table 4-2. Each of these sensor types requires a processor to integrate the signals and translate them to a liquid flow rate. It should be noted that these meters could be used for single point readings or as part of a remote-read, long term monitoring scheme. A SCADA system can be a highly effective communication and processing network for such metering.

4.2.3 Leak Detection Equipment*

The most common form of water distribution system leak detection is from proactively searching for leaks in the field. These searches, or leak surveys, must be planned carefully and conducted in a disciplined manner for the results to be meaningful. Leak surveys are conducted using a wide variety of tools to aid in discovery of potential system leaks. Most of these leak detection approaches locate leaks by observing the presence of, or change to, physical property (noise, temperature, etc.) that occurs only when a pipe leaks. Understanding the strength and weaknesses of each approach can help the operator select the best application for the system. A number of these technologies are discussed below.

The integrity of underground infrastructure is often difficult to evaluate. A large part of the capital investment of a public water utility can be attributed to its underground assets. Due to low visibility, these assets are easy to forget and hard to assess, but are absolutely critical to the

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use. See the disclaimer discussion in the front material of this document.

sustainability of the utility. The utility should actively search for leaking water mains, evaluate the magnitude of these leaks, and have a program in place to prioritize and address leaks. Since a direct measurement of the leak's flow rate is difficult, secondary indicator measurements that are frequently easier to apply can be used as surrogates. These secondary measures typically fall into a number of techniques: acoustic, thermal, electromagnetic, and chemical. Each technique has its own strengths and weaknesses. Not all leak detection techniques can determine where the leak is located and even fewer can assess the magnitude of the leak.

Some leak detection methods discussed below may require dewatering of pipes to install sensors or equipment. When using a leak detection method that requires dewatering, it is likely that disinfection and testing of the dewatered section will be required before the water line is put back into service. This ensures that no source of contamination has been introduced to the water supply by the testing procedures. Contact your state or primacy agency for their requirements for disinfection and testing after dewatering pipelines.

Table 4-2. Temporary Flow Meter Types			
Meter Type	Operating Principle	Notes	
Ultrasonic	Utilizes “time-of-flight” measurements of wave propagation (Doppler shift) of an applied ultrasonic signal to determine the fluid velocity.	Advantages	Highly accurate flow detection for stable flows.
		Disadvantages	• Not accurate in regions of temperature change. • Requires one 100-240V AC, 50-60 Hz power source.
		Accuracy	+/- 1%
		Cost	Capital: \$3,000-\$4,000
Magnetic Induction	Relies on the conductive properties of the liquid. The flow passes through a magnetic field producing a voltage difference over the cross-section of the flow area proportional to the average flow velocity. By knowing the liquid conductivity and the magnetic field strength, the flow velocity can be calculated.	Advantages	Relatively inexpensive and accurate across a wide range of flow rates.
		Disadvantages	• Requires 1 100-240VAC, 50-60 Hz power source. • Must be inserted in-line (flanged connections).
		Accuracy	+/- 0.5%
		Cost	\$2,500-\$4,000
Insertion Flow Meter	Inserts a probe (or pair of probes) into the flow stream. Probe element can use: (a) Ultrasonic. (b) Magnetic induction. (c) Paddle wheel. (d) Turbine.	Advantages	• Probes have little impact on flow or head loss. • Probes create little flow disturbance. • Higher accuracy & stability than clamp-on meters.
		Disadvantages	• Requires welding insertion points if one does not exist or 1-1/2” threaded fitting on pipe. • Requires water flow through line be stopped during meter insertion.
		Accuracy	+/- 0.5%
		Cost	Probe: \$400 - \$1,000 Water Use Monitor/ Totalizer: \$400-\$700

4.2.3.1 Acoustic Devices

Two distinctive audible noises are produced as pressurized water breaches the water main. The first noise is produced by a shockwave created when the water is forced through the opening. (The differential pressure between forcing the water out of the pipe must usually exceed 15 psi for substantial audible sonic waves to be generated and therefore detected.) These sounds are normally in the 500 to 800 Hz range and are propagated through both the pipe and the water. These sonic waves travel substantial distances in the pipe and therefore can be detected for hundreds of feet from the actual break site. The second noise generated is typically in the 20 to 250 Hz range and is produced by the impact of the water stream on the surrounding pipe bedding materials, as well as water circulating through the cavity caused by the leak (Hammer and Hammer, 2003). These sound waves travel through the ground and are therefore restricted to a much shorter distance of travel before they are attenuated and can no longer be identified from the background noise. These lower frequency sound waves can be used to help spot the exact location of the break as the operator continues to listen along the pipe. There are many sounds carried by the pipes such as the noise of water moving through and around various appurtenances, to pumping sounds to street noises. Every distribution system has its own unique acoustic signature that changes from one point in the system to another. It takes time to recognize and understand the various noises that are part of normal system operation. Acoustical leak detection equipment is designed to allow the operator to detect and identify sounds that are most characteristic of a pressurized pipeline leak. An experienced operator with distribution system operating knowledge is a key factor in effective leak detection.

Listening Rods/Sticks

Listening rods are among the simplest and oldest form of leak detectors in use. A listening rod aids the user in hearing the noises that water makes as it is forced from a pipe. The listening rod in its simplest form is a steel rod, several feet in length, with an earpiece at one end to help block out outside noises. The tip of the rod is placed on the pipe if exposed, or more frequently on a hydrant or valve stem. Sounds from the leak source are transmitted through the steel rod to the listener. If the user is in close enough proximity to the leak site, the lower frequency ground waves can also be detected. It takes operator practice and skill to successfully use a listening rod, but it is an effective and inexpensive tool. Table 4-3 provides more detail regarding listening rods/sticks.

Table 4-3. Listening Rods/Sticks	
Prevalent Application	Leak Detection
Strengths	• Simplicity. • Rugged, no mechanical parts, no electronics. • Requires no calibration.
Weaknesses	• Requires substantial practice to use well. • May be hard to differentiate between normal and leak noises in noisy systems. • Hard to pinpoint location of leak.
Set-up Time	1-2 minutes – time it takes to apply to top of hydrant or open and a valve box and expose top of isolation valve.
Average On-station Time	2-5 minutes (varies) – highly dependent upon skill of operator and familiarity with the sounds of the system.
Cost	\$15-\$25, with case \$50 - \$60
Photo	 Ref: http://www.pollardwater.com/pages_product/P679sonoscope.asp
Notes	The experienced water system operator can become very adept at detecting smaller water leaks using a simple contact listening device. However, the detection of larger leaks and the location of any leak can be very difficult.

Geophones

The geophone is a completely mechanical listening device that operates much like the physician's stethoscope. A set of listening tubes extends from the operator's ears down to listening-heads placed directly on the ground above the pipe to be evaluated. An experienced operator, moving the heads along the pipe, can become adept at detecting leaks. The stereo-effect of the two listening heads permits the operator to accurately locate the site of the breach. While the simplicity of the device makes it very rugged and inexpensive to operate in the field, it can miss some sounds that are traveling in the pipe and water system. Leakage sounds for non-metallic pipe or the low-frequency sounds of water impacting the surrounding bedding do not travel well through the pipe but rather travels through the ground. Geophones are best used for detecting leak sounds that are propagated largely through the ground. Table 4-4 provides more detail regarding geophones.

Table 4-4. Geophone Leak Detection	
Prevalent Application	Leak detection and location.
Strengths	• Simple and ease of use. • Rugged construction. • Requires no power.
Weaknesses	• Requires operator experience to become proficient. • May miss some classes of leaks. • Pipeline route needs to be marked so that operator can place phones directly above line.
Set-up Time	5 minutes – some unpacking and assembly on first test required.
Average On-station Time	2-5 minutes for leak detections, with another 5-20 minutes for leak location.
Cost	\$350 - \$400
Photo	 Ref: http://www.heathus.com/InfoCenter/geophone.pdf
Notes	Once a leak sound has been detected, the two listening heads are placed on either side of the suspected leak site. By careful listening to the difference in sound intensities, the experienced operator can isolate the general area of the leak.

Hydrophones

There are a wide variety of acoustic listening devices that use a hydrophone (piezoelectric crystal materials that produce an electric signal in response to acoustic impacts) to pick-up the sounds of leaking when placed on the piping system or in some cases on the ground above the pipe. These instruments are enhanced versions of the listening rod coupled with a battery powered sound amplifier to enhance the sound being transmitted. Testing on the ground along the pipe must augment the static listening to the pipe leak sounds to accurately locate these leaks. Many devices are also equipped with frequency range filters to permit the operator to filter out non-leak causing noises and better concentrate on noises coming from the pipe in the frequency range most indicative of a leak. A number of more sophisticated acoustic leak detectors have added various degrees of digital processing to the amplification systems. These detectors aid the operator by providing digital and graphic readouts of sound strength to assist in identifying leak locations. Many instruments attempt to correlate the amplitude of the leak noise to leak flow rates to provide the operator with an indication of leak magnitudes.

While the hydrophone greatly adds to the ability to detect leaks, operator experience and judgment is needed to understand the testing intervals that are needed along various sections of the system. The distance that leak sounds will travel and can be detected depends on both the pipe material and diameter. Table 4-5 provides an indication of how these detection distances vary, and Table 4-6 provides more detail regarding hydrophones.

Table 4-5. Leak Noise Travel for Distances in <u>Distribution</u> Mains* (for a 5 gpm leak at 60 psi)		
Type of Pipe	Pipe Dia.	Typical Sound Travel Distance
Iron Pipe	6"	1,000 – 1,200 ft
	12"	800 – 1,000 ft
	24"	600 – 800 ft
AC Pipe	6"	800 – 1000 ft
	12"	700 – 900 ft
	24"	400 – 600 ft
PVC Pipe	6"	400 – 600 ft
	12"	200 – 300 ft
	24"	100 – 150 ft
Leak Noise Travel Distances in <u>Service</u> Lines (for a 2 gpm leak @ 50 psi)		
Copper Tubing		600 – 1,000 ft
Galvanized Steel Pipe		800 – 1,200 ft
"Poly" Plastic Tubing		50 – 100 ft

*Courtesy Subsurface Leak Detection, Inc., 4040 Moorpark Avenue, Suite #104, San Jose, CA 95117.

Table 4-6. Hyrdophone Leak Detection	
Prevalent Application	Leak Detection, location, and quantification.
Strengths	• Numerous operator aids to enhance leak detection and location. • Can better fix location of water leakage. • Some detection heads can be designed to optimize use on non-metallic pipe.
Weaknesses	• Requires some operator training. • Requires experienced operator to interpret what is being heard. • Equipment needs moderate care in the field. • Higher cost.
Set-up Time	5 minutes – some unpacking and assembly on first test required. Time it takes to apply to top of hydrant or open a valve box and expose top of isolation valve.
Average On-station Time	2-5 minutes for leak detections, with another 5-20 minutes for leak location.
Cost	\$1,200 - \$4,000, depending on features
Photo	 Ref: http://www.subsurfaceleak.com/PDFs/LD-15_brchr.pdf
Notes	Specialized listening heads are available to connect directly to the pipe (valve or hydrant) or for use on the ground above the pipeline.

Leak Noise Loggers

Leak noise loggers are a modification of an acoustic leak noise detection recording. Leak noise loggers combine a listening head with a digital recorder into a single sensor that can be attached to the system and left in place to operate over an extended period of time. At the end of the testing period, the loggers are removed and their time-marked data downloaded to specialized leak characterization and detection software for analysis. The frequency of sampling and recording sound intensity information is preset by the operator and can range from once per millisecond to once per minute and can remain in place for several days, limited only by the data storage capacity of the unit. More sophisticated loggers can be set to turn on and turn off, sampling only during the quieter, low-flow hours. Some models of leak noise loggers contain radios that will download their stored data when queried, resetting themselves for follow-on recording. This data transmission feature is useful for extended period measurements when the change in identified signals can be used to confirm and quantify leakage magnitudes. Leak noise loggers can be an effective, low-cost method of taking continuous measurements, especially when nighttime logging is desired. By deploying and rotating groups of leak noise loggers, technicians can collect minimum consumption hour leak noise data without having to deploy personnel during these hours. Leak noise loggers can be deployed permanently at high priority or inaccessible sites in order to maintain ongoing leak surveillance. Alternatively, permanently installed low-cost leak noise loggers can be installed intermittently on customer service connection piping with noise alerts conveyed to the water utility through a fixed network automatic meter reading (AMR) system. Such added capabilities are making a stronger business case for AMR since these systems now provide multiple capabilities beyond periodic customer meter readings.

Leak noise loggers are most successful when used for leak detection on cast iron, ductile iron, steel, concrete, and transit pipe. Leak detection in PVC needs longer run times. Table 4-7 provides more detail regarding leak noise loggers.

Table 4-7. Leak Noise Loggers	
Prevalent Application	Leak noise sound intensity sampling and recording.
Strengths	• Provides long-term record over several days. • Requires only setup and no on-site operator during recordings. • May be used with other loggers and leak correlators to quantify and locate leaks. • Requires limited operator training to set logger in field.
Weaknesses	• Subject to easy theft unless protected. • Requires a trained technician to analyze recorded leak noise data and direct leak pinpointing activities.
Set-up Time	20-30 minutes, including time to set logger sampling rate and recording period. Required revisit to download and/or remove data logger.
Average On-station Time	1 – 3 hours, depending on pipe material. PVC requires longer data collection periods. Additional time is needed to analyze leak noise patterns and direct follow-up leak pinpointing.
Cost	\$19,000 - \$21,000 (includes factory training).
Photo	 Ref: http://www.subsurfaceleak.com
Notes	These devices are most accurate for leaks in pipes < 16" and are more difficult for leak detection in pipes > 36". For the most accurate leak locating, more than a single correlation should be used for each leak detected.

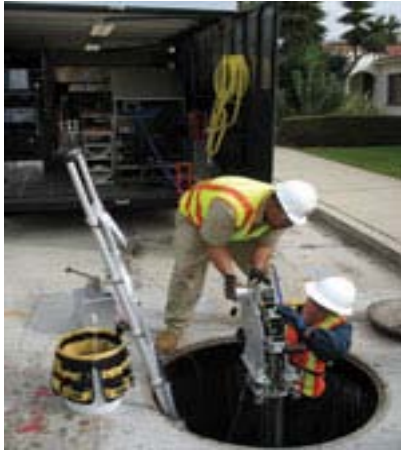
Leak Noise Correlators

It is not unusual for larger leaks to generate both lower frequency and lower noise intensities than recently formed, smaller leaks. Smaller pipe penetrations may result in higher discharge velocities that produce a louder, more characteristic sound for the same pressure differential across the pipe than older larger pipe leaks. These larger leaks can, therefore, be even more difficult to detect and locate, especially in portions of a distribution system that are generating a wide range of noise profiles (Lahlou, 2001). Leak noise correlators are computerized listening devices that utilize two or more highly sensitive sound detection sensors placed on each side of the suspected leak and transmit (or connect by hard-wire) to a computer that filters and calculates a leak's location relative to the sensor array. Sound from a leak site travels at a fixed speed which depends on the size and material of the pipe. The filtering and digital processor of the correlator is able to identify and delineate sounds typical of water breaks. Comparing the arrival times of these sounds as detected by each of the two sensors, the computer of the leak noise correlator can integrate their arrival times and thereby infer the distance of the leak site from the listening heads. The result of this integration is then displayed to the operator. The leak noise correlator with two fixed microphones is able to mimic the action of an operator with a single microphone moving back and forth across the water main listening for the quality and amplitude of a leak sound. Faster and more accurate leak locations are possible using a correlator in the hands of a trained and experienced operator. Some leak noise correlators are wireless and provide the flexibility needed to accurately locate leak sites along highly inaccessible routes. Table 4-8 provides more detail regarding correlators.

Table 4-8. Leak Noise Correlators	
Prevalent Application	Leak detection and pinpointing.
Strengths	• Accurate delineation of leak noises from complex sonic background. • Accurate pinpointing of leak source on pipeline. • Greatly reduced time, especially along a highly inaccessible route. • Can locate leaks in PVC and DPE pipe.
Weaknesses	• Requires factory training. • Requires moderate care in the field.
Set-up Time	10-20 minutes.
Average On-station Time	30-60 minutes, but may be longer if attempting to detect during periods of high demand.
Cost	\$20,000 - \$32,000, dependent on ancillary equipment (typically includes factory training).
Photo	 Ref: http://www.utsleak.com
Notes	Not unusual for the accuracy of leak locate to be better than 1m/100 meters.

Streaming Cable Inline Acoustic Leak Detectors

Many techniques for detecting leaks in smaller diameter, metallic distribution lines cannot be used for larger transmission mains or for concrete or PVC type pipe materials. For lines greater than 12 inches, streaming cable inline detection may be applicable. In this approach, the acoustic sensor is placed at the end of a long cable (up to 6,000 feet) that is fed into the pressurized water main. A small parachute at the head of the sensor pulls it along the pipe while a trained operator on the surface listens to the acoustic signal being returned by the sensor. An odometer on the cable measures the distance that the sensor has traveled. The sound of water spewing from a hole in the side of the pipe is easily distinguished by the operator who notes the location. Furthermore, a well-trained and experienced operator can accurately estimate the flow rate of the leak from its acoustical signature. Table 4-9 provides more detail.

