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MONTENEGRO
GOOD LOCAL GOVERNANCE

Unaccounted for Water: Manual of Practice

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CHAPTER 1

1 INTRODUCTION

1.1 Understanding Water Loss

Historically, in most parts of the world, water was seen as an infinite resource, and it was believed that given sufficient capital investment, additional water sources could always be developed, when needed. Therefore, lost water was largely ignored by water utilities or simply accepted as a part of the operations of a water supply system.

With the increased rate of population growth that has occurred more recently around the world; the migration of rural populations to more urban centers; the need to access more distant and/or more costly sources of supply; and the increased cost to produce each unit of potable water, it is now unrealistic to allow water loss to be ignored or simply accepted.

When the water industry speaks about water loss, it will often use the term "unaccounted-for-water" (UFW). However, as will be discussed later in this Manual in Chapter 3, the expression unaccounted-for-water may be a bit misleading.

Currently, around the world, different governmental organizations, professional institutions, consultants, and system operators use terminologies, define their use, and apply calculations in different ways in what they feel is toward the same end objective, to reduce water loss. This approach not only hinders any attempt to built a coherent and accountable historical database for a given water utility, but also makes it impractical to apply benchmarking techniques across an industry. As a result, it becomes very difficult to demonstrate responsible management and use of an important natural resource, such as water. Standardization of terminology and, consequently, the calculations that follow, are important and essential to the water industry as much as they are in any other industry.

In the last few years, the problem of standardization of terminology and calculations in addressing water balance has begun to be resolved by the collective efforts of a number of larger, national professional water associations working in concert through the efforts of the International Water Association (IWA).

Lost water is that portion of the total amount of water that is abstracted or withdrawn, treated, and transported to the ultimate users, but for some reason does not get there, in fact, or is not measured as used water, and therefore is not being recognized as "revenue water" or sold water.

Water loss occurs in two fundamental ways:

- Water lost from the distribution system through leaks, tank overflows, improperly open drains, or system blow-offs. This is water that never gets to the point of end use. These losses are referred to as "real losses" or sometimes called technical losses.

- Water that reaches a customer or other end user, including beneficial and unauthorized use, but is not properly measured or tabulated. These water losses are essentially "paper" losses and are referred to as "apparent losses" or sometimes called administrative losses.

Relative to real water losses, apparent water losses typically have a much greater short-run marginal cost effect, since they affect revenues of the water utility at the retail customer rate.

Today, the water industry is beginning to enter a new era in water management, where water accountability, as a valued product, is rising in importance and receiving regulatory oversight in much the same way that financial accountability has been traditionally viewed.

1.2 Water Loss and Water Demand Management

As the capital and operating costs of water supply continue to increase, per unit of capacity installed, or per unit of water produced, the water industry is becoming more aware of water demand management. This is often first addressed as a need for conservation efforts, which are efforts to reduce the use of water or to use it more efficiently.

However, high real losses require water suppliers to extract, treat, and transport greater volumes of water per day than their customers need or demand. This apparent need for additional water then creates an unnecessary demand to supply that water.

1.3 Real and Apparent Water Loss

Under 1.1 above, both ***real water loss*** and ***apparent water loss*** were defined in the context of the aggregate water loss problem. In beginning to consider the problem of water loss, it is important to have a practical understanding of why water losses occur.

1.3.1 Why Real Water Losses Occur

The most common form of real losses in water supply systems is "leakage", which occurs for a number of reasons, to include:

- Poor installation and workmanship in the distribution system
- Poor installation and workmanship in service connections
- Poor piping and connection materials
- Mishandling of materials before installation
- Improper backfilling procedures around pipes
- Pressure fluctuations in the distribution system
- Excessive system and/or zone pressures
- Corrosion around connections
- Vibration and traffic loading over buried pipelines

In British leakage management terminology, a distinction is made between "reported leaks" versus "unreported leaks", or more literally, "reported bursts" and unreported leaks. When a pipe bursts, it is obvious that it will be recognized, reported and repaired within a fairly reasonable period of time. The same is not true for small leaks that are not the result of a pipe burst, or actually never surface to become observed. These leaks are continuous and, although less dramatic, collectively account for a greater total amount of water loss in a water supply system.