Table 4-9. Inline Acoustic Leak Detection (Streaming Cable)	
Prevalent Application	Leak location and flow rate estimation for large diameter transmission mains.
Strengths	• Highly accurate as the detector is moved to the source of the sound. • Applicable for large diameter transmission mains. • Can be used on all types of pipe materials. • Can estimate leak size and water loss flow rate. • Line does not have to be taken out of service to test.
Weaknesses	• Length of single run depends on pipe configuration. • Commercial application requiring a trained contractor. • Cannot directly evaluate corrosion conditions of pipeline or tensioning wire in PCCP pipe lines.
Setup Time	Variable depending on the access to the water main, but 1 hour is average.
Average On-station Time	1 – 3 hours, depending on pipeline size and condition. Older mains take longer to map and characterize numerous leaks.
Cost	Variable depending on the site and application. Mobilization/demobilization costs of \$6,000-\$12,000 are not uncommon with on-site time separately billed.
Photo	 Ref: http://www.ppic.com
Notes	Streaming cable detection systems frequently have the ability to replace the acoustic sensor with a CCTV head and return to the leak site to inspect and record the pipe, providing the operator with a clear view of the condition and approach needed to make repairs.

Free-Floating Inline Acoustic Leak Detectors

A relatively new and impressive technology for detecting leaks in larger transmission mains is the free-floating inline acoustic detector. One such system is the SmartBall® by Pure Technologies. In this approach, a small plastic ball houses acoustic sensing equipment in its core. The ball is inserted into the pressurized pipeline, where it travels along the length of the pipe with the flow listening for and recording the distinctive sound of water leaking from the pipe. Acoustic transmitters with unique transmission signatures are located along the pipeline and are recorded by the ball. These markers pinpoint the exact location of the ball in the pipe when a leak signal is detected. When the ball is removed downstream, its “onboard” data is downloaded and analyzed by a technician who maps the leaks in the pipeline and estimates leak flow rates. Table 4-10 provides more detail.

Table 4-10. Inline Acoustic Leak Detection (Free-Floating)	
Prevalent Application	Leak location and flow rate estimation for large diameter transmission mains.
Strengths	• Can assess pipes from 0.5 to 20 miles long. • No cable to impede distances. • Any pipeline material. • Can detect air pockets in pressurized pipes. • Easily flows through valves and fittings.
Weaknesses	• Balls can get lost or trapped in system. • Cannot provide video assessment. • Cannot be used for pipelines with high water pressure (>400 psi) as the insertion and retrieving procedure may not be feasible. • If surface sensors are used to monitor the pulses, these sensors have to be moved along the pipe length if the survey involves long pipe lengths. • Commercial application requiring a trained contractor.
Setup Time	Variable depending on the access to the water main, but 1 hour is average.
Average On-station Time	Variable depending on the length of the line to be assessed and flow rate through the main.
Cost	\$3,000 - \$4,500 per mile (average)
Photo	 Ref: http://www.puretechnologiesltd.com
Notes	Have very high location accuracy, saving time and minimizing disturbance to effect repairs. Can also be used to identify pipe joints and locate valves or other features in the pipeline.

Acoustic Fiber Optics (AFO)

Recent research has found some success using listening devices connected via either a fiber optic cable (Higgins and Paulson, 2006) or hydrophones arrayed along an insulated copper cable that are streamed into the water main at a valve or other fitting. This technique, which is used for condition assessment as well as leak detection, is primarily used in large-diameter transmission mains, particularly pre-stressed concrete cylinder pipe (PCCP). The listening devices can be placed as a permanent or quasi-permanent installation in key water mains that are critical to the reliability of the system. The cable detects sounds that are transmitted to a digital processing and recording device. Circuitry in the digital processor filters-out random and system noises, focusing on noises most frequently associated with pipeline breaks. Once a break is detected, its location along the cable is provided to the operator.

Acoustic Fiber Optics (AFO) can detect the distinctive “ping” that is made when a pre-tensioning wire in a PCCP fails. A profusion of such wire breaks over a relatively short period of time may be a precursor to a rupture of the pipeline in that area. These systems when properly installed and monitored can be an effective element in both a leak detection and asset management program. AFO installation requires dewatering of the distribution system site, but not necessarily the complete dewatering of the entire system. Cable lengths exceeding 40 km have been used. Cable receiver and processing equipment must be provided with an external power source for continuous operation but lend itself to SCADA interface.

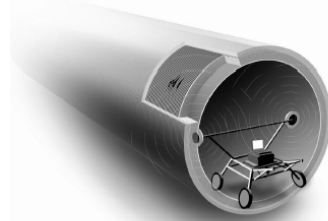
A laser is used to project light down the fiber, and a data acquisition system monitors reflections generated by the acoustic activity in a pipeline. The entire fiber cable acts as a sensor so, in effect, the sensor is never further than a pipe diameter from a pre-tensioning wire break. An advantage of the system is that no electronics are placed in the water flow, so monitoring system noise is nearly eliminated. AFO is a sophisticated technology that requires considerable effort to implement and manage. It is designed specifically for critical transmission pipelines, whose failure would result in disruption to supplies as well as significant damage to property. It is beneficial in circumstances where such large-diameter PCCP piping exists. Table 4-11 provides more detail regarding AFO cables.

Table 4-11. Acoustic Fiber Optic Cable	
Prevalent Application	Condition assessment and detection of small leaks before they become major for large diameter, particularly PCCP pipelines. May be a good approach for exceptionally critical mains that cannot be taken out of service to repair main failures or major leaks.
Strengths	• Provides long, continuous record of main integrity. • Can be highly accurate in detecting and locating water leaks. • Can track growth of leak site size to accommodate economical repair schedule. • May not have to be dewatered, but pressure must be removed to place the cable. • Can detect breaks in pre-tensioning wires in PCCP pipelines which can evidence failure potential in these assets.
Weaknesses	• Requires unidirectional flow to prevent cable from becoming entangled in valves and fittings. • False positive and negative readings. • Significant cost requirement justifies use on only critical large diameter, PCCP pipelines.
Set-up Time	12-18 hours installation time depending on size and complexity of main.
Average On-station Time	30-60 days. Can also be set up as a permanent in situ system listening for changes in the main noises that may indicate the formation or growth of water loss sites.
Costs	Typically a contracted service, equipment not owned by the utility. Service contract placement / removal costs of \$2,000 - \$10,000 plus monitoring costs of \$15-\$25 per foot of main. Utility must also dewater line and open access pits.
Photo	 Ref: http://www.puretechnologiesltd.com
Notes	Many of these systems are proprietary and may only be contracted as an occasional or ongoing service. Cost includes monitoring (active listening) and analysis by the contractor over an extended period of time with periodic reports of findings. Installation may require disinfection and testing before the pipeline is placed back into service.

Electromagnetic Field Detection

Electromagnetic (EM) field detection is a proven proprietary electromagnetic inspection technology for evaluating the current condition of large-diameter, pre-stressed concrete cylinder pipelines (PCCP). Owners of these critical water pipelines can use EM technology to identify distressed pipe sections within their infrastructure, which allows them to detect leaks and pipe sections with high rupture risk potential on these important assets. Once a pipe is dewatered, EM equipment can be deployed to locate and quantify existing wire breaks along individual pipe sections of PCCP pipelines.

A mobile energy head generates an electromagnetic field inside a PCCP and measures the changes within this field caused by broken pre-tensioning wires. By providing information on the number of broken wires in each pipe, EM detection enables the most effective remediation strategy to be put into action. This process is often used as a first step in a long-term management program for pre-stressed pipelines. Once the survey is completed and the current condition of the pipeline is determined, a long-term acoustic monitoring program can be instituted. This monitoring program, in conjunction with a GIS-based structural risk management program, can ensure the long-term integrity of the asset. EM is a sophisticated technology that requires considerable effort to implement and manage. It is designed specifically for critical transmission pipelines, whose failure would result in disruption to supplies as well as significant damage to property. It is beneficial in circumstances where such large-diameter PCCP piping exists. Table 4-12 provides more detail regarding EM field detection.

Table 4-12. Electromagnetic Field Detection	
Prevalent Application	Similar to acoustic monitoring, electromagnetic field detection is a technique for surveying, mapping, and evaluating the integrity of large-diameter PCCP pipe.
Strengths	• Generates record of PCCP water main integrity. • Non-destructive test can spot broken pre-tensioning wires before they appear on the surface.
Weaknesses	• Pipeline must be dewatered. • Pipeline may have to be disinfected and tested before being placed back into service. • Interference from adjacent metallic pipelines may occur.
Set-up Time	24-48 hours, depending on size and complexity of main, time to dewater main, and time to excavate service pit at both ends.
Average On-station Time	Set-up time: Requires that line entry and exit points be uncovered, line dewatered, and line opened. Preparing the line, inspection, and equipment insertion can take 1-2 hours. The inspection takes about 15-min per 1,000-ft of water main to be inspected (assumes straight, unencumbered path).
Cost	Actual inspection and analysis costs average \$15,000-\$30,000 per mile of pipeline to be inspected (exclusive of the on-site work required to prepare the pipeline for inspection). Process is proprietary and must be contracted.
Photo	 Ref: http://www.puretechnologiesltd.com
Notes	A two-tier analysis is typically provided. A qualitative analysis of the data takes about 2 days to return to the utility and permits immediate repairs as needed before line is placed back into service. A longer, 30-day detailed analysis is then provided the utility.

4.2.3.2 Thermal Detection

Unlike acoustic devices that detect a property of the leak, thermal detection devices look for the temperature differences in the surrounding ground caused by saturation due to the leaked water.

Thermography

Thermography measures the infrared radiation (heat) emanating from the ground. Areas along a water main in which a leak site is active will frequently exhibit saturated conditions just below the surface that may or may not be apparent on the surface. These saturated zones tend to be somewhat warmer than their surroundings in the cooler winter months. Conversely, these areas may appear cooler than their surroundings in the warmer summer months. Infrared measurement of the general area can help detect these areas of temperature differentiation and locate the leak site. The operator can use simple hand-held infrared meters with digital temperature gauges to locate the general area to excavate for the leak. When used on a larger scale, whole-site thermography has been successful at photographing temperature variations and locating leaking below slabs, pavement, and even buildings. Infrared measurement locating is most frequently used in conjunction with other methods of detection to better locate the best potential excavation sites. Table 4-13 provides more detail regarding thermography.

Table 4-13. Thermal Water Leak Detection	
Prevalent Application	Leak locating.
Strengths	• Can narrow the general area of leak site locating. • Simple to use.
Weaknesses	• Relies on temperature variations which may not be very large. • Gives no indication of the size of the leak. • Leaks may be masked by ground water.
Set-up Time	5-10 minutes.
Average On-station Time	15-30 minutes depending on ground conditions.
Cost	\$150 - \$10,000 – hand-held infrared meters are fairly inexpensive, but whole-site thermography can become expensive and is probably best accomplished through a knowledgeable contractor.
Photo	 Visible photo on the left and thermal photo on the right. The water leak from the transmission main shows up as a dark blue area. Ref: http://www.thermal-imaging-survey.co.uk/archive/pipeline.htm
Notes	While thermal leak detection techniques can be used for local applications, it also can be used in much larger detection areas such as for long runs of transmission mains.

4.2.3.3 Electromagnetic Detection

Various forms of electromagnetic detection devices have been developed for use in locating buried utilities, especially pipelines. Some of these same technologies are being extended to help identify leaks in these pipelines.

Ground Penetrating Radar (GPR)

GPR, also known as ground probing radar, subsurface radar, georadar, or earth sounding radar, locates and evaluates subsurface leaks without the need to expose them (Eyuboglu et al. 2003). Most GPR units operate by transmitting electromagnetic waves (125 MHz to 370 MHz) into the ground that subsequently bounce off of subsurface objects and return to the receiver head of the unit. The returned signal is processed into a picture of subsurface objects including plastic pipes, rocks, and voids. Water leaking from a pipe usually can be detected and the exact location of the pipe breach can be identified real-time as the operator moves the lawn mower-sized unit along the length of and back and forth across the pipeline. Enhanced signal processing is being developed to help the operator refine the investigation. Table 4-14 provides more detail regarding GPR.

Table 4-14. Ground Penetrating Radar	
Prevalent Application	Leak detection, locating, and quantification.
Strengths	• Relatively independent of pipe material – can detect leaks in metallic, concrete, and plastic pipes. • Can detect leaks in any pipe >1”. • Compact unit easily transportable. • Moderate operator training and support are required. • 3-4 m depth detection possible.
Weaknesses	• Requires access to route along top of pipeline. • Takes training and experience to accurately delineate leak detections. • Definition can be highly dependent on pipeline bedding and ground water conditions.
Set-up Time	10-20 minutes, assuming site is clear of inhibiting structures or vegetation.
Average On-station Time	1-3 hours, depending on the length and accessibility of line to be inspected. Pipeline needs to be located and marked prior to radar scan to improve leak detection results.
Cost	\$15,000 - \$31,000, depending on the size and mounting of the radar head.
Photo	 Ref: http://www.geodetic.com.au/category1541_1.htm
Notes	Only moderate operator training and support are needed to operate equipment and locate pipes, but significant experience can be required for the detection of water leaks using ground-penetrating radar. While GPR quickly and accurately detects the pipeline, considerable interpretation is frequently required to see the signature of a leak.

4.2.3.4 Chemical Detection

Chemical detection techniques rely on the introduction of a detectable gas into a dewatered line or a liquid to the water. If detected outside of the pipe, it is an indication of a breach in the pipe wall. Due to the restrictions on products that can be used in conjunction with potable water supplies, these techniques must be used with forethought and great care. The local drinking water regulatory agency should be consulted before considering chemical detection.

Tracer Gas

Tracer gas, also called “Gas Sniffing,” is an emerging leak detection technology that was developed by the petroleum industry as a passive approach to detecting pipeline leaks. It has some applicability in the potable water sector, especially in those applications where the line can be taken out of service, dewatered, and tested. The technique requires the injection of an inert gas, typically a 5% hydrogen-nitrogen mixture, into a pipeline to be tested. Electro-chemical sensors are then used to detect the presence of hydrogen gas in the air just above the ground atop the tested pipeline. Once the detectors are calibrated for the ambient levels of free atmospheric hydrogen gas, they can be used to detect and locate main leak sites. In many cases the intensity of the detected hydrogen will provide indication of the size of pipeline breaches. The most frequent configuration is a hand-held detection unit (USACE, 2001). Some experimental work has been attempted using gas detection technology on operating systems. Due to the sensitivity of some waters to the nitrogen carrier gas used in this method, this technique has only limited application for some systems that must remain in operation. This technique is more applicable to leak detection on newly constructed pipelines as part of the commissioning process to ensure a leak-free system. It is used less often on active pipelines which must be dewatered. Table 4-15 provides more detail regarding tracer gas detection.

Table 4-15. Tracer Gas Detectors	
Prevalent Application	Leak detection and site location.
Strengths	• Non-destructive testing approach. • Facilitates location of multiple leak sites. • Not dependent on pipe material, water pressure, or physical shape of leak. • Can be used with either operating or dewatered lines, but dewatered application results in greater sensitivity.
Weaknesses	• Some systems may have to be dewatered to use. • Needs careful calibration of sensors to achieve usable accuracy. • Requires extensive operator training. • Sensitivity may be somewhat weather dependent. • More applicable to verify newly constructed pipelines than to identify leaks on active pipelines
Set-up Time	8-12 hours, depending on the dewatering and preparation time required.
Average On-station Time	1-2 days, depending on complexity and geometry of the section to be tested.
Capital Cost	\$16,000-\$18,000, depending on number and type of equipment attachments.
Photo	 Ref: http://www.schoonoverinc.com/products/Leak%20Detection/leak%20detection.htm
Notes	Gas detection methods are more accurate at detecting the existence of a leak in the pipeline than at locating the position of the leak due to the multiple paths that the escaped gas may take to the surface. It is very difficult to quantify the magnitude of the leak using this method. The procedure may also require disinfection and testing before the pipeline is placed back into service.

Tracer Liquids

Although infrequently used, leak detection is sometimes possible with the use of liquid tracer markers. A water system operator may be faced with determining if the water that is seen on the surface of the ground is coming from the public water system. Such an analysis can be facilitated by injecting a conservative (decay constant of zero) marker into the water system and then testing for this marker in the surface waters. A number of markers can be used depending on the nature of the water systems. Chlorine, although not technically considered a conservative marker, is easily injected and detected and is used in many distribution systems. However, chlorine residual dissipates quickly after water leaves the pipe and migrates through soil; therefore, the reliability of chlorine as an indicator is limited. Chlorine can serve as a marker for those systems that do not maintain a chlorine residual. Fluoride is another chemical that can be injected into either chlorinated or non-chlorinated system as a marker. Many water utilities maintain a chlorine and fluoride residual in the distribution system water so these chemicals are readily available as a basic tracer. The appearance of fluoride in the surface waters is then a positive indicator of leakage from the water main, although exact location and magnitude of the leak are not highly enlightened by the process. A number of manufacturers market fluorescent dyes for use in public water systems that can be injected into the distribution system and in very low concentrations are invisible to the eye in natural light, but which fluoresce under ultraviolet light (blacklight). The dyes should be NSF Standard 60 Certified for use in a potable water system. Quantification of leakage can be attempted with fluorometer measurement of the marker dispersion of the marker. This technique is highly susceptible to interferences from the soil complex and the amount of ground water present. Table 4-16 provides more detail regarding tracer liquid leak detection. It should be noted that addition of any tracer, including chlorine and fluoride, may be subject to state drinking water program approval.

Table 4-16. Tracer Liquid Detectors	
Prevalent Application	Leak detection.
Strengths	• Can affirm the existence of a leak in the water distribution system from its appearance on the surface.
Weaknesses	• Not very accurate method for pinpointing a leak source. • Gives little information on the magnitude of the flow. • Propensity for false negatives. • May not be approved for use by local health agencies.
Set-up Time	1-3 hours for preparation of field injection site.
Average On-station Time	1-3 hours, depending on speed that marker diffuses in line and migrates to the surface.
Cost	\$100-\$300, mainly a function of the injection pump and system connection costs.
Photo	 Ref: http://www.usabluebook.com
Notes	Dye tracer studies in water systems require metering into the stream to maintain levels low enough not to be objectionable to water aesthetics but of great enough concentration to be detectable in area where leaking is suspected. More widely used in the wastewater sector.

4.2.4 Leak Locating Services and Other Potential Sources for Equipment and Expertise

It can be expensive and it takes experience to accurately locate leaks using many of the methods described. For larger municipalities or any system planning to develop a proactive loss control and monitoring plan it makes financial sense to acquire equipment and train staff to operate it. Smaller systems might not benefit from making this investment and extensive commitment. There are other options available to smaller systems that might be more feasible.

It may be possible to borrow or rent the equipment from a nearby water system that has leak detection equipment or from a rental service. It may also be advantageous for a water system to contract their leak locating services to other municipalities to help offset equipment cost and staff training. For smaller systems, periodically hiring a commercial leak locating service may be the

economical choice. Small water systems should talk to their primacy agency or local experts to learn of the available resources. Funding may also be available from state revolving funds or other programs for water audits.

4.2.5 Predicting Leakage Rates

While full analysis is beyond the scope of this document, two important leakage modeling concepts should be mentioned. They are: Background and Bursts Estimates (BABE) component analysis and the Fixed and Variable Area Discharges (FAVAD) pressure-leakage relationship.

BABE is a concept that was developed by Allan Lambert in 1993 for the UK National Leakage Control Initiative. It is used for calculating components of Real Losses based on the various parameters. For the analysis, real losses on different parts of the infrastructure are characterized as:

- Background leakage at joints and fittings (Background leakage occurs as flow rates too low for sonic detection if not visible).
- Reported leaks and bursts (high flow rates with short duration).
- Unreported leaks and bursts (moderate flow rates with duration depending on the method of active leakage control).

BABE is a statistical component analysis model and performs better with larger samples. BABE analysis can be used for calculating components of Current Annual Real Losses (CARL) and components of minimum hour night flows. Typical leakage flow rates are specified at a standard pressure and are adjusted to actual pressure using appropriate assumptions for Fixed and Variable Area Discharge path (FAVAD) N1 values. The N1 value is a calculation factor based on the piping system. Component analysis is a modeling technique that allows the utility to enter assumed times for leak awareness, location, and repair times and estimates the component volume of losses for the various types of leaks occurring in the system. Component analysis reveals current leakage conditions and shows how much leakage savings the utility can achieve if they improve their active leakage control activities for individual classes of leakage.

The recognition and understanding of the pressure-leakage relationship is a significant recent advancement in leakage management. A hole or leak in a pipe has an expected leakage rate based on the size of the hole, shape of the hole, and the pressure. The FAVAD concept introduced the idea that the leakage rate of flow may increase or decrease with changing pressure levels due to the area of the leak changing. For instance a crack in a plastic pipe may get wider at higher pressures and thus allow proportionally more water to escape. In the simplest versions of the FAVAD equation, the Leakage Rate L (Volume per unit time) varies with Pressure $N1$ or

$L_1/L_0 = (P_1/P_0)^{N1}$. N1 values can be calculated from tests on sectors at night. Values derived for sectors in the UK, Japan, Brazil, Cyprus, USA, Australia, and New Zealand have shown that N1 generally varies between 0.50 and 1.50, with occasional values up to 2.5. Small acoustically undetectable leaks at joints and fittings typically have N1 values around 1.50, as do larger leaks and bursts on flexible pipes. Detectable leaks and bursts on rigid pipes normally have N1 values close to 0.50, meaning the leakage rate is much less variable with pressure changes. The advanced understanding of the pressure-leakage relationship has allowed the technique of pressure management to be developed as a means to economically reduce background leakage rates as well as remove pressure transients and slow water main ruptures.

The BABE and FAVAD concepts are used in multiple software packages that help water system managers design leakage management strategies that are appropriate for their water distribution system leakage characteristics.

4.2.6 Pipe Repair, Rehabilitation and Replacement

4.2.6.1 Pipe Repair Techniques and Considerations

A major center of focus of an effective water loss management program is repair, rehabilitation, or complete replacement of water pipeline assets. Repair typically depends on trained crews, using the appropriate materials, equipped with the adequate tools to safely repair leaks quickly and securely. As expensive as repairing a leak can be, fixing it a second time can more than double the investment in labor and materials while destroying customer satisfaction.

4.2.6.2 Pipe Repair/Replacement Personnel

A trained and experienced crew that has working knowledge to conduct effective and timely leak repairs is priceless. The repair approach will depend on the leak and the environmental conditions in which the repair must be made. If the leak site is the result of small corrosion pitting or puncture holes, a repair clamp will usually work quickly and well. Leaks that result from large-hole formation or long cracks may require replacement of one or more sections of the pipe. For large steel pipe, repair may take the form of in situ welding. Repair crews need to be trained on a variety of fix approaches.

4.2.6.3 Available Equipment and Materials

It is prudent and common for utilities to maintain an inventory of parts to support leak repairs in their distribution systems. An analysis of the leak repair history of the utility can greatly facilitate the selection of appropriate materials and quantities to stock. Many smaller operations have found that it is advantageous to reach out to neighboring water utilities that may have similar repair parts and equipment needs to be aware of what might be available in their stock in

case of an emergency. Finally, for larger scale events, over 30 states have now formed mutual assistance networks called Water & Wastewater Agency Response Network (WARN) (<http://www.nationalwarn.org>) to provide expansive help between water utilities within a state and, in many cases, even across state lines. While WARN is primarily for disaster response, a large catastrophic failure of a major transmission line may require more resources than a PWS has available and may need assistance from a WARN partner.

4.2.6.4 Leak Repair Techniques

A variety of technologies are available to repair pipeline leaks depending on their location and size. Many studies have shown that the most significant portion of leak repair cost and time is attributed to uncovering the leak site and dewatering. From there, the repair techniques are relatively easy. For this reason, a growing portion of the leak repair market is centered on approaches that do not require that the pipeline be uncovered. The following approaches, while certainly not exhaustive, are meant to provide the user with a representation of the level of effort and potential costs that may be encountered using such techniques.

Wrapping

Some small pipe leak repairs may be made using a surface wrap depending on pipe material. Many of these products take the form of a fiberglass cloth impregnated with a resin that is activated by water. The cloth comes ready to apply and does not require any mixing or measuring. The application is largely insensitive to pipe temperature at the time of application, and many brands can even be applied under water. Cracked pipes can be wrapped with the cloth and secured with a pressure sensitive rubber tape. Corrosion holes are typically patched with a two-part epoxy before being wrapped. Some products are designed for application while the pipe is under pressure, avoiding the necessity to shut-off the water service. Table 4-17 provides more detail regarding pipe wrapping.

Table 4-17. Wrapping	
Prevalent Application	Small holes and short cracks that will not tend to lengthen.
Description	• Cloth comes in 4", 6", and 8" widths. • Cloth rolls up to 50' long. • Patches rated for line service up to 300 psi.
Application Time	• Cure time 30-60 minutes before line pressure can be applied. • Total application time 1-2 hours. • Patch needs 24 hours to fully set before backfilling water main. • Typically limited to repairs on pipes 4" and under. • Product must be NSF certified in most states.
Average On-station Time	Highly variable depending on site conditions: • Traffic conditions & traffic control needed. • Depth of pipe & availability of excavation equipment. • Depth of trench and shoring required. • Trench dewatering. • Availability of new bedding and backfill material. • System flushing. • Surface restoration.
Cost	\$15-\$75 – repair kit, depending on pipe size, with 2 – 4 hours repair time.
Photo	 Ref: http://www.prime-line.net/urethane.html
Notes	Works on PVC, copper, concrete, most metals, plastic, and rubber pipe materials.

Repair Clamps

Repair clamps are collars that can be fitted around the outside of the pipe to patch the hole or break. The metal collar contains a partial or full size gasket that is subsequently compressed

onto the surface of the pipe by the clamp providing a pressure tight fitting to stop the leak. Table 4-18 provides more detail regarding repair clamps.

Table 4-18. Repair Clamps	
Prevalent Application	Small holes and short cracks that will not tend to lengthen.
Description	• Clamp usually made of stainless steel. • Clamping bolts & nuts made of stainless steel or low alloy. • Gasket material made from Styrene-Butadiene (SBR) or Nitrile (Buna-N). • Sized to match the O.D. of the pipe in lengths of 6"-15".
Application Time	1 hour – Majority of time needed to clean, remove corrosion from the outside of the pipe, and disinfect the pipe surface in preparation for clamp placement.
Average on-station time	Highly variable depending on site conditions: • Traffic conditions and traffic control needed. • Depth of pipe and availability of excavation equipment. • Depth of trench and shoring required. • Trench dewatering. • Availability of new bedding and backfill material. • System flushing. • Surface restoration.
Cost	\$30-\$200 per clamp, depending on type and size.
Photo	 Ref: http://www.subsurfaceleak.com

Sliplining

An effective approach for rehabilitating a deteriorating water main without having to uncover it is a process known as sliplining. In this process, the existing pipeline is rehabilitated by pulling a thin-walled plastic liner inside the existing, cleaned pipe to seal its leaks. Sliplining leaves the

host pipe intact and uses it for structural support of the much thinner plastic lining. Once the liner is in place, hot water is pumped through it, causing the liner to become malleable, expand and tightly seal onto the surface of the old pipe. In this approach, the original pipe provides the strength and structure for the pipeline while the liner provides pipeline integrity and improved system performance. Excavation is only needed at intervals along the pipe to facilitate entry and exit from the line and for reconnecting services. There is an added cost of jointing techniques when limited to using short pipe lengths. Poorly applied grouting can lead to buckling. Sliplining does not work well in pipelines with many elbows and isolation valves. Table 4-19 provides more detail regarding sliplining.

Table 4-19. Sliplining	
Prevalent Application	Repair of multiple holes in pipeline without excavation.
Description	Grinding, flushing, and lining of existing pipelines with thin-walled plastic linings to seal the line.
Average On-station Time	The on-station time is highly variable. Sliplining may require extensive carrier pipe preparation and cleaning before lining can begin. Also, connections of laterals and service connections must be made following lining. Repair times of 5-10 days per 1,000 foot of pipe to be lined can be expected.
Cost	\$120-\$135 per foot installed (by commercial contractor). The price includes materials, shipment, line preparation, on-site pipe fusion, placement & thermal setting, and tapping. Price does not include system dewatering, access pit excavation (350-500 ft), and restoration.
Photo	 Ref: http://www.undergroundolutions.com
Notes	Sliplining processes require that the lining be re-tapped at all connections. Several new camera-driven and computer controlled tapping machines have greatly reduced the time this re-tapping takes.

4.2.6.5 Pipe Replacement

Open Trench Replacement

It is not unusual for a repair crew to discover that the section of leaking pipe is far too deteriorated to repair with the application of a simple repair clamp. In these cases, it may be necessary to replace one or more lengths of the pipe. While pipe replacements are best done using the same material as the existing pipe, lack of pipe stock or desire to upgrade to a less corrosive pipe material may dictate that the replacement length be another material. Pipe couplings and spool pieces to connect the replaced pipe section are readily available. Table 4-20 provides more detail regarding open trench pipe replacement.

Table 4-20. Replacement (Open Trench)	
Prevalent Application	Required when pipe condition is too poor to support a local patch or already has several patches.
Description	Replacement of one or more lengths of pipe (10', 15', 20' lengths) with new pipe.
Average On-station Time	It is not unusual to expend 60%-80% of the total on-site time opening the trench, dewatering the work site, backfilling, and repaving the site. The actual pipe replacement once the trench and bedding have been prepared is 2-3 hours per pipe length.
Cost	\$100-\$300 per foot of open trench, depending on pipe type, size, and location.
Photo	 Ref: AWWA, "Images on Tap," August 2005
Notes	Flanged couplings and spool pieces may be required to connect the replacement pipe to the existing system. These ancillary pieces, sized for the specific pipe being repaired, are typically maintained by the utility as part of the emergency repair materials.

Trenchless Replacement

Aging infrastructure in water systems often means failing joints, leaking valve seals, and corroded pipes, all contributing to substantial leakage from the system. A major obstacle in repairing these elements is their inaccessibility. Many water mains cannot be effectively uncovered and replaced when they are located in congested areas and critical traffic arteries. One approach to replacing these leak-ridden lines is to drag a new pipe through the existing pipeline using a flexible and typically much smoother pipe material (e.g., PVC, HDPE, or Fusible C-900). The annular space between the new pipe and the old pipe should be grouted to provide added stability to the new line. If the new pipe is small enough with respect to the host pipe, some applications have used stand-offs in lieu of grouting. Although the inside diameter of the new pipeline is usually somewhat smaller than the host pipe, the increased smoothness can actually result in lower headloss, and naturally, no lost water due to leaking. This technique requires a long area of space for assembly and joining of the new pipe sections. This limits the application to pipe sizes of 8 to 96 inches in diameter.

An alternative approach is to destroy the existing pipe as the new one is being dragged through it. This technique can permit the same-sized or even larger diameter pipe to replace the former pipeline. Pipe bursting can be a reasonable-cost approach to replacing long lengths of the system in areas where excavation may be difficult or impossible. A “pipe bursting” head is dragged through the existing pipeline, using it as a pathway. As the head is pulled through, it fractures and expands the existing pipeline making room for the replacement main. The replacement pipe is attached to the bursting head and dragged into the line in one pass. Trenchless pipe replacement is most effective where long, uninterrupted runs of new pipe are needed. The approach is less cost-effective in areas where numerous fittings must be placed on the new pipe or services must be reconnected as the pipe must be exposed at each location that such an attachment or service is needed. Table 4-21 provides more detail regarding trenchless pipe replacement.

Table 4-21. Replacement (Trenchless)	
Prevalent Application	Complete replacement of transmission or distribution main.
Description	Fusion welded or restrained joints are required on the replacement pipeline.
Average on-station time	Highly dependent on length of pipe to be replaced, ease of opening end pits, and ease of drag through line. 3-7 days are not unusual for the replacement of 1,000-foot of water main.
Cost	\$80-\$95 per foot installed (by commercial contractor). Highly dependent on the size of the line to be replaced, the configuration, pipe depth, and ease of opening end work pits. Pits required every 500-700 ft of line. Costs do not include cost of access pit excavation or restoration.
Photo	 Ref: http://www.premierplumbing.biz/residential.html
Notes	Due to the initial equipment investment and the specialized training that is needed to operate, trenchless pipeline replacement is frequently a proprietary process and is contracted to a specialty company by a utility.

4.2.7 Selecting Replacement Pipe

When it is neither economically feasible nor practical to attempt a repair, wholesale replacement of the deteriorated pipe might be the practical solution. When opting to replace pipe, questions such as the following should be addressed:

- How large is the pipe?
- Has there been or will there be growth in the area requiring a larger pipe?
- Is the soil type aggressive?
- Can significant movement be expected due to poor soils or seismic activity?
- Will temporary bypass piping be necessary?
- What is the expected pressure?
- How big of a potential is there for surge?

- How much of a disruption and inconvenience will replacing the pipe be?
- Will design and/or construction be done in house or contracted?
- If a different pipe material is selected, will different equipment and training be required to repair and maintain it?

Administrators must also answer financial questions such as:

- How is the work to be financed?
- Is the replacement pipe to be a relatively short term solution or is a long service life required?

The answers to these questions will begin to determine the size and type of material that best meets the requirements. Tables 4-22 through 4-24 and Figure 4-1 are taken from *Deteriorating Buried Infrastructure Management Challenges and Strategies* (EPA, 2002) and present material property criteria and comparisons for different pipe materials to illustrate the array of variables that will affect performance and costs. Figure 4-1 presents a flow chart decision process to help decide a course of action as to whether to repair or replace a pipe.