A significant finding of more recent leakage correction efforts has been the large amount of water loss occurring on the customer service piping, which goes from the service main or, the property line shut-off valve, to a single or multiple user premise. It has been determined that in many systems, the cumulative losses occurring in these small diameter pipes constitute the greatest total source of real losses. This problem is complicated by the fact that the service lines are often defined by utility policy to be owned and maintained by the customer. Since the loss is usually occurring before the customer meter, the customer is not motivated to repair it at his cost until it creates a problem on his property.

1.3.2 Why Apparent Water Losses Occur

The term "apparent water loss" is not to imply that this type of loss is not a significant issue in water supply system management. Rather, apparent water losses are significant for two reasons:

- Relative to real water losses, apparent water losses typically have a much greater short-run marginal cost effect, since they affect revenues of the water utility at the retail customer rate.

- An inappropriate assessment of apparent water losses (under estimated) often results in real losses being overstated in the water balance audit (to be discussed later in the Manual), potentially misguiding water loss management planning and programs, by placing an inordinate emphasis on leakage, while potential revenue recovery goes unattended.

Apparent water losses are normally characterized to occur in three primary ways:

- Errors in water flow measurement
- Errors in water accounting
- Unauthorized or "illegal" connections

The following provides a brief description of how the water losses occur in each of the three ways characterized.

1.3.2.1 How Errors in Water Flow Measurement Occur

Water flow measurement is the result of using meters of different types, depending on the user type and the water demand patterns of that user/customer. Therefore, errors in flow measurement are the result of factors that can affect accurate meter performance. Some of the major reasons why water meters fail to measure water flow accurately include the following:

- Meter wear over time
- Water quality impact on the meter
- Chemical build-up on the meter
- Poorly manufactured meters
- Local conditions of extreme heat or cold
- Incorrect meter installation

- Incorrect meter sizing
- Incorrect specification of meter type for the application
- Unauthorized tampering with the meter
- Lack of routine testing and maintenance
- Incorrect meter repair

Many systems use estimates for customer usage when customer meters do not exist. These are often consumption "norms" by classes of users. Although consumption norms may provide a means of distributing the total cost of water supply services across the customer base, to arrive at a tariff per unit of water, it should not be confused with actual water flow measurement. In fact, the use of consumption norms can lead to many distortions in understanding what is actually happening in the water supply system. Where consumption norms are the only currently available means to arrive as water usage, care should be taken to establish a rational means of establishing such norms.

Where customer meters do exist, then the process of meter reading can also be considered as a potential area for measurement error. With the increasing use of automatic meter reading (ARM) devises, manual meter reading and data transfer errors can be greatly reduced. However, routine assessment of the meter reading operations, and data transfer into the information management system (billing system) should be standard procedure for a water utility.

1.3.2.2 How Errors in Water Accounting Occur

Once a customer is documented in the customer account system and the usage data is entered into the system, water accounting errors can occur in a number of ways, to include the following:

- Customer water usage data is modified during billing adjustments
- Customers are inadvertently or intentionally omitted from billing records and go unmonitored, and therefore, unbilled
- Certain users are granted non-billed (free or subsidized) status, and usage is not recorded
- Human errors occur during data analysis and billing
- Weak policies create loopholes in billing and water accounting
- Meter reading or billing systems are poorly structured
- Changes in real estate ownership or other changes in customer account status are tracked poorly or not at all
- Technical and managerial relationships in assessing, reducing, and preventing water loss are poorly understood or implemented

As previously stated, water accountability must assume the same importance and regulatory enforcement as financial accountability, if the water industry is going to truly begin to address the seriousness of water loss.

1.3.2.3 How Unauthorized or Illegal Usage Occurs

Water utilities must always be alert to the fact that there is a segment of the society that will attempt to obtain water supply service illegally and without making payment. Such social behavior can be observed both in systems with metered customer connections and without metered customer connections.

In metered systems, tampering with the meters or the meter reading equipment may be attempted in order to lower the reading. Where large meters exist, and by-pass piping has been provided as a part of a standard installation, some customers have been known to open valving around the meter, to have some of the water supply flow through the unmetered, by-pass piping, thus under-recording the actual usage. Additionally, some customers will attempt to make a separate connection to the service piping, underground and ahead of the meter, to provide an unmetered supply for a portion of their needs.

In unmetered systems, the motivation of such people is to totally avoid being recognized and recorded as a customer, since the volume of water consumed is not a factor. Illegal usage in such cases will be the result of making unauthorized connections for new end users such as homes or businesses. Such situations are best prevented when the water utility has a close working relationship with the building inspector/regulator within the local government. In this way, all construction permits must have, as one element of approval, the agreement of the water utility to provide service, making it clear that a new user is about to be connected to the system.