Material Property	DI	PVC	HDPE
Tensile strength	60,000 psi	7,000 psi	3,200 psi
Compressive strength	48,000 psi	9,000 psi	1,600 psi
Yield strength	42,000 psi	14,500 psi	5,000 psi
Ring bending stress	48,000 psi	none specified	none specified
Impact strength	17.5 ft-lbs/in	0.75 ft-lbs/in	3.5 ft-lbs/in
Density	441 lbs/ft ³	88.6 lbs/ft ³	59.6 lbs/ft ³
Modulus of elasticity	24,000,000 psi	400,000 psi	110,000 psi
Temperature range	< 150° F	< 140° F	-50 to 140° F under press.
Thermal expansion	0.07" per 10° F per 100'	0.33" per 10° F per 100'	1" per 10° F per 100'
Corrosion resistance (int)	Good - w/cement lining	Excellent	Excellent
Corrosion resistance (ext)	Good - w/polywrap	Excellent	Excellent
UV resistance	Excellent	Gradual strength decline	Yes - w/carbon black
Abrasion resistance	Excellent	Good	Good
Cyclic resistance	Excellent	Fair	Good
Permeation resistance	Yes	No - solvents & petroleum	No - solvents & petroleum
Scale & growth resistance	Good	Excellent	Excellent

Table 4-23. Comparison of Distribution Size Pipe Materials - Pipe Properties			
Pipe Property	DI	PVC	HDPE
Trade organization	DIPRA	Uni-Bell	PPI
AWWA designation	C1 51	C900 and C905	C906
Diameter range	3" - 64"	4" - 12" (C900) 14" - 48" (C905)	4" - 63"
Pressure range	350 psi	100 psi - 200 psi	50 psi - 255 psi
ID range (8")	8.425"	7.76" - 8.33"	6.918" - 8.136"
Wall thickness range (8")	0.25"	0.362" - 0.646"	0.265" - 1.182"
Weight range (8")	21.1 lbs/ft	6.6 lbs/ft - 11.4 lbs/ft	5.1 lbs/ft - 11.06 lbs/ft
OD nominal (8")	9.05"	9.05"	9.05"
Buoyant (8" 100 psi)	No	Yes	Yes
Surge allowance	100 psi	125 - 200% of press. rating None for 14" - 48" (C905)	50 - 100% of press. rating
Surge potential (8" 100 psi)	53.6 psi per 1 ft/sec .V	17.6 psi per 1 ft/sec .V	9.8 psi per 1 ft/sec .V
Integrity under vacuum	Excellent	Good	Poor
C-factor	140	150	150
Standard pipe lengths (8")	18 ft or 20 ft	20 ft	40 ft or 50 ft
Type of joints	Push-on or mechanical	Push-on or mechanical	Heat fused
Max joint deflection (8")	5°	3°	Radius = 20 - 50 times OD
Compatible w/DI fittings	Yes	Yes	Yes - in DI sizes

Table 4-24. Comparison of Distribution Size Pipe Materials - Operational Considerations			
Operational Consideration	DI	PVC	HDPE
Ease of installation	Subjective	Subjective	Subjective
Can be direct tapped	Yes	Yes	No
Need for special installation equipment	No	No	Yes
Need for special bedding for typical installations	No	Yes	No
Need for joint restraint	Yes	Yes	No
Ability to locate underground	Excellent	Poor - needs tracer wire	Poor - needs tracer wire
Applicable for above ground installations	Yes	With opaque material for UV resistance	Yes - w/proper support
Applicable for aqueous installations	Yes	Yes	Yes - but potential for flattening is high
Anticipated service life	100 years	50 - 100 years	50 years

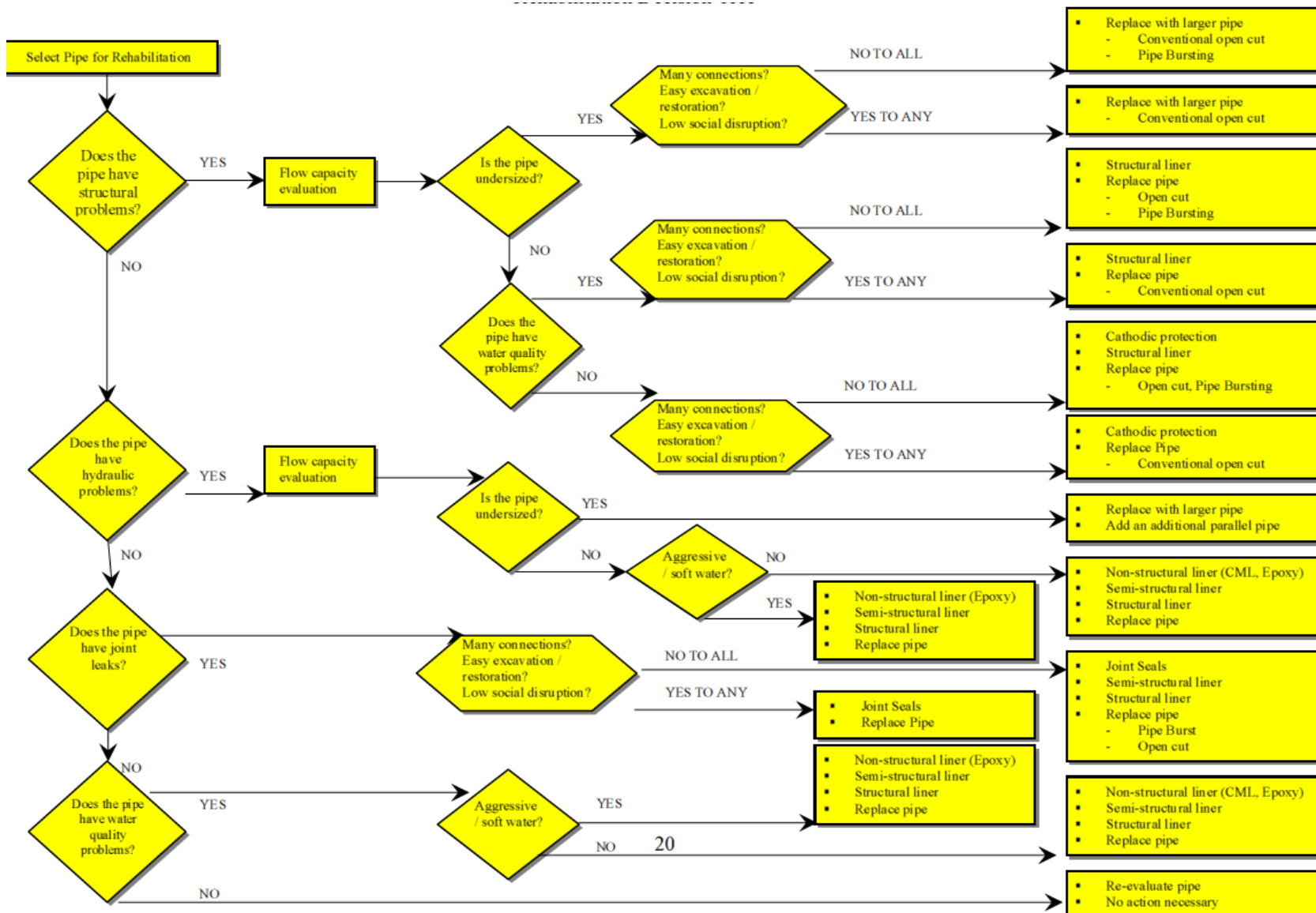


Figure 4-1. Pipe Rehabilitation Decision Flow Chart.
Source: (EPA, 2002) Deteriorating Buried Infrastructure Management Challenges and Strategies (2002),

4.2.8 Operation and Maintenance Programs and Preventative Measures

4.2.8.1 Effective Design and Construction

An effective water loss management program is one that incorporates leak prevention techniques over the life cycle of the distribution system. The decision made in the design and construction phase may impact the operations of the system for years to come. There is a growing awareness within the water industry of the importance of sound asset management. Asset management is the awareness to manage all real assets throughout the life cycle of the public water system. Water loss management heavily depends on controlling the type of assets that are brought into the inventory and continuously monitoring and addressing issues as they arise.

4.2.8.2 Material Standards

The selection of material will always be driven by the economics of the project. However, heavy consideration should be placed on sustainability, durability, and applicability of the materials. Material standards set by organizations such as AWWA, International Standards Organization (ISO), American Society for Testing Material (ASTM), NSF International, and American National Standards Institute (ANSI) are developed by incorporating experiences of thousands of system operators, trade organizations, manufacturers, and other agencies and organizations. For example, NSF/ANSI 61 focuses on eliminating contaminants or impurities that indirectly enter the drinking water through treatment chemicals, process media, or components of the drinking water system. These standards provide the foundation for a utility to establish its own basic standards of materials that are to be used for all system replacements and extensions. Establishing and maintaining a utility's "approved products list" helps to assure that the distribution system will be developed with materials best suited for the community.

4.2.8.3 Design Standards

Standard-setting organizations can provide invaluable service by detailing specific design approaches that can then be adopted by the utility for their work. Design standards provide the foundation to guide both the design and construction of a distribution system, which will have the greatest possibility of maintaining its integrity throughout its operating life. Due to their strength and durability, many communities use ferrous piping systems (cast iron, ductile iron, steel, etc.). The design should incorporate corrosion control in ferrous metal pipelines. Water chemistry and protective coatings can be used to protect the inside of the pipe while a wide range of techniques (e.g., poly-wrapping, sacrificial anode placement, impressed current) are available to protect the outside of the pipe from ground water and galvanic cell corrosive action.

4.2.8.4 Construction Management

The integrity of the distribution system must be maintained over time to minimize leakage over the life of the asset. The use of crews with experience installing water distribution systems and regular inspection throughout the process minimizes the probability of experiencing issues post-construction. The construction of a distribution system is highly complex, requiring excellence in project management, careful material acceptance, handling, storage, and exacting installation to provide a piping system which is to carry hundreds of pounds per square foot of pressure throughout its lifetime. Training can prepare in-house construction crews for construction challenges that they will encounter. Well-written and enforced contract language can go a long way toward soliciting and qualifying a contractor. Key to the process is the utility's project manager and the construction inspector. The inspector should ideally have extensive experience in pipeline construction using the materials and equipment chosen for the utility's project. The project manager should document testing of the system throughout the duration of the construction. This testing typically refers to pressure, performance, and bacteriologic testing.

4.2.8.5 Effective Maintenance

An effective water loss management program should establish a maintenance program targeted toward minimizing leakage through proactive action. Once a distribution system has been properly constructed and placed in service, routine maintenance should be conducted to monitor the system's performance and identify repairs/rehabilitation as needed. Ongoing maintenance will maintain the public water system operating at optimal performance and maximize the full life expectancy of the system.

4.2.8.6 Corrosion Control

Several types of very effective corrosion control systems exist to protect the metallic piping systems. Impressed current systems utilize an active direct current (DC) that is impressed onto the pipeline making it cathodic, thereby protecting it from corroding. This current (10-50 amps, 50 volt) is provided via buried electric cable from an AC/DC rectifier, receiving power from the area electrical system. The anode of the system is a buried probe that will corrode over time. Properly sized impressed current cathodic protection (ICCP) systems are highly effective at preventing corrosive leaks in the system. ICCP systems must be maintained to assure their proper and continued operation. Both the rectifiers and the anodes of these systems must be routinely inspected. If either fails to perform, the pipeline will become unprotected and may be exposed to failure due to pipe corrosion.

Sacrificial anodes (usually magnesium) can be used for effective corrosion control. In these systems the anode bags are buried in the ground close to the pipeline and directly wired to the

pipeline. The sacrificial anode will corrode more readily than the ferrous material pipeline, providing a current flow to the pipe making it cathodic and protecting it. These anode bags must be inspected routinely (most easily with a multimeter probed to the bag to measure the voltage and current flow) to assure their continued integrity. Once a bag is expended, it must be replaced.

Similar to the protection of the outside of ferrous pipelines from the corrosion due to water in contact with the pipe, the inside of the pipeline that is naturally in contact with the water may also suffer corrosion and need to be protected. Corrosion of pipes can be the result of the water quality characteristics (e.g., pH, alkalinity, biology, salts, and chemicals). Corrosion is principally controlled by the pH, buffer intensity, alkalinity, and concentrations of calcium, magnesium, phosphates, and silicates in the water. Corrosion inhibitors can be added to the water as part of the normal water quality operations to reduce corrosion. These inhibitors can reduce the potential for the metal surface to be under the influence of an electrochemical potential by producing an inhibiting layer between the water and the pipe material (CDC, 2007).

4.2.8.7 Valve Exercising & System Flushing

Well-established annual valve exercising and system flushing programs play an integral part in maintaining system integrity and reducing water loss. The principal purpose of a valve-exercise program is to assure that the valve is operable across its full range. System flushing programs are typically used to maintain water age and quality. Both of these programs can easily incorporate water loss management elements. Crews equipped with hydrophones or geophones can use the opportunity to listen to the system at the valve locations and can view the valve surrounding area for evidence of potential leaking. The valve exercising leaves a valve in a confirmed position (either fully open or fully closed). Virtually all field leak detection techniques require that the configuration of the system be known so that flows can be isolated from the portion of the system being investigated. It is common for a detection crew to believe that a valve is open (or closed) when in reality it was left in an unexpected position by others. Similarly, main flushing programs take crews to a large number of hydrants/blow-offs in the system. A crew equipped and trained to listen can often detect water running at these common system leak points.

4.2.8.8 Effective Operations and Active Pressure Management

The final element in a comprehensive water loss management program is an informed operations plan. The way that a distribution system is operated can play an effective role in reducing water loss from the system and should be given consideration when establishing a leak management program.

4.2.8.9 System Modeling

A tool growing in popularity for planning, design and operating support is the distribution system hydraulic model. PC-based hydraulic models are now affordable for even modest-sized water operations. The standard hydraulic model provides the user with an easily configurable way to understand a system's operating parameters (flow rates, pressures, water quality, age, etc.). But the heart of any hydraulic model is its calibration against field reality. Once calibrated, the model can provide the water professional a standard for how the system "should" operate. If during annual maintenance activities the system performs differently from the model's projections, a major water loss or growing minor leaking may be one reason. Likewise, annual maintenance activities afford a perfect opportunity to recalibrate the model as needed. Integrating model routine calibration and output analysis with maintenance activities provides a potent tool for identifying and potentially even locating system losses.

4.2.8.10 Meter Assessment, Testing and Replacement Programs

Meters are key components to obtaining funds required to operate and maintain a PWS, and therefore, maintaining a meter assessment, testing, and replacement program that optimizes revenue and aids in locating losses should be a priority of any operation and maintenance program. Section 3.5 discusses all of the aspects that should go into any metering program.

4.3 EVALUATION

After each water audit compilation, the PWS manager should evaluate the data to determine where improvements can be made or where further information is required. Data gaps in the information the PWS has regarding its components and the component maintenance status should be reviewed and updated as information becomes available. After each intervention the water system manager should evaluate how successful the actions were. This may be immediately apparent, such as locating and repairing a leak, or may take significant analysis, such as evaluating whether a meter replacement program is improving customer metering results. If the goals of an action were not met, the water system manager should seek to determine why not and remedy the cause if possible.

The evaluation process reviews the results of the previous audit and the performance indicators for potential areas of improvements and signs of impending problems. Because water systems require maintenance and are always subject to deterioration, the entire process must be repeated periodically as indicated in Figure 1-2.

4.4 SUMMARY - ASSEMBLING A COMPLETE WATER LOSS CONTROL PROGRAM

It can be overwhelming to consider all of the pieces that go into a water loss and control program if you do not already have one, although many of the pieces may already exist in your system. The following sections list the activities and components water utility managers need to consider to meet the specific demands for their systems.

4.4.1 Putting the Pieces Together

Consider how your utility is going to implement the following aspects of a loss control policy answering: Who? What? When? Where? Why? How often? and How much? for each aspect.

- Record keeping.
- Audit/Balance PI and benchmark analysis.
- Economic analysis.
- Metering—locating, sizing, initial installation, validation, replacement.
- Meter reading or AMR.
- Additional system monitoring including SCADA.
- Data transfer—billing, data error analysis.
- Leakage Management Program:
 - Periodic leak detection sweeps.
 - DMA, zone flow analysis, and other leak testing.
 - Leak locating—method and training.
 - Leak repair.
 - Repair, rehabilitate, or replace analysis.
 - Repair, rehabilitate, or replace design.
 - Repair, rehabilitate, or replace execution.
 - Pressure management.

Many of the items mentioned above were only briefly described in this guidance. Larger water utilities can often manage most of this work in-house. Medium-sized and small water utilities may need to utilize contracted services in order to achieve program objectives.

4.4.2 Finding Help

Many agencies, associations, and consortia are able to provide advice. Neighboring water systems with established programs are often willing to help smaller water systems' managers. State and Federal regulatory agencies often have programs and experts available to provide assistance. The Association of State Drinking Water Administrators (ASDWA) provides links to state drinking water and primacy agency home Web pages from their Web site at <http://www.asdwa.org>, and the EPA Office of Ground Water and Drinking Water provides a Web site to assist the public and PWS operators at <http://water.epa.gov/drink/index.cfm>. From this site, state drinking water information and state contacts can be also be found. The Alliance for Water Efficiency, an organization dedicated to the efficient and sustainable use of water is also a source of information and resources (<http://www.allianceforwaterefficiency.org>). The Alliance serves as a North American advocate for water efficient products and programs, and provides information and assistance on water conservation efforts.

Appendix A

Summary of Selected State Water Loss Policies

Appendix A - Summary of Selected State Water Loss Policies

The following information is excerpted and summarized from
Summary of State Agency Water Loss Reporting Practices by
Janice A Beecher. (2002) The full report may be found at:
<http://www.awwa.org/Resources/Waterwiser.cfm>
(see Beecher Reference for possible source locations)

Janice Beecher's *Survey of State Agency Water Loss Reporting Practices Final Report to The American Water Works Association* (2002) is the most recent and complete comparison of water loss policy by state. In this white paper, a case is argued for acceptance of water loss control standards, including reliable accounting, followed by results of a survey which describes the state of water accounting and related public state and regional policy.

Surveys were conducted with organizations and state agencies with water policy influence. A total of 37 surveys were completed, 34 from states, the rest from multi-state agencies. Policy for 11 other states was found through internet searches. This resulted in information on 46 jurisdictions, of which 43 were states. Ten issues were covered by the survey, including:

- water-loss policy,
- water-loss definitions,
- methods for accounting and reporting,
- setting standards and benchmarks,
- setting goals and targets, planning requirements,
- data compilation and publication,
- offers of technical assistance,
- giving performance incentives, and
- requiring or advising audits and enforcement if applicable.

Broadly defined, some sort of water loss policy was found in 36 jurisdictions.

A definition of water loss was given by 17 jurisdictions. It was most commonly expressed as the remaining percentage of water not recorded as billed versus water pumped into the system.

It was found that 20 state agencies and two water management districts require or provide guidelines for water accounting and/or water loss reporting.

None of the jurisdictions covered were found to impose sanctions on systems failing to meet any of the requirements. Table A-1 shows the summary of the finding for the 2002 survey. The other category in the table below represents the following agencies DRBC = Delaware River Basin Commission, SJRWMD = St. Johns River Water Management District, SWFWMD = Southwest Florida Water Management District.

Table A-1 Summary Policy Findings				
Issue	Jurisdictions	States (n = 43)	Other (n=3)	Total (n = 46)
Has some sort of Water-loss Policy Statement	AZ, CA, CT, FL, GA, HI, IN, IA, KS, KY, LA, MD, MA, MN, MD, NV, NH, NY, NC, OH, OR, PA, RI, SC, TN, TX, UT, VT, VA, WA, WV, WI, WY, DRBC, SWFWMD, SJRWMD	33	3	6
Has Formal Definition of Water Loss	AZ, CA, GA, HI, KS, MD, MA, MN, MO, OR, PA, RI, SC, TX, WI, DRBC, JRWMD	15	2	17
Accounting and Reporting	AZ, CA, GA, HI, IA, KS, KY, MD, MA, MN, MO, NY, OH, OR, PA, RI, TX, WV, WI, WY, SWFWMD, SJRWMD	20	2	22
Has Standards and Benchmarks	AZ, CA, GA, HI, IN, KS, KY, LA, MD, MA, MN, MO, NC, OH, OR, PA, RI, SC, TX, UT, WA, WV, WI, DRBC, SWFWMD, SJRWMD	23	3	26
Sets Goals and Targets	AZ, CA, FL, GA, HI, KS, KY, ME, MD, MN, MO, NM, OH, OR, PA, RI, TX, WI, SWFWMD, SJRWMD	18	2	20
Has Planning Requirements	AZ, CA, CT, FL, GA, HI, IA, KS, MD, MA, MN, MO, NV, NH, OR, PA, RI, SC, TX, VT, VA, WA, WV, WI, SWFWMD, SJRWMD, DRBC	24	3	27
Compilation and Publication by Jurisdiction	AZ, CA, HI, KS, KY, MN, PA, RI, WI, SWFWMD	9	1	10
Provides Technical Assistance	AK, CA, FL, GA, HI, KS, KY, ME, NV, ND, OR, PA, RI, SC, TN, TX, VT, WI, SWFWMD	18	1	19
Offers Performance Incentives	CA, GA, HI, IN, IA, LA, MN, NC, RI, TX, VT, SJRWMD	11	1	12
Performs Auditing and Enforcement	AZ, GA, HI, KS, MD, MN, NH, OH, OR, PA, SC, TX, WI, SWFWMD, SJRWMD	13	2	15

Table A-2 shows unaccounted for water standard for selected states

Table A-2 Selected State Standards for Unaccounted-for Water		
State	Agency	Standard
Arizona	Department of Water Resources	10% (large) 15% (small)
California	Urban Water Conservation Council	10%
Florida	Southwest Florida Water Management District	12% or less
Florida	St. Johns River Water Management District	10%
Georgia	Environmental Protection Division	Less than 10%
Indiana	Department of Environmental Management	10 to 20%
Kansas	Kansas Water Office	15%
Kentucky	Department of Energy, Water and Sewer Branch	15%
Louisiana	Department of Environmental Quality	15%
Massachusetts	Department of Environmental Protection	15%
Minnesota	Department of Natural Resources	10%
Missouri	Department of Natural Resources	10%
North Carolina	Division of Water Resources	15%
Ohio	Public Utility Commission and Environmental Protection Agency	15%
Oregon	Water Resources Division	10-15%
Pennsylvania	Public Utility Commission	20%
Pennsylvania	Bureau of Water and Wastewater Management	10-15%
Rhode Island	Water Resources Board	10-15%
South Carolina	Public Service Commission	7.5%
South Carolina	Department of Health and Environmental Control	10%
Texas	Water Development Board	10 to 15%
Texas	Natural Resources Conservation Commission	20%
Washington	Department of Health	20% (10% proposed)
West Virginia	Public Service Commission	15%
Wisconsin	Public Service Commission	15% (large) 25% (small)
Delaware River Basin Commission	Delaware River Basin Commission	15%

It should be noted that, since the completion of the survey report in 2002, a number of the above-listed agencies have implemented new requirements for regular water audits using the AWWA/IWA water audit methodology, and no longer employ an “unaccounted-for” percentage as a performance indicator. These include the California Urban Water Conservation Council, Delaware River Basin Commission and agencies in the states of Georgia, Pennsylvania, and Texas.

Appendix B

Miscellaneous Data

Appendix B - Miscellaneous Data

Table B-1 Estimated per/Capita/Day Water Use by State						
State	Abbrev.	Gal/ Day/ Capita		State	Abbrev.	Gal/ Day/ Capita
Alabama	AL	100		Nebraska	NE	115
Alaska	AK	79		Nevada	NV	213
Arizona	AZ	150		New Hampshire	NH	71
Arkansas	AR	106		New Jersey	NJ	75
California	CA	147		New Mexico	NM	135
Colorado	CO	145		New York	NY	119
Connecticut	CT	70		North Carolina	NC	67
Delaware	DE	78		North Dakota	ND	86
Dist. Of Columbia	DC	179		Ohio	OH	50
Florida	FL	111		Oklahoma	OK	85
Georgia	GA	115		Oregon	OR	111
Hawaii	HI	119		Pennsylvania	PA	62
Idaho	ID	186		Puerto Rico	PR	67
Illinois	IL	90		Rhode Island	RI	76
Indiana	IN	76		South Carolina	SC	81
Iowa	IA	66		South Dakota	SD	85
Kansas	KS	86		Tennessee	TN	143
Kentucky	KY	70		Texas	TX	218
Louisiana	LA	124		Utah	UT	80
Maine	ME	58		Vermont	VT	75
Maryland	MD	105		Virginia	VA	138
Massachusetts	MA	66		Washington	WA	74
Michigan	MI	77		West Virginia	WV	52
Minnesota	MN	148		Wisconsin	WI	163
Mississippi	MS	123		Wyoming	WY	48
Missouri	MO	86	Virgin Islands	VI	23	
Montana	MT	129	United States Avg.			105
Source: Soley et al. Water Distribution System Handbook, Larry W Mays.2000 Pub. McGraw-Hill						

Table B-2 Snapshot of high water loss within distribution systems							
Name	State	Volume Input (MG/Year)	Water Losses (MG/Year)	Loss Percentage	Population Served	Per Capita Loss in Gallons/Year	Value of Losses (2008 Yr USD)
Philadelphia Water Department	PA	97,637	30,448	31.18%	1,670,000	58,465	\$32,272,301
Cleveland Division of Water	OH	94,000	27,000	28.72%	1,500,000	62,667	\$28,617,713
Memphis Light, Gas & Water	TN	54,798	8,330	15.20%	908,222	60,335	\$8,829,094
Cincinnati Water Works	OH	47,047	8,303	17.65%	900,000	52,274	\$8,800,477
Jefferson Parish Water Department	LA	25,098	6,055	24.12%	425,108	59,039	\$6,417,787
Portland Water District	ME	9,293	1,678	18.06%	190,000	48,911	\$1,778,538
Ann Arbor Utilities Department	MI	6,222	1,604	25.78%	163,500	38,055	\$1,700,104
Duluth/ Public Works & Utilities/ Water	MN	8,774	1,424	16.23%	99,600	88,092	\$1,509,319
North Penn Water Authority	PA	3,311	538	16.25%	80,000	41,388	\$570,234
Waterloo Water Works	IA	5,212	812	15.58%	75,000	69,493	\$860,651
Lorain Utilities Department	OH	4,250	850	20.00%	74,000	57,432	\$900,928
Madison County Water Department	AL	2,326	623	26.77%	67,200	34,613	\$660,327
Elmira Water Board	NY	2,509	634	25.27%	65,000	38,600	\$671,986
Lebanon Authority	PA	2,371	500	21.08%	57,000	41,596	\$529,958
Selmer Utility Division	TN	800	200	25.00%	55,000	14,545	\$211,983
Renton	WA	2,666	498	18.66%	51,140	52,131	\$527,838
Williamsport Municipal Water Authority	PA	2,610	917	35.13%	51,000	51,176	\$971,942
Albany	OR	3,163	788	24.91%	41,000	77,146	\$835,213
Eastpointe Water and Sewer	MI	1,386	359	25.88%	34,077	40,673	\$380,510
Lake County East Utilities	OH	1,394	219	15.72%	26,650	52,308	\$232,121
Paradise Irrigation District	CA	2,801	464	16.57%	26,000	107,731	\$491,801
Cordele	GA	4,911	746	15.19%	21,600	227,361	\$790,697

Table B-2 Snapshot of high water loss within distribution systems							
Name	State	Volume Input (MG/Year)	Water Losses (MG/Year)	Loss Percentage	Population Served	Per Capita Loss in Gallons/Year	Value of Losses (2008 Yr USD)
Shoshone Municipal Pipeline	WY	4,911	746	15.19%	21,600	227,361	\$790,697
Piqua Municipal Water System	OH	721	152	21.10%	20,500	35,171	\$161,107
Fredericksburg	VA	1,460	365	25.00%	20,000	73,000	\$386,869
Clearfield Municipal Authority	PA	487	115	23.61%	17,000	28,647	\$121,890
Bellingham DPW	MA	598	140	23.43%	15,000	39,867	\$148,388
Miami Utility Dept.	OK	788	210	26.61%	14,500	54,345	\$222,582
Glens Falls Water Department	NY	1,364	334	24.48%	13,000	104,923	\$354,012
City of Converse-Public Works	TX	501	150	29.85%	11,508	43,535	\$158,987
Spencer Municipal Utilities	IA	585	93	15.90%	11,500	50,870	\$98,572
Anson County Water System	NC	2,467	614	24.87%	11,200	220,268	\$650,788
Berea College Utilities	KY	851	154	18.10%	11,000	77,364	\$163,227
Crossett Water Commission	AR	512	85	16.52%	9,000	56,889	\$90,093
Warren County Utility District	TN	600	100	16.67%	7,200	83,333	\$105,992

Source: AWWA, 2003

* Greater than 15% total water loss, of which more than 50% was real loss.

Appendix C

Water Audit Worksheet Examples

Appendix C - Water Audit Worksheet Example

Texas Water Development Board - Water Audit Worksheets and Instructions

TWDB (Texas Water Development Board) and Mark Mathis. 2008. *Water Loss Manual*. Austin, Texas: Texas Water Development Board. The Water Loss Manual and worksheets are available at:

http://www.twdb.state.tx.us/assistance/conservation/Municipal/Water_Audit/Leak_Detection/WaterLossManual_2008.pdf

Texas Water Development Board Water Audit Worksheet

A. WATER UTILITY GENERAL INFORMATION

1. Water Utility Name: _____
2. Contact: Name _____
Telephone# _____ Email Address _____
3. Reporting Period: From ____/____/____ to ____/____/____
4. Source Water Utilization, percentage: Surface Water _____% Groundwater _____%
5. Population Served:
 - a. Retail Population Served _____
 - b. Wholesale Population Served _____
6. Utility's Length of Main Lines, miles _____
7. Number of Wholesale Connections Served _____
8. Number of Retail Service Connections Served _____
9. Service Connection Density _____
(Number of retail service connections/Miles of main lines)
10. Average Yearly System Operating Pressure (psi) _____
11. Volume Units of Measure (check one):
 _____ acre-ft _____ million gallons _____ thousand gallons _____ gallons

**Assessment
Scale**

B. SYSTEM INPUT VOLUME

12. Water Volume from own Sources _____
13. Production Meter Accuracy (enter percentage) _____%
14. Corrected Input Volume _____
15. Wholesale Water Imported _____
16. Wholesale Water Exported _____
17. **System Input Volume** _____
(Corrected input volume, plus imported water,
minus exported water)

		Assessment Scale
C. AUTHORIZED CONSUMPTION		
18. Billed Metered	_____	_____
19. Billed Unmetered	_____	_____
20. Unbilled Metered	_____	_____
21. Unbilled Unmetered	_____	_____
22. Total Authorized Consumption	_____	
D. WATER LOSSES		
23. Water Losses <i>(Line 17 minus Line 22)</i>	_____	
E. APPARENT LOSSES		
24. Average Customer Meter Accuracy <i>(Enter percentage)</i>	_____ %	_____
25. Customer Meter Accuracy Loss	_____	
26. Systematic Data Handling Discrepancy	_____	_____
27. Unauthorized Consumption	_____	_____
28. Total Apparent Losses	_____	
F. REAL LOSSES		
29. Reported Breaks and Leaks <i>(Estimated volume of leaks and breaks repaired during the audit period)</i>	_____	_____
30. Unreported Loss <i>(Includes all unknown water loss)</i>	_____	_____
31. Total Real Losses <i>(Line 29, plus Line 30)</i>	_____	
32. Water Losses (Apparent + Real) <i>(Line 28 plus Line 31) = Line 23</i>	_____	
33. Non-revenue Water <i>(Water Losses + Unbilled Authorized Consumption) (Line 32, plus Line 20, plus Line 21)</i>	_____	

G. TECHNICAL PERFORMANCE INDICATOR FOR APPARENT LOSS

34. Apparent Losses Normalized
(Apparent Loss Volume/# of Retail Service
Connections/365) _____

H. TECHNICAL PERFORMANCE INDICATORS FOR REAL LOSS

35. Real Loss Volume (*Line 31*) _____

36. Unavoidable Annual Real Losses, volume (calculated) _____

37. Infrastructure Leakage Index (calculated)
(*Equals real loss volume divided by unavoidable
annual real losses*) _____

38. Real Losses Normalized
(Real Loss Volume/# of Service Connections/365)
(*This indicator applies if service connection
density is greater than 32/mile*) _____

39. Real Losses Normalized
(Real Loss Volume/Miles of Main Lines/365)
(*This indicator applies if service connection
density is less than 32/mile*) _____

I. FINANCIAL PERFORMANCE INDICATORS

40. Total Apparent Losses (*Line 28*) _____

41. Retail Price of Water _____

42. Cost of Apparent Losses
(*Apparent loss volume multiplied by
retail cost of water, Line 40 x Line 41*) _____

43. Total Real Losses (*Line 31*) _____

44. Variable Production Cost of Water*
(**Note: In case of water shortage, real losses
might be valued at the retail price of water
instead of the variable production cost.*) _____

45. Cost of Real Losses
(*Real loss multiplied by variable production
cost of water, Line 43 x Line 44*) _____

46. Total Assessment Score _____

47. Total Cost Impact of Apparent and Real Losses _____

Water Audit Worksheet Instructions

(All numbers used in this worksheet are for example purposes only)

The following instructions can be used in completing the Water Audit Worksheet. The instructions are labeled by line number shown on the worksheet. The Water Audit Worksheet requests that the water utility enter general information and water supply, consumption, and loss quantities. It also requests assessment scores representing the degree of validation of individual components. For those components that include an assessment line, enter a number between 1 and 5. (See Appendix 1.3 for more information.) If a component does not apply, then enter 0 (for example, if the water utility does not import any water, enter 0 for wholesale water imported). You may visit the TWDB Web site for the online version of the water audit:

http://www.twdb.state.tx.us/assistance/conservation/Municipal/Water_Audit/wald.asp

A. Water Utility Information

1. **Water Utility Name:** List the formal name of the water utility for which the water audit exists.
2. **Contact:** List the name of the primary contact person responsible for completing the water audit for the water utility, the telephone number, and email address.
3. **Reporting Period:** Enter calendar year or fiscal year dates for the reporting period.
4. **Source Water Utilization:** Enter percentages to represent the proportions of surface water and groundwater withdrawn for source water supply. Remember that the total of the two percentages must equal 100%.
5. **Population Served:** List separately the retail and wholesale populations served. You may multiply the number of connections by three if needed to estimate the retail population.
6. **Utility's Length of Main Lines, miles:** List the total length of pipeline in the water distribution system in miles.
7. **Number of Wholesale Connections Served:** List the number of wholesale interconnections supplying water to other water utilities.
8. **Number of Retail Service Connections Served:** List the number of retail customer service connections served by the utility's water distribution system.
9. **Service Connection Density:** Calculate the service connection density by dividing the number of retail customer service connections by the length of miles of pipeline in the water distribution system.
10. **Average Yearly System Operating Pressure:** List the average pressure across the entire water distribution systems for the audit period. If a hydraulic model of the network exists, the average pressure can be calculated by the model; otherwise, an estimate can be used.
11. **Volume Units of Measure:** Select the volume units of measure for the water audit. The units must be consistent throughout the entire water audit. If choosing million gallons for system input (from production meters), then authorized consumption (billed and unbilled) and all other entries must also be entered in million gallons. This typically requires a conversion for billed metered consumption.

B. System Input Volume: The total water supplied to the infrastructure. It is the total of all production meter readings for the entire year. List the volume or percentage requested in each item, along with the scores from Appendix 1.3 that in your judgment best represent the degree of validation of the data.

12. **Water Volume from own Sources:** Includes all water taken as source water from permitted sources, such as rivers, lakes, streams, and wells.

13. **Production Meter Accuracy (enter a percentage):** Achieved by calibrating or verifying the accuracy level (expressed as a percentage) of production meters. For example purposes, if the meter over-registered by 4 percent, enter 1.04; if it under-registered by 4 percent, enter .96.

14. **Corrected Input Volume (calculated automatically online):** The sum obtained when the production meter adjustment is either added to or subtracted from the system input volume. Divide “water volume from own sources” by the production meter accuracy. You must add the decimal point when the calculation is done manually (for example, to .96).