1.3.3 Complexity of Water Loss Control

Clearly, from the discussions above, water loss control is not a single issue with a single answer. Because of this fact, water utilities must decide to employ a multidimensional approach to water loss control optimization programs. In this regard, every employee of the utility must be made aware of the problem and what their role is in reducing both real and apparent water losses. This must be complemented with a public/customer education program so that the general public is made more aware of the economic value of water and the need to treat its usage in a valued way.

For the water utility, the first step in such a process is the water balance audit, which will be discussed in detail in Chapters 6 and 7 of this Manual.

1.4 Financial Impact of Water Loss

Water losses, both real and apparent, have a significant financial impact on the water utility. These impacts occur as increased capital expenditures, increased operating costs and decreased revenues.

1.4.1 Increased Capital Expenditures

When real losses occur, they deprive the end users of the availability of a portion of the installed capacity of the system infrastructure. As the real demand of these end users increases, additional capital investments will be needed prematurely, due to the real losses, to provide additional system capacity to serve these demands.

1.4.2 Increased Operations and Maintenance Costs

Every unit of water produced (m3) has a unit cost (Euro) of operation and maintenance associated with it. If that unit of water is lost, and not made available to be sold to the end user/customer, then the unit cost to produce it is wasted. Since this cost must be recovered, it will increase the unit price of each unit of water that is actually measured and sold to the end users.

1.4.3 Decreased Revenues

When end users benefit from the water supply system, but do not pay for that service because of illegal connections or unauthorized usage, they not only affect the cost of the system to provide that service, by demanding water, but also deprive the system of revenues for the quantity of water they use.

1.5 Using Standard Terminology for Water Loss

One of the initial challenges facing the water industry in addressing the issue of water loss control and reduction is to agree on standard terminology and definitions when considering the components of a water balance audit. This Manual has addressed this issue in detail in Chapter 3, and has largely accepted the terminology and definitions recommended by the International Water Association.

A glossary of terms and definitions has been prepared and included in the Annexes of this Manual. The users of this Manual should take the time to familiarize themselves with the glossary so that the industry begins to address this the critical issue of water loss in "one language".

1.6 Performance Indicators for Water Loss

Like any other business entity, a water supply utility needs to ask itself, "How am I doing?" This question is best answered by assessing defined performance indicators. If such indicators are consistently applied, then water utilities can compare performance across a whole water industry to assess performance and the trend of that performance across the industry.

The water industry has been making a closer assessment of the factors that effect water distribution efficiency and this has resulted in some major revisions to the types of performance indicators that should be considered in assessing water loss specifically, and over all water utility performance, in general. Chapter 4 of this Manual is dedicated to this most important topic in efficient water utility performance and how it relates to water loss.

CHAPTER 2

2 ROLE OF METERING IN WATER LOSS CONTROL AND WATER DEMAND MANAGEMENT

Metering is an essential component of an effective water loss optimization program. There is a well known expression, "If you don't measure it, you cannot manage it." Water flows must be accurately measured, if they are to be quantitatively traced in the path that they follow from source to consumer.

Even to this day, the low priority placed on metering of water, either in production and distribution, for purposes of achieving loss control; or in consumption, for purposes of demand management and improved revenue generation, is disturbing and must change, if the water industry is going to be able to cost-effectively meet the needs for water in the future.

Similarly, in water demand management, providing water service without measuring its usage removes the "finite" sense of the resource from the mind of the consumer. If any amount of water is available for the same cost, it is natural for the customer to hold water in lower regard than other vital commodities such as food, health care, transportation, electricity, telephone, etc. The vast majority of these vital needs are purchased per unit volume of commodity or service, not at flat billing rates for unlimited usage. Using constant or flat rates devalues water in the mind of the consumer, and what we do not value, we waste. This is an unfortunate aspect of human nature.

2.1 Metering

2.1.1 Importance of Metering

A fundamental philosophy of this Manual is that the metering of water flow, at all appropriate points in the water supply system, is fundamental to sound and responsible water management. It is understood that many water managers who will use this Manual may not have the level of metering that is discussed in this chapter of the Manual. The purpose of this chapter is to expose the user to the total concept of flow metering in a water supply system, for both loss control and demand management, so that all future strategic plans include goals for achieving this recommended level of metering, as quickly as possible.