Example: If “water volume from own sources” registered 1.8 MG/year through two production meters, which were found to be collectively under-registering flow by 4 percent, then the corrected input volume (CIV) is:

$$\text{Corrected Input Volume} = (1,800,000)/(0.96) = 1,875,000$$

15. **Wholesale Water Imported:** Amount of purchased wholesale water transferred into the utility’s water distribution system from other water suppliers.

16. **Wholesale Water Exported:** Amount of wholesale water transferred out of the utility’s distribution system. It may be put into the system initially but is only in the system for a brief time for conveyance reasons.

17. **System Input Volume:** Calculated as the corrected input volume plus water imported minus water exported (Line 14, plus Line 15, minus Line 16).

C. Authorized Consumption: All water that has been authorized for use or consumption by the utility or its customers. Remember to convert these volumes into the same units as the water delivery volume. Note: Any type of legitimate consumption should be classified in one of the four components of authorized consumption.

18. **Billed Metered:** All retail water sold and metered.

19. **Billed Unmetered:** All water sold but not metered.

20. **Unbilled Metered:** All water metered but not billed, such as back flushing water, parks, golf courses, and municipal government offices.

21. **Unbilled Unmetered:** All water not billed or metered, such as flushing fire hydrants.

22. **Total Authorized Consumption:** The total of the above four components, automatically calculated in the online worksheet.

D. Water Losses: Water delivered to the distribution system that does not appear as authorized consumption.

23. Calculated as the difference of the system input volume and total authorized consumption (Line 17 minus Line 22).

31. **Total Real Losses:** This value is calculated automatically online as the sum of reported breaks and leaks and unreported loss.
 32. **Water Losses:** Calculated as the sum of apparent losses and real losses. This value should equal the value of Line 23. This line is included as a balancing check.
 33. **Non-revenue Water:** Calculated as the sum of apparent losses, plus real losses, plus unbilled metered consumption and unbilled unmetered consumption. This is the water that does not contribute to the water utility billings.
- G. Technical Performance Indicator for Apparent Loss:** Performance indicators are quantitative measures of key aspects within the utility. Using these indicators, the utility will have a history to track its performance from year to year. One performance indicator exists for apparent loss.
34. **Apparent Losses Normalized:** Calculated as the volume of apparent loss, divided by the number of retail customer service connections, divided by 365 days. This performance indicator allows for reliable performance tracking in the water utility's efforts to reduce apparent losses.
- H. Technical Performance Indicator for Real Loss:** Several performance indicators exist for real loss.
35. **Real Loss Volume:** This is the quantity from Line 31.
 36. **Unavoidable Annual Real Losses:** Calculated reference value using the equation shown in Table 3-2. This is a theoretical value of the technical low level of leakage that might be attained in a given water utility, based upon several system specific parameters.
 37. **Infrastructure Leakage Index:** This performance indicator is calculated as the ratio of real losses over the unavoidable annual real losses. The index measures the water utility's leakage management effectiveness and is an excellent performance indicator for comparing performance among water utilities. The lower the value of the infrastructure leakage index, the closer the utility is operating to the theoretical low level of the unavoidable annual real loss. Appendix 1.4 gives general guidance on setting preliminary leakage reduction targets using the infrastructure leakage index without changing water pressure.
 38. **Real Losses Normalized:** Calculated as the real loss volume, divided by the number of retail service connections, divided by 365. Use this calculation if the service connection density is greater than, or equal to, 32 per mile. This indicator allows for reliable performance tracking in the water utility's efforts to reduce real losses.
 39. **Real Losses Normalized:** Calculated as the real loss volume, divided by the number of miles of pipeline, divided by 365. Use this calculation if the service connection density is less than 32 per mile. This indicator allows for reliable performance tracking in the water utility's efforts to reduce real losses.

I. Financial Performance Indicators

- 40. **Total Apparent Losses:** List the volume from line 28.
- 41. **Retail Price of Water:** Water utility rate structures usually feature multiple tiers of pricing based upon volume consumed. For the water audit, it is best to use a single composite price rate to represent the retail cost of water, which is used to place a value on the apparent losses. The largest number of accounts in most utilities is residential accounts; therefore, the residential pricing tier may be used in place of weighted calculations to determine a composite rate.
- 42. **Cost of Apparent Losses:** Calculated by multiplying the apparent loss volume by the retail price of water. This represents the potential amount of missed revenue due to apparent losses.
- 43. **Total Real Losses:** List the volume from line 31.
- 44. **Variable Production Cost of Water:** Marginal production cost including variable costs, which are typically the costs of raw water, energy, and chemicals. If applicable, the cost of raw water should include the price of take or pay contracts. These costs are applied to determine the cost impact of real losses. In cases of water shortage, real losses might be valued at the retail price of water instead of the variable production cost.
- 45. **Cost of Real Losses:** Calculated by multiplying the real loss volume by the variable production cost of water. These costs represent the additional operating costs incurred by the water utility due to the real losses (in other words, leakage).
- 46. **Total Assessment Score:** Add the individual assessment scores to obtain a total.
- 47. **Total Cost Impact of Apparent and Real Losses:** Calculated by adding lines 42 and 45. This amount indicates the cost inefficiency encountered by the water utility for losses. This cost value can be objectively weighed against potential loss control programs to determine the cost effectiveness of such programs.

If you or the utility has any software application questions, please call Mark Mathis at 512-463-0987 or email: mark.mathis@twddb.state.tx.us

For more information on water audits, visit the American Water Works Association Web site: <http://www.awwa.org/Resources/topicspecific.cfm?ItemNumber=3653&navItemNumber=1583>

The Massachusetts Department of Environmental Protection (MassDEP)
Water Audit Guidance Documents January 2006

Guidance Audit Forms and worksheets are available at the MassDEP Web site:
<http://www.mass.gov/dep/water/approvals/wmgforms.htm#audit>.

WMA
PWSID#:
Name:
City/Town:

WATER MANAGEMENT ACT PROGRAM

Guidance Document and Forms For a Water Audit

General

A Water Audit identifies how much water is lost and what that loss costs the public water supplier. Records and system-control equipment (such as meters) are thoroughly checked for accuracy. The overall goal of the Water Audit is to help the public water supplier select and implement programs to reduce the water works system losses.

The Water Audit should be performed annually by the public water supplier. In this manner, the public water supplier will determine the volume of lost water; the need to do regular field leak detection and; the dollar value of water that is lost. Water audits allow for adjustments to be made to metering system calculations and acceptable meter errors.

Forms for a Water Audit

There are six (6) forms used in the preparation of a Water Audit that are included in this document. All utilize gallons as input data. An explanation of these forms is as follows:

Form 1 - Uncorrected Total Water Supply from Sources of Supply Master Meter Readings - This form is used to summarize pumping records from sources of supply for the most recent three (3) years.

Form 2 - Uncorrected Customer Meter Records - This form is used to summarize metered readings for individual users for the most recent three (3) years.

Form 3 - Pumping and Treatment Costs - This form outlines the average base pumping and treatment costs from the sources of supply.

Form 4 - Source Meter Error Adjustments to the Total Amount of Water Supplied to the System - This form takes water source meter errors determined after calibration to adjust known gallonage errors.

Form 5 - Distribution System Large Service Meter Adjustments - This form provides a gallonage adjustment to large distribution system meter errors, after calibration.

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Form 6 - Water Audit Worksheet - This form is the worksheet that summarizes water losses and costs associated with unaccounted for water, based on information derived on Forms 1 through 5.

Forms

This section outlines the input of data in order to obtain an accurate unaccounted for water percentage and costs associated with those losses to the public water supplier. All records should be utilized during the same twelve (12) month time period.

Water Audit Worksheet or Form 6

Form 6 is utilized to record and compute corrections to the water works systems metering components. Please follow the following format and record all computations on **Form 6**.

Review of Production and Sale Records

- a. Review production records to tabulate the volume of water received from all sources of supply for the most recent three (3) years and complete **Form 1**.
- b. Calculate an average of the three (3) most recent yearly totals from Form 1 and enter **on Line 1, Form 3 and on Line 1 on Form 6**.
- c. Review customer meter records to determine the total quantity of water sold and unsold for the past three (3) years and enter on **Form 2**.
- d. Calculate an average of the three (3) most recent yearly Totals from Form 2 and enter on **line 4 on Form 6**.
- e. Estimate the amount of water sold but not metered for the past 3 years, and enter this figure on **Form 2, Line c**. Divide Line c by 3 and enter this average on **Line 6 on Form 6**,

Pumping and Treating Costs - Form 3

- a. Review purchasing records for the past 3 years to determine the total and average chemical, fuel, electricity, water purchase, and other costs to pump and treat water. Enter these figures on **Form 3**. Then perform the calculations indicated in the lower section of **Form 3**.

Enter results on **line 15 on Form 6**.

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b. If water is purchased from another entity(s), please determine the volume using the format below, and enter on **Line 2 - Form 3**.

No.	Year	Annual Volume	Annual Volume	Total
1.	_____	_____	_____	_____
2.	_____	_____	_____	_____
3.	_____	_____	_____	_____

Total _____ divide by 3 and enter on **Line 2 - Form 3**

Source Meter Errors

Source Meters: any meter (venturi, etc.) that records flow from sources of supply.

List in tabular form the types, locations, frequency of calibration and calibration program for the water supply system source meters.

Source meters should be calibrated to verify the accuracy through standard field testing, pitometer or other reliable methods. Testing should include evaluation of the primary device and the meter registration unit. For venturi's - calibration should be performed twice a year. All other meters should be tested as outlined in AWWA specifications or WMAP permit requirements for meter testing time periods.

Form 4 should be completed for all source meters to report adjustments resulting from source water meter errors for the past 3 years. Divide total adjustments for the past 3 years by 3 to calculate average source meter adjustments. This average source water meter adjustment, in gallons, should be entered on **Form 6 on- line 2a.**

Evaluation of System Components

Provide an explanation that outlines the program that the water works system utilizes to evaluate system components such as valves that provide: pressure relief, altitude control on storage tanks, pressure reducing, and surge relief.

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Name:
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If a documented estimate of volume of water can be made from faulty operating conditions, this gallonage should be entered on **Line 2b on Form 6.**

<u>Type of Device</u>	<u>Total Volume</u>	<u>How Documented</u>
1. _____		
2. _____		
3. _____		
<u>Total</u>		

Unmetered Authorized Uses of Water

If there are unmetered but authorized uses of water, this annual estimate should be entered on **Line 9 on Form 6.** These uses include:

<u>Type of Unmetered Uses</u>	<u>Annual Volume</u>	<u>How Documented</u>
1. Fire fighting and training	_____	_____
2. Bleeders	_____	_____
3. Watermain flushing	_____	_____
4. Storage Tank Overflows	_____	_____
5. Public Construction Uses		
a. Sewer System Maintenance	_____	_____
b. Street Cleaning	_____	_____
c. Construction	_____	_____
d. Other _____	_____	_____
Total Volume	_____	Enter on <u>Line 9 on Form 6</u>

Water used by municipal buildings and schools, golf courses, public cemeteries, and municipal pools should be metered or otherwise be determined to be Unaccounted-for Water.

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PWSID#:
Name:
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Unmetered Miscellaneous Losses of Water

Provide an estimate of unmetered miscellaneous losses attributed to bleeders, unauthorized connections, backwash waters and theft. Enter this figure on **Line 10 on Form 6.**

Distribution System Large Service Meter Errors

Form 5 should be completed for all **distribution system large service** meters to report adjustments resulting from large in line meter errors for the past 3 years. Divide total adjustments for the past 3 years by 3 to calculate average source meter adjustments. This average large service meter meter adjustment, in gallons, should be entered on **Form 6 on line 5a.**

Accounting Systems

A Certified Public Accountant (CPA) could review billing and accounting procedures. The entire accounting procedure should be evaluated including meter reading frequency, printing of billing statements, cash flow improvements, water rates and all systems that are related to producing accurate and timely water bills.

Adjustments to water sales that reflect any error made in billing and accounting procedures should be entered on **Line 5b on Form 6.**

Please provide a written statement on how adjustments were determined and attach to the water audit.

Completion of Water Audit

The Water Audit - Form 6 should be completed and the quantity of water calculated as unaccounted-for water (UAW). The forms should be evaluated to determine areas that need attention and prioritization for water works system improvements.

The submittal should include the water meter testing procedures and certification for each calibrated metering system and appended to the report, if available.

				TOTAL ANNUAL AMOUNT							(in million gallons per year)			
YEAR	SOURCE	SOURCE	SOURCE	SOURCE	SOURCE	SOURCE	SOURCE	SOURCE	SOURCE		TOTAL	Comment		
	1	2	3	4	5	6	7	8	9					

TOTAL

Avg. = Total divided by 3 =

Enter on Line 1 - Form 6 and
Enter on Line 1 - Form 3

FORM 2 - UNCORRECTED CUSTOMER METER RECORDS

TOTAL WATER SOLD

YEAR	RESIDENTIAL	INDUSTRIAL	COMMERCIAL	AGRICULTURAL	INSTITUTIONAL	OTHER	TOTAL

Line a TOTAL

Line b = Total divided by 3 =

Enter on Line 4 - Form 6

CALCULATIONS

- | | | |
|----------|---|--|
| 1 | Total amount of water metered in system over the past three years (Line a _____) | |
| 2 | Average total amount of water metered over past 3 years (Line b = Line a/3 = _____) | |
| 3 | Estimate of total amount of water sold but not metered in past 3 years (Line c _____) | |
| 4 | Average of the total amount of water sold but not metered over past 3 yrs. (Div. Line c by 3 = _____) | |
| | Enter on Line 6 - Form 6 | |

FORM 3 - PUMPING AND TREATMENT COSTS

Annual Costs for the past three (3) years

No.	Category	Year	Year	Year	Total	Average = Total Divided by 3
		\$	\$	\$		\$
1	Chemicals					
2	Fuel					
3	Electricity					
4	H2O Purchase					
5	Other					
				TOTALS	Line a =	

CALCULATIONS

Line 1	Average of the total amount of treated and pumped water supplied to the system over the past three years Form Line a - Form 1		
Line 2	If water is purchased, average of the amount purchased over the past three years See Page 4		
Line 3	Total amount of water supplied from total of sources and total purchased Add Lines 1 and 2		
Line 4	Average pumping and treating divided by the purchasing cost of water Divide Totals - Line a (from above) by Line 3		
			Enter on Line 15 Form 6

FORM 4 - SOURCE METER ERROR ADJUSTMENTS TO THE TOTAL AMOUNT OF WATER SUPPLIED TO THE SYSTEM

Year									
No.	Meter Location	Meter Test Date	Calibration/ Test	Meter Error % (+ or -)	time	Total Metered (gallons)		Adjustment in gallons (+ or -)	
1					x		=		
2					x		=		
3					x		=		
4					x		=		
5					x		=		
6					x		=		
7					x		=		
8					x		=		
9					x		=		
10					x		=		
11					x		=		
			AVERAGE PERCENT:		TOTAL ADJUSTMENTS:				
Year									
No.	Meter Location	Meter Test Date	Calibration/ Test	Meter Error % (+ or -)	time	Total Metered (gallons)		Adjustment in gallons (+ or -)	
1					x		=		
2					x		=		
3					x		=		
4					x		=		
5					x		=		
6					x		=		
7					x		=		
8					x		=		
9					x		=		
10					x		=		
11					x		=		
			AVERAGE PERCENT:		TOTAL ADJUSTMENTS:				
Year									
No.	Meter Location	Meter Test Date	Calibration/ Test	Meter Error % (+ or -)	time	Total Metered (gallons)		Adjustment in gallons (+ or -)	
1					x		=		
2					x		=		
3					x		=		
4					x		=		
5					x		=		
6					x		=		
7					x		=		
8					x		=		
9					x		=		
10					x		=		

FORM 5 - DISTRIBUTION SYSTEM LARGE SERVICE METER ADJUSTMENTS									
Year									
No.	Meter Location	Meter Test Date	Meter Size	Meter Error % (+ or -)		Total Metered (gallons)	Adjustment in gallons (+ or -)		
1					X		=		
2					X		=		
3					X		=		
4					X		=		
5					X		=		
6					X		=		
7					X		=		
8					X		=		
9					X		=		
10					X		=		
11					X		=		
12					X		=		
AVERAGE PERCENT:						TOTAL ADJUSTMENTS:			
Year									
No.	Meter Location	Meter Test Date	Meter Size	Meter Error % (+ or -)		Total Metered (gallons)	Adjustment in gallons (+ or -)		
1					X		=		
2					X		=		
3					X		=		
4					X		=		
5					X		=		
6					X		=		
7					X		=		
8					X		=		
9					X		=		
10					X		=		
11					X		=		
12					X		=		
AVERAGE PERCENT:						TOTAL ADJUSTMENTS:			
Year									
No.	Meter Location	Meter Test Date	Meter Size	Meter Error % (+ or -)		Total Metered (gallons)	Adjustment in gallons (+ or -)		
1					X		=		
2					X		=		
3					X		=		
4					X		=		
5					X		=		
6					X		=		
7					X		=		
8					X		=		
9					X		=		
10					X		=		
11					X		=		
12					X		=		
AVERAGE PERCENT:						TOTAL ADJUSTMENTS:			
CALCULATION									
AVG. ADJUSTMENT = Add Total Adjust. for each year and divide by 3									
								Enter on Line 5a - Form 6	

FORM 6 - WATER AUDIT WORKSHEET

Please place gallonage value in the Results in mgd column and perform calculations.

Line No.	DESCRIPTION
1	Uncorrected Total Water Pumped From Sources of Supply
2a	Adjustments to Total Water Supply Master Meter Error
2b	Faulty valve controlling devices
3	Corrected Total Water Supply Add Lines 1, 2a and 2b)
4	Uncorrected Customer Meter Records Total Amount Sold
5a	Adjustments to Metered Water Sales - meter error
5b	Billing Procedure error
6	Total Amount of Unmetered Water 'sold'
7	Corrected Total Quantity of Water Sold Add Lines 4, 5a, 5b and 6
8	Total amount of water not sold Subtract Line 7 from Line 3
9	Total Unmetered Authorized Public Uses of Water See Page 5
10	Total Unmetered Miscellaneous Losses See Page 5
11	Total Identified Water Losses Add Lines 9 and 10
12	Total Unidentified Water Losses- Subtract Line 11 from Line 8
13	Potential water system leakage in gpd per mile of watermain. Divide Line 12 by 365 then divide by total system miles of watermain
14	Percentage of unaccounted for water that may be attributed to leakage - Divide Line 12 by Line 3
15	Pumping and treating cost per gallon of water Line 4 on Form 3
16	Annual Expenditure Due to Unidentified Water Losses Multiply Line 12 by 15

FORM LINE		RESULTS
		(+ or -)
1	Line 1	
4	Line 2a	
Pg. 5	Line 2b	
Unadjusted Total	-	Line 3
2	Line 4	
5	Line 5a	
Pg. 6	Line 5b	
2	Line 6	
Adjusted Total	-	Line 7
Unmetered	-	Line 8
Pg. 5	Line 9	
Pg. 5	Line 10	
Estimated	-	Line 11
UAW	-	Line 12
Leakage/mile	-	Line 13
UAW leakage %	-	Line 14
Cost/gallon	3	Line 4 \$
UAW Cost		\$

AWWA Free Water Audit Software V4.2[©]
Software Screenshot Examples

Available from the American Water Works Association at:

<http://www.awwa.org/Resources/WaterLossControl.cfm?ItemNumber=47846&navItemNumber=48155>

AWWA Water Loss Control Committee (WLCC) Free Water Audit Software v4.2

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WAS v4.2

PURPOSE: This spreadsheet-based water audit tool is designed to help quantify and track water losses associated with water distribution systems and identify areas for improved efficiency and cost recovery. It provides a "top-down" summary water audit format, and is not meant to take the place of a full-scale, comprehensive water audit format.

USE: The spreadsheet contains several separate worksheets. Sheets can be accessed using the tabs towards the bottom of the screen, or by clicking the buttons on the left below. Descriptions of each sheet are also given below.

THE FOLLOWING KEY APPLIES THROUGHOUT:

	Value can be entered by user
	Value calculated based on input data
	These cells contain recommended default values

Please begin by providing the following information, then proceed through each sheet in the workbook:

NAME OF CITY OR UTILITY: COUNTRY:

REPORTING YEAR: START DATE(MM/YYYY): END DATE(MM/YYYY):

NAME OF CONTACT PERSON: E-MAIL: TELEPHONE:

Ext.:

PLEASE SELECT PREFERRED REPORTING UNITS FOR WATER VOLUME:

Click to advance to sheet..

Click here: [1](#) for help about units and conversions

Instructions	The current sheet
Reporting Worksheet	Enter the required data on this worksheet to calculate the water balance
Water Balance	The values entered in the Reporting Worksheet are used to populate the water balance
Grading Matrix	Depending on the confidence of audit inputs, a grading is assigned to the audit score
Service Connections	Diagrams depicting possible customer service connection configurations
Definitions	Use this sheet to understand terms used in the audit process
Loss Control Planning	Use this sheet to interpret the results of the audit validity score and performance indicators

Comments:

Add comments here to track additional supporting information, sources or names of participants

If you have questions or comments regarding the software please contact us at: wlc@awwa.org

AWWA Water Loss Control Committee

Instructions 1

AWWA Free Water Audit Software V4.2 Instructions Page Screenshot.

Screenshot used with permission.

AWWA WLCC Free Water Audit Software: Reporting Worksheet
Back to Instructions

Water Audit Report for:
Reporting Year:

Please enter data in the white cells below. Where available, metered values should be used; if metered values are unavailable please estimate a value. Indicate your confidence in the accuracy of the input data by grading each component (1-10) using the drop-down (left) of the input cell. Hover the mouse over the cell to obtain a description of the grades.
PLEASE CHOOSE REPORTING UNITS FROM THE INSTRUCTIONS SHEET BEFORE ENTERING DATA

WATER SUPPLIED
<< Enter grading in column 'E'

Volume from own sources:
Master meter error adjustment (enter positive value):
Water imported:
Water exported:
WATER SUPPLIED: 0.000

AUTHORIZED CONSUMPTION

Billed metered:
Billed unmetered:
Unbilled metered:
Unbilled unmetered: 0.000
Default option selected for Unbilled unmetered - a grading of 5 is applied but not displayed
AUTHORIZED CONSUMPTION: 0.000

WATER LOSSES (Water Supplied - Authorized Consumption) 0.000

Apparent Losses
Unauthorized consumptions: 0.000
Default option selected for unauthorized consumption - a grading of 5 is applied but not displayed
Customer metering inaccuracies: 0.000
Systematic data handling errors: 0.000
Apparent Losses: 0.000

Real Losses (Current Annual Real Losses or CARL)
Real Losses = Water Losses - Apparent Losses: 0.000
WATER LOSSES: 0.000

NON-REVENUE WATER
NON-REVENUE WATER: 0.000

= Total Water Loss + Unbilled Metered + Unbilled Unmetered

SYSTEM DATA
Length of mains:
Number of active AND inactive service connections:
Connection density:
Average length of customer service lines:
Average operating pressures:

COST DATA
Total annual cost of operating water system: \$/Year
Customer retail unit cost (applied to Apparent Losses):
Variable production cost (applied to Real Losses): \$/

PERFORMANCE INDICATORS

Financial Indicators
Non-revenue water as percent by volume of Water Supplied:
Non-revenue water as percent by cost of operating system:
Annual cost of Apparent Losses:
Annual cost of Real Losses:

Operational Efficiency Indicators
Apparent Losses per service connection per day:
Real Losses per service connection per day*:
Real Losses per length of main per day*:
Real Losses per service connection per day per meter (head) pressure:
Unavoidable Annual Real Losses (UARL):
From Above, Real Losses = Current Annual Real Losses (CARL):
Infrastructure Leakage Index (ILI) [CARL/UARL]:

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

WATER AUDIT DATA VALIDITY SCORE:
Add a grading value for 9 parameter(s) to enable an audit score to be calculated

PRIORITY AREAS FOR ATTENTION:
Based on the information provided, audit accuracy can be improved by addressing the following components:
1: Billed metered
2: Customer metering inaccuracies
3: Total annual cost of operating water system
For more information click here to see the Grading Matrix worksheet

AWWA Free Water Audit Software V4.2 Data Entry Page Screenshot.
Screenshot used with permission.

Appendix D

Check Up Program for Small Systems (CUPSS) Example



Appendix D

Check Up Program for Small Systems (CUPSS)



Credits, debits, new equipment, old equipment, repairs, upgrades...it is a lot to keep straight. The U.S. Environmental Protection Agency (EPA) has created a tool to help water systems keep all aspects of asset management straight: the Check Up Program for Small Systems (CUPSS). CUPSS is a free software package that has a downloadable, detailed user manual to help water and wastewater systems use the software to best help them.

What is CUPSS?

CUPSS is a simple, easy to use asset management program that helps small utilities manage and finance existing and future drinking water and wastewater infrastructure. CUPSS is stand-alone, user-friendly software with an attractive interface and tutorial, delivered on CD. The end-user for CUPSS is a small public water system or wastewater facility serving less than 3,300 customers or medium-sized systems new to asset management. The program offers personalized, intuitive navigation, including areas like “My Check Up Reports” and “My CUPSS Plan.”

Why use CUPSS?

CUPSS can assist in water loss management. Operation and maintenance schedules can be entered, including daily, weekly, monthly and yearly tasks. A user could set-up tasks to monitor loss and the regular maintenance of assets. The software allows for the task to be assigned to specified day(s) and time(s). It also helps create a schematic of a system and an inventory of its equipment. Small icons can be linked to show pumps, distribution lines, chemical systems, wells, and other parts of a system and how they work together.

The schematic can be created along with an inventory list. CUPSS serves as an asset inventory database. When creating the inventory, the software asks for the condition and age of each item. The cost, maintenance schedule and supplier and/or manufacturer can be added for each inventory item. Also, a notes field is available to add any additional information a user wants to note for the asset.

CUPSS provides Check Up and CUPSS Plan reports. The Asset Check Up report tool provides a report of assets entered and their risks. The Financial Check Up Report tool projects a 10 year financial status. My CUPSS Plan tool creates a customized asset management plan. This comprehensive feature draws information entered throughout CUPSS and formats the information into a user-friendly report.

Where do I find CUPSS?

Basic information about CUPSS, software download and training materials may be found at <http://water.epa.gov/infrastructure/drinkingwater/pws/cupss/index.cfm>.

Selected Screen Captures from the CUPSS Software Program

Check Up Program for Small Systems (CUPSS)

Set-up | Switch Utility | Create User | Help | Training | Exit

My Home | My Inventory | My O & M | My Finances | My Check Up | My CUPSS Plan

Beauty View Acres Subdivision - DW [Print Blank Worksheet](#)

The asset inventory form allows you to enter information about your assets. This information will then be used in several of the CUPSS reports and to generate your prioritized asset list. **(*) Indicates required fields**

Basic Information

* Asset Name Select Associated Asset
 * Location Select Associated Location [Add]
 * Asset Category * Asset Type
 ID Size
 Latitude Longitude
 Notes

Status and Condition - Required to Calculate Priority

* Condition * CoF
 * Redundancy Can this asset be repaired? ☐ Yes ☒ No
 * Asset Status Can this asset be rehabilitated? ☐ Yes ☒ No
 Select Asset Show asset in the schematic? ☐ Yes ☒ No

Asset Risk Matrix

Consequence of Failure

Low Risk High Risk

Low Probability High Probability

Inventoried Asset List

- Source
 - Well#1
 - pump
 - well property
 - Wellhouse Tampa
- Pumping Facility
 - Main valve
 - Security
 - Chlorinator
 - Well House
- Treatment
 - Chlorine testing
- Storage
 - Storage Tank
- Distribution

Figure D-1. Asset Inventory window. The Asset Inventory window has 4 parts: (1) Basic Information, (2) Status and Condition, (3) Cost and Maintenance and (4) Manufacturer and Supplier. This figure shows the first 2 parts.

Status and Condition - Required to Calculate Priority			
* Condition	Select Condition Rating	* CoF	Select CoF Rating
* Redundancy	Select Redundancy	Can this asset be repaired?	☐ Yes ☒ No
* Asset Status	Select Status	Can this asset be rehabilitated?	☐ Yes ☒ No
Select Asset Replaced	Select Asset Being Replaced	Show asset in the schematic?	☐ Yes ☒ No

Cost and Maintenance			
* Installation Date		Original Cost	
* Expected Useful Life		* Replacement Cost	
		Routine Maintenance Cost	Select Frequency
☐ Maintained According to Factory Recommendation			Create a task

Manufacturer and Supplier - Optional			
Model Number		Supplier	Select Existing Supplier
		Manufacturer	Select Existing Manufacturer
Address			
City, State, Zip		Select state	
Phone, Fax			

Cost and Maintenance

* Installation Date			Original Cost		
* Expected Useful Life			* Replacement Cost		
			Routine Maintenance Cost		Select Frequency 

☐ Maintained According to Factory Recommendation 

[Create a task](#)

Manufacturer and Supplier - Optional

Model Number ?

Supplier ?

Manufacturer ?

Address

City, State, Zip

- **wennhouse rampa**
- **Pumping Facility**
 - Main valve
 - Security
 - Chlorinator
 - Well House
- **Treatment**
 - Chlorine testing
- **Storage**
 - Storage Tank
- **Distribution**
 - Water Production Meter
 - Tank
 - Distribution

Figure D-2. Asset Inventory window continued. The Asset Inventory window has 4 parts: (1) Basic Information, (2) Status and Condition, (3) Cost and Maintenance and (4) Manufacturer and Supplier. This figure shows the 3 of the 4 parts.

Check Up Program for Small Systems (CUPSS)

Check Up Program for Small Systems Set-up | Switch Utility | Create User | Help | Training | Exit

My Home My Inventory My O & M My Finances My Check Up My CUPSS Plan

Beauty View Acres Subdivision - DW Inventory

The following is a list of assets currently in your inventory. To sort the table click on the column headings. To edit the information, right click on the selected record and click "edit row".

Priority	Asset	Category	AssetType	Condition	CoF	Redundancy	Replacement Date
1	Well#1	Source	Wells and Springs	Poor	Catastrophic	0%	2009-02-01
2	pump	Source	Pumping Equip...	Good	Catastrophic	0%	2011-02-01
3	Main valve	Pumping Facility	Pumping Equip...	Fair (Average)	Major	0%	2011-02-01
4	Security	Pumping Facility	Security Equipm...	Good	Minor	0%	2009-02-01
5	Tank	Distribution	Distribution / C...	Good	Catastrophic	0%	2036-02-01
6	Chlorinator	Pumping Facility	Disinfection Equ...	Fair (Average)	Insignificant	0%	2008-02-01
7	Distribution	Distribution	Distribution / C...	Good	Major	0%	2038-02-01
8	Water Producti...	Distribution	Distribution / C...	Fair (Average)	Minor	0%	2035-02-01
9	Chlorine testing	Treatment	Lab / Monitorin...	Excellent	Insignificant	100%	2008-02-01
10	well property	Source	Land	Excellent	Insignificant	0%	2308-02-01
11	Storage Tank	Storage	Concrete & Met...	Good	Moderate	0%	2055-02-01
12	Well House	Pumping Facility	Pumping Equip...	Good	Major	0%	2019-02-01
Not Available	Wellhouse Tampa	Source	Wellhouse	None	None	None	None

<< Return

Figure D-3. My Inventory List. On this page, you can see a list of all saved assets. Each asset is given a priority based on the information entered in the Asset Inventory form.

Appendix E

Case Studies of Implemented Water Loss Control Programs

Washington County Service Authority, Abingdon Virginia

The Washington County Service Authority (WCSA) is a public utility that provides water to the residents of Washington County, Virginia. Washington County is located in the Appalachian Mountains of southwest Virginia and covers approximately 566 square miles. The WCSA serves almost 90 percent of the residents of Washington County with water and is the third largest waterworks in Southwest Virginia. Its distribution system covers approximately 300 square miles with 900 miles of pipeline serving more than 19,000 customers. This amounts to almost 240 feet of pipeline per customer. Due to its mountainous location, elevation variation within the water system is 1,147 feet, translating to a potential pressure differential of 493 psi. The distribution system has 27 water pumping stations and 39 pressure zones. The maximum normal operating system pressure is 250 psi.

A majority of the pipeline in WCSA's system was installed in piecemeal fashion with inadequate planning and design for future growth. Pipe sizes range from ½" to 20" in diameter and pipe materials consist of galvanized steel, cast iron, ductile iron, asbestos cement, PVC and stainless steel.

WCSA's Continuing Strategies to Achieving Water Loss Control

Capital Improvement Program. In 1997, WCSA began a program to measure and reduce its non-revenue water (NRW) based on an *Agenda for Improvement* developed using AWWA's QualServe Self-Assessment and Peer Review Program. In 1999, WCSA recognized that a systematic approach to distribution system improvement was needed. WCSA hired a consulting firm to develop a hydraulic model of the distribution system and help create a Capital Improvement Program (CIP) for water infrastructure replacement. From this master plan, 18 major projects in the distribution system were identified and prioritized. WCSA also identified 25 improvement projects to be included. Eight of the 18 master plan CIP projects and all 25 of WCSA identified projects have been completed. The total project cost for the combined 33 projects is \$12.6 million, of which, \$3.9 million was related to its' meter replacement project. Direct results of the implementation of the WCSA's CIP have eliminated 12 water pumping stations. Six additional water pumping stations along with five welded steel storage tanks are also planned for elimination as a result of the proposed improvements.

Funding for WCSA's CIP was achieved through: rate increases, increases in customer base, restructured connection and usage fees, grants, and no-interest and low-interest loans. Major portions of the CIP plan are described below.

Meter Replacement Program. In-house evaluations revealed that the WCSA's customers' meters were near the end of their service lives or were in need of maintenance. The evaluation also revealed that of the meters were too large for their estimated flow rate. Random meter accuracy testing was employed for the first time in the water system to better confirm these findings. WCSA found there was sufficient evidence to believe that a meter replacement program would be a valuable endeavor due to significant under-registration.

Radio-read meters were selected as the meter replacement type. This allowed one WCSA staff member to read all customer meters in one week; a task that historically required five employees nearly two months to complete. It also all allowed monthly billing as opposed to bi-monthly billing, and developed a routine meter testing program. Replacement began in 1999, utilizing existing meter department staff and some additional summer help. By the end of the replacement process in 2000, the WCSA's NRW had been reduced by 11%. This resulted in more than an 11% increase in water and wastewater revenue, since wastewater bills are generated from water meter readings. The meter program has also revealed that there are about 1700 water meters that are not being billed and intends to investigate this further.

Process and Blow-off Metering. Process meters were installed to measure water used in treatment plants and during operations such as cleaning facilities. Blow-off meters were installed to measure water "blown-off" during line flushing activities. These additions helped the utility identify and measure more than 4 million gallons of NRW each month.