Flow measurement should occur at multiple points along system network pathways to account for valid uses and assess loss that may be occurring between the two metering points. The primary metering points used in water supply systems around the world typically include:

- Production metering
- District or zone metering
- Customer metering

Metered water flow data is the basis for establishing the water audit balance. Similar to a financial balance statement, an accurate water balance statement should be prepared by the water supplier at a regular interval, such as annually, to coincide with the financial reporting cycle. Just as financial balance statements track the flow of money into and out of various accounts, the water balance audit tracks the quantities of water that flow into and out of the distribution system, and identifies all of its uses and losses. In progressive water loss management programs, all three levels of metering described above are utilized to provide a high level of accountability in the auditing process.

2.1.2 Production Metering

Production or master meters measure the bulk flows that are the input to the distribution system. Having functioning, accurate production meters is the foundation of sound water resource management, yet there are many water utilities that have no production meters, or have meters that are not routinely maintained and therefore do not function accurately. Water utilities must make it a high priority to install production meters and to invest in a routine program of calibration and testing to insure accurate flow data. This is the first step in a process to gain control of the water loss situation in a water supply system.

When considering the issue of water production and the metering of production, water utility managers should consider the following points of measurement that relate to production.

- Production at the source, such as the transmission main leading from a natural spring
- Connection to another utility that is providing a bulk supply under a supply contract
- Transmission main leading from a well or well field
- Transmission main leading from a water treatment plant

A particular water supply system may have some or all of these points of production to measure to arrive at the total amount of production, or more properly the "input" to the distribution system.

2.1.3 District or Zone Metering

Measuring water flows within defined districts or zones is a technique that has been used for many years. However, the application techniques and sophisticated technology that can be used with this approach have evolved greatly in more recent years.

A metered district or zone is established by defining a discrete district or zone within the water distribution system by closing valves in such a way as to leave only one or two pipelines to supply water to the defined district or zone. Portable or permanent flow meters are used at the input point(s) to measure water supply into the district or zone on a continuous basis. The data of greatest interest in these measurements, from the standpoint of loss control, is the rate of flow occurring in the early morning hours, when most of the population is asleep and legitimate water usage is at a minimum.

Since leaks will continue to waste water on a 24-hour basis, at a relatively constant rate, leakage is at its maximum percentage of the total flow during these hours. This method of night flow leakage measurement is now the standard means of quantifying leakage in most progressive leakage management programs.

2.1.4 Customer Metering

Customer meters measure water flow at the point of use or the end user. The definition of "point of use", however, may vary from utility to utility. Some systems provide one water meter to each customer service pipe, regardless of whether the service pipe supplies a single dwelling with one family, or a multi-unit dwelling serving any number of families and therefore people. Other systems utilize tiers of sub-metering within large buildings to measure flow to each dwelling unit, which is the true end user point.

For purposes of water loss control, metering of customers, whether single or multiple within a building, is sufficient to provide the necessary flow data to conduct a water balance audit and water loss analysis. The degree of sub-metering is more important in water demand management and the equitable billing of tariffs that are structured to encourage water conservation.

2.2 Quantifying Water Flow and Demand Without Fixed Metering

The current reality is that fixed metering, at the three levels that were described above, does not exist today in the vast majority of water supply systems. However, given this current reality, water supply system managers can still develop and implement water loss control programs that can have beneficial results, while fixed metering systems are being purchases and installed over time.

Many water supply system managers, who have pumped systems that provide "input" to the water distribution system, accurately record pump run times and use the pump performance data to calculate total water provided (produced) as input to the system.

Other managers use portable meters and conduct periodic "profiling" of districts or zones, or of customer types to determine norms to be used for demand by customer types. This technique can also be very effective in identifying districts or zones with high leakage (night testing) or with large numbers of unauthorized or illegal connections.

2.3 Water Flow Meter Selection, Installation, Testing and Maintenance

It is not the intent of this Manual to present a thorough understanding of water meters and their proper application. However, there are some specific issues that should be considered in the context of metering and water loss control. These issues relate to the proper selection of flow meters, their installation, and the routine testing and maintenance that should be undertaken, once the investment in meters has been made.

2.3.1 Large Water Meters

Large water meters, often referred to as master meters, are the meters used to measure production, as well as in the measurement of flows in districts and zones. Master meters come in various types, shapes and sizes to include: differential pressure, Venturi, Dall tube, orifice plate, proportional flow, magnetic, ultrasonic, turbine, propeller, and vortex, to name a few. It does not really matter which type of meter a utility installs. What matters is that the meter is functioning to its specifications, the data recorded is compatible with other system data, and the utility understands the limits of the meter that it has installed.