Line Replacement Program. A large portion of the existing lines in WCSA's distribution system are old, small, or of a material that reduces optimum hydraulics and/or water quality. Replacement of substandard lines would reduce water loss, increase water quality and hydraulic efficiency. Another substantial benefit would be reduce cost associated with repairing frequent breaks.

A geographic information system (GIS) was used by the WCSA staff to develop a detailed inventory of the water system. It identified: pipe sizes and types, lines with a high number of leaks and breaks, and lines with a high number of water quality complaints. The inventory revealed almost 200 miles of 2" or smaller galvanized pipe. Galvanized pipe accounts for more than 22% of the entire system. The WCSA estimated that water lost in galvanized lines was costing more than \$340,000 annually in production costs alone.

WCSA initiated its Line Replacement Program in 2000 and has replaced an average of 40,000 feet of line or 1% of its distribution system yearly. WCSA has calculated that each repair costs an average of \$550, resulting in an estimated \$270,000

annual cost for galvanized pipe repair. Eighty-six percent of the inventoried leaks and breaks repaired from January 2004 through December 2005 involved galvanized line.

System Pressure Modifications. In 1997, WCSA had only six pressure reducing valves (PRVs) with only two that were operational. The system averaged eight to ten water line breaks per month. Today, 20 PRVs have been installed along with other modifications to reduce excess pressure throughout the distribution system. Two pressure zones were modified to reduce pressure by 20 psi, resulting in a significant decrease in water demand and a reduction in NRW. As a result of the pressure reductions WCSA has also experienced a significant system-wide reduction in the number of monthly breaks. By 2003, the number of breaks was reduced to an average of two breaks per month.

SCADA System. WCSA has automated 90% of its distribution system operations through use of a Supervisory Control and Data Acquisition (SCADA) system that monitors every storage tank, pump station and control valve within the system. This results in:

- Better tracking and record keeping
- Continuous monitoring for flow and pressure changes, possibly indicating a leak or break
- Increased efficiency in resource usage
- Better control and the monitoring of tank levels
- Improvements in water quality because of the improved tank turnover

District Metered Area Monitoring. To monitor the distribution system for real and apparent losses, the distribution system was divided into 26 smaller regions to identifying losses within specific areas. These District Metered Areas (DMAs) were established largely by pressure zones. Magnetic flow meters were installed at points in the system where changes in pressure occur such as at a pump station or PRVs. Magnetic flow meters, called DMA master meters by WCSA, record the amount of water flowing into each DMA. Customer meters, process meters and blow-off meters also record the amount of water consumed in each DMA. By comparing the amount of water flowing into the DMA master meters, with the amount consumed, WCSA calculates an estimated NRW volume within each DMA. This allows WCSA to locate and prioritize NRW loss repairs.

Information from the DMA magnetic flow meters is recorded in a database and compared to previous DMA readings. Weekly comparisons help indicate unusual events within a DMA. A spike in the amount of water entering a DMA could indicate unauthorized use, unusual customer consumption, or operational changes within the DMA. Each spike is investigated and its cause is recorded in the database for future reference. The DMA Monitoring Program identified four DMAs of significant NRW concerns. In 2003, system-wide NRW averaged 51 million gallons a month and the NRW within these four DMAs accounted for 25 million gallons per month making them a priority for repair and investigation.

WCSA has estimated that the metering, piping, and DMA upgrades will result in a NRW loss reduction from nearly 2.6 Million gallons a day to about 1million gallons a day. WCSA continues to look for ways to reduce NRW within the utility. While important and cost-saving steps have been taken, there are still other opportunities for improvement.

The Water & Wastewater Authority of Wilson County, Tennessee

Reducing Real Losses (Leakage) in a Rural System Using a Bottom-up Approach

The Water & Wastewater Authority of Wilson County, Tennessee was established July 21, 1975. The Authority was formed to study existing water facilities in the county, to take appropriate action to improve the public water supply and distribution system in the county, and to effectively supply public water throughout as much of the county as economically feasible, giving special emphasis to the eastern half of the county. The Authority purchases 100% of the potable drinking water as treated water from four different supplies through a total of 15 supply meters which are normally read manually on a daily basis. Water is distributed to the eastern half of Wilson County though 321 miles of main to 6,926 service connections. The water main sizes range from 2" to 10" but consist mostly of 6" lines. Nearly all of the mains are PVC.

The distribution system consists of nine pumping stations. Four of these pumping stations supply five ground level storage facilities that range in size from 50,000 gallons (gal) to 500,000 gal. The remaining five pumping station use variable frequency drives to provide pressure to higher elevations of the distribution system. The system pressure ranges from approximately 25 psi to 140 psi. Most customer service lines are ¾" and are generally copper or black rolled plastic. The customer base is primarily rural residential. At present, all water meters are read manually each month.

The Authority uses the AWWA Water Audit Software to conduct a top-down water audit annually. The system input meters are operated, maintained, tested, and calibrated by the water suppliers. The unbilled unmetered water (fire department usage, system flushing and tank cleaning) is tracked and recorded for the Water Audit. The Authority also has the following assets to help in its leak detection efforts.

- The Executive Director has over 25 years of water loss experience.
- A GIS mapping system is in place.
- All storage tanks and seven of the nine pumping stations are on telemetry.
- The Authority owns three electro-acoustical water leak detectors, pipe locators and valve box locators.
- The only major purchase by the Authority was a portable Ultrasonic Liquid Flowmeter for a cost of \$8,500.

The Authority's present focus is to implement methodologies to reduce leaks that tend to run for a long duration and to identify the main breaks before they affect the level of service to the customers. Locating main leaks before they become breaks allows the main leaks to be repaired under positive pressure with a repair clamp. This eliminates the need to cut the pipe and depressurize the distribution system. If the system is depressurized, bacteriological samples must be taken and the depressurized section of the system may need to be disinfected. Repairing main breaks under pressure is important in maintaining water quality and service to the customers.

The Authority uses sonic detection equipment to help locate leaks. It has a customer density of 22 connections per mile with an average distance between listening points on services of 240'; although it is not unusual for the distance between listening points to be over 2,000' making sonic leak detection by direct contact ineffective in many areas. The water mains are often located in soil, in areas that are difficult to access in off-the-road right-of-ways. Listening for leaks is more effective when the main is located under pavement or in the shoulder of the road since leak noise does not attenuate well though looser soils. The Authority's system pressures can dip to around 25 psi at higher elevations, which also adds to acoustical leak detection method difficulties since leak noise falls as pressure drops. Therefore, the Authority has implemented other methodologies to identify and prioritize the areas where leakage exists.

To help locate leaks the Authority has established 16 District Metered Areas (DMAs) that measure input from the water suppliers' supply meters, temporary metering, or via drop testing of a water storage facility. Twelve of the DMAs are gravity fed from the water suppliers though one or two input meters for each DMA. Four of the larger DMAs, represent 64% of the total system. Each of these four DMAs includes a pumping station supplying water to one or two ground level storage tanks at high elevations within the DMA. Each storage tank has telemetry which polls tank levels every 30 minutes. The Authority monitors the Minimum Night Flow (MNF) via the telemetry on the four larger DMAs. The MNF is typically between 1:30 AM and 3:30 AM when the consumption within the DMA is at its lowest. At night the DMA is fed via gravity flow from the water storage tank only; the pump station is off. Changes in the Tank levels are converted to gallons per minute (gpm) feeding the DMA. The input meters measuring the water supplied to the 12 gravity feed DMAs serving the remainder of the distribution system are normally read daily. The daily readings are compared to the prior day's readings to determine if leakage may be occurring. If a daily reading increases and leakage is suspected then a portable ultrasonic liquid flowmeter is normally installed at the input meter and flow is datalogged at one minute intervals. If leakage is suspected based upon telemetry data at one of the four larger DMAs, a portable ultrasonic liquid flowmeter is installed on the main line at the storage tank before it entering the distribution system. On smaller DMAs, sonic leak detection methods are typically used to pinpoint the leakage.

Minimal consumption occurs during the MNF period since the customer base is primarily rural residential. It is assumed the normal consumption during the MNF period is for toilet flushing and a factor of 1.5 gal per customer per hour is used for this

Legitimate Nighttime Consumption (LNC). Some night time lawn irrigation may occur within subdivisions. Any other known consumption is also taken into consideration. This bottom-up field data can be related to the Real Losses per length of main per day performance indicator contained in the AWWA Water Audit. In theory, the sum of the field measurement calculations of Real Losses should be approximately equal to this performance indicator if the AWWA Water Audit and the bottom-up field measurement and calculations and estimates are accurate. At the Authority, the following Operational Efficiency Indicators are used for Real Loss target setting:

- Real Losses per length of main per day: 645.59 gallons/mile/day or 0.448 gpm per mile of water main (645.59 gal/mile/day divided by 1440 minutes/day).
- Unavoidable Annual Real Losses (UARL): 60.78 million gallons/year or 0.36 gpm per mile of water main (60,780,000 g/y divided by 365 days/year divided by 1440 minutes/day divided by 321 miles of water main).
- Infrastructure Leakage Index (ILI) (Real Losses/UARL): 1.24
 - o In order for the ILI to equal 1.0 the Real Losses need to equal the UARL. If the Authority could reduce the Real Losses in the MNF period to 0.36 gpm per mile of water main then it could reach an ILI of 1.0 and be at the technically lowest limit of leakage that can be achieved if all of today's best technology could be successfully applied. It may not be cost effective for water systems to reach an ILI of 1.0. The Economic Level of Leakage (ELL) should be determined prior to making major investments in an effort to reach an ILI of 1.0. The Authority does not plan to make any major investments to reduce the present ILI. It is using this information to prioritize the DMAs for intervention.

The Authority set a preliminary target to maintain the MNF levels of Real Losses at or below 0.36 gpm per mile. For example, the Trousdale Ferry DMA contains 56 miles of water main therefore the Real Losses should be maintained at a level of 20 gpm (0.36 gpm/mile times 56 miles). The MNF should be maintained at or below 53 gpm (LNC of 33 gpm plus Real Losses of 20 gpm). The Trousdale Ferry DMA is one of the four largest DMAs in the System. The pumping station and water storage tank level are monitored via telemetry. If the pumping station is not running during the MNF period and the tank level is dropping at a rate greater than 53 gpm then one should consider intervening to determine if the occurrence is due to an exceptional nighttime user or leakage. To verify and refine the telemetry readings when there is a suspected leak, the portable ultrasonic liquid flowmeter is installed at the Trousdale Ferry storage tank. For the MNF period, the datalogger is set to record flow at one minute intervals. This data can then be evaluated to determine the lowest flow level in the MNF period. Using this or a similar measurement approach within all the DMAs will allow the prioritization of DMAs for intervention starting with the DMA having the greatest Real Losses in gpm per mile of water main.

Trousdale Ferry DMA LNC Calculation

The Trousdale Ferry DMA has 1,332 service connections therefore the LNC during the MNF period would be 33 gpm (1.5 gal/customer/hr times 1,332 customers divided by 60 min/hr). Any constant flow during the MNF period in excess of 33 gpm is then considered the Real Losses (leakage) in gpm.

Trousdale Ferry DMA Actual Field Study Scenario. The Trousdale Ferry DMA has been the most active DMA requiring intervention. The Authority began the DMA MNF monitoring in 2007. The DMA is isolated by closing a 1" bypass line and a ¾" bypass line that allows water to flow into two other DMAs. The pump station is turned off and the DMA is provided water solely via the Trousdale Ferry storage tank. The GIS system was used to identify valves that can be used to divide the DMA into smaller sub-DMAs. The services within the DMA areas are counted to determine the LNC. A step test is then used, via these shut-off valves, to isolate the smaller sub-DMAs. This process can isolate areas as small as the distances between two main line valves. During the step testing, the datalogger in the flowmeter at the storage tank records flow at 30 second intervals and another person reads and notes the flow rate on the flowmeter, which updates continuously. The specified valves are closed creating a step and a newly created area within the DMA. The time all valves are closed and opened is recorded in order to correlate with the datalogged flow. The drop in the flow on the flowmeter is noted when the specific valve is closed. The flow rate is allowed to stabilize for about five minutes after shutting the valve. The valve is then opened slowly to re-establish flow to the area which was isolated. The flow rate will increase at some level depending upon the amount of leakage and/or consumption occurring downstream of the valve and the length of time the valve was closed.

In January, 2010 the telemetry data indicated that the Trousdale Ferry DMA appeared to have higher than normal MNF. Therefore, the portable ultrasonic liquid flowmeter was installed at the Trousdale Ferry storage tank and the MNF data was recorded on January 11, 2010. The MNF identified a 120 gpm range which is excessive. See the Trousdale Ferry DMA Initial Test Results.

Trousdale Ferry DMA Initial Test Results

TF DMA MNF = 120 gpm
 TF DMA LNC = 33 gpm
 TF DMA Real Losses = 120 gpm – 33 gpm = 87 gpm
 TF DMA Miles of Water Main = 56
 87 gpm/56 miles = 1.6 gpm/mile

On January 12, 2010 step testing was implemented in the Trousdale Ferry DMA. When TF DMA East was isolated at 1:29 AM the flow dropped from 120 gpm to 87 gpm for a net decrease of 33 gpm. The actual flow of 87 gpm is the MNF into TF DMA West and the 33 gpm decrease in flow is the MNF in TF DMA East. The east and west step results are summarized below.

Trousdale Ferry DMA West Step Results

TF DMA West MNF = 87 gpm
 TF DMA West LNC = 11 gpm
 TF DMA West Real Losses = 87 gpm – 11 gpm = 76 gpm
 TF DMA West Miles of Water Main = 22
 76 gpm/22 miles = 3.5 gpm/mile

Trousdale Ferry DMA East Step Results

TF DMA East MNF = 33 gpm
 TF DMA East LNC = 22 gpm
 TF DMA East Real Losses = 33 gpm – 22 gpm = 11 gpm
 TF DMA East Miles of Water Main = 34
 11 gpm/34 miles = 0.3 gpm/mile

The results show the vast majority of the leakage is in the TF DMA West at 3.5 gpm/mile versus 0.3 gpm/mile in TF DMA East. Therefore additional step testing was performed in the TF DMA West. When TF DMA SW was isolated at 2:08 AM the flow dropped from 120 gpm to 50 gpm for a net decrease of 70 gpm. This 70 gpm decrease in flow represents the MNF in TF DMA SW. The Southwest step results summarize this.

Trousdale Ferry DMA Southwest Step Results

TF DMA SW MNF = 70 gpm
 TF DMA SW LNC = 8 gpm
 TF DMA SW Real Losses = 70 gpm – 8 gpm = 62 gpm
 TF DMA SW Miles of Water Main = 14
 62 gpm/14 miles = 4.4 gpm/mile

Obviously the leakage is occurring within the TF DMA SW, which contains 14 miles of water main. Additional step testing was performed within the TF DMA SW and the leakage was isolated by 3:15 AM to a 1,700' section of the distribution system. The actual step testing field work took less than two hours and covered 56 miles of water distribution main.

Personnel walked the suspected leak area and used an electro-acoustical water leak detector to listen to all services in the meter boxes, main line, valves and hydrants but could not locate the leak. Personnel then used the ground microphone to listen for impact fountain sounds created by underground leaks. The soil was frozen, aiding sound transmission, and the leak was located but could only be heard within a 2' radius directly over the leak. The leak was excavated and was discharging into an underground sink hole explaining why it was not apparent on the surface. The leak had occurred at a repair clamp installed many years ago.

Without the implementation of the DMA MNF/Step Testing approach this leak could have gone undetected for many years. The actual leak rate was estimated to be 65 gpm range, which is approximately 94,000 gal/day or over 34,000,000 gal/year. No

customers in the area experience any low pressures due to the leak. The MNF is in the 50 gpm range. Therefore the decrease in flow from MNF prior to step testing of 120 gpm compared to the MNF after the leak was repaired of approximately 50 gpm yielding a decrease in the MNF of 70 gpm, which is approximately equal to the estimated leak rate from the step testing of 65 gpm. The DMA analysis after the leak was repaired is summarized in the Trousdale Ferry DMA Post Repair Results text box showing the level of Real Losses was restored back to a level below the system target of 0.36 gpm/mile.

Trousdale Ferry DMA Post Repair Results

Trousdale Ferry DMA MNF = 50 gpm
 Trousdale Ferry DMA LNC = 33 gpm
 Trousdale Ferry DMA Real Losses = 50 gpm – 33 gpm = 17 gpm
 Trousdale Ferry DMA Miles of Water Main = 56
 17 gpm/56 miles = 0.3 gpm/mile (System Target is 0.36 gpm/mile)

The Authority now plans to improve the water loss control program through the following methods:

- Improving the confidence and accuracy of the water audit report input data.
- Adding additional programming within the telemetry system to alert the Authority of potential breaks.
- Installing data collection and telemetry on the 15 supply meters eliminating manual reading and increasing data resolution.
- Conducting monthly water audits for non-revenue water at the DMA level.
- Increasing the frequency of routine sounding of system components to identify small leaks not identified by step testing.
- Installing automatic meter reading/advanced metering infrastructure systems on customer meters to reduce apparent losses (customer metering errors), increasing system revenues, and improve accuracy of water audit data.
- Implementing pressure monitoring and consider pressure management opportunities.

At the time of this writing, a draft water audit report was prepared for FY09/10 ending 6/2010 and the results showed that the Infrastructure Leakage Index (ILI) decreased from 1.24 in FY08/09 to 1.11 in FY09/10 and the Real Losses per length of main per day decreased from 645.59 gallons/mile/day in FY 08/09 to 575.49 gallons/mile/day in FY09/10. The aggressive bottom-up approach implemented by the Authority is yielding positive results.

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