When a meter location has been determined, the installation should consider the following important key points, if long term successful meter performance is desired.

2.3.1.1 By-Pass Piping

The meter installation should provide for by-pass piping, such that the meter can be taken out of service for testing, maintenance and repair, while still insuring full water supply service to the customers.

2.3.1.2 Meter Access

Large meters should not be crowded into locations where they will be costly or overly time consuming to access. The harder it is to get to the meter, the more likely that servicing the meter will be ignored.

2.3.1.3 Test Oriented Meter Installation

If possible, meters should be installed to allow for in-place testing. This installation information should be provided by the meter supplier. If it is not readily available, then either design your own test procedure and install the meter accordingly, or select another meter supplier who can provide such information.

2.3.2 Customer or Revenue Meters

Particular attention should be paid to the selection of meter types and sizes for customer meters. This is particularly true of larger customers such as commercial and industrial customers. Likewise, the meters for larger customers should be tested and calibrated more often, since they represent a significant revenue impact to the utility.

When sizing customer meters, it is very important not to base the decision on only 24-hours of data. A customer's consumption can very greatly throughout the day, week, or year, for various reasons. Care should be taken to locate seasonal use information and also to understand the type of consumption in each specific case.

The installation of customer meters should take into consideration the following:

- Position meter in a horizontal plane for optimum meter performance.
- Locate meter so that it is readily accessible for reading, servicing and/or testing.
- Provide leak tight, permanent setting to ensure that the meter can be removed for service without negatively affecting customer's plumbing.
- Protect meter from freezing and other conditions that could damage the installation.
- Provide high-quality inlet shutoff valve to allow meter maintenance.

CHAPTER 3

3 UNDERSTANDING WATER BALANCE IN WATER SUPPLY SYSTEM

3.1 Importance and Objectives of a Standardized Approach to Water Balance

A water balance calculation seek to identify the destination and uses of all water entering a distribution system. This is the first step in the process of valuing water as a finite resource that has a cost associated with every unit produced. In this way, water is no different than the inflow of revenues into any business and the outflow of expenses. No business could survive, if it did not know exactly how much it was spending and for what. The same must be true when it comes to accounting for water.

3.2 Components of a Water Balance and Use of Standard Definitions[1]

To be able to perform a water balance analysis, it is essential that the water industry apply the same terminology and definitions to the components that make up the water balance. The standard water balance components that follow below are based on the IWA recommended best practice. Each component of the water balance needs to be specifically defined, in order to have a clear, accurate and consistent understanding by al who refer to it.

Figure 3-1, Standardized Water Balance Components, provides a rational basis for considering the components of a water balance for any given water supply system. In this context, it is important to establish definitions for some key components that define the area of water loss. A glossary of applicable terminologies, with their definitions is included in Annex A of this Manual of Practice.

Water Produced: The volume of water treated for input to water transmission mains or directly to the distribution system.

Water Imported/Exported: The volumes of bulk transfers across operational boundaries.

System Input Volume: The volume of water input to a transmission system, distribution system, or both. This is therefore equal to Water Produced plus Water Imported (positive value) / Exported (negative value).

System Input Volume = Water Produced + Water Imported/Exported

Authorized Consumption The volume of metered and/or unmetered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorized to do so for commercial and industrial purposes.

Note that authorized consumption includes items such as firefighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water. These may be billed or unbilled, metered or unmetered according to local practice.

Water Losses = System Input Volume – Authorized Consumption Volume

[1] Source: International Water Association (IWA) “The Blue Pages”, October 2000.

These major water balance components are further divided into subcomponents, as shown in Figure 3-1 below. The convention used in the water balance is to present all volumetric data in the water balance on a per year basis.

Figure 3-1 Standardized Water Balance Components

<table>
<tr><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th></tr>
<tr><td rowspan="10"><u>SYSTEM INPUT VOLUME</u>
M^3/Year</td><td rowspan="4">Authorized Consumption
M^3/Year</td><td rowspan="2"><u>Billed Authorized Consumption</u>
M^3/Year</td><td>Billed Metered Consumption (incl. water exported)</td><td rowspan="2"><u>Revenue Water</u>
M^3/Year</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2"><u>Unbilled Authorized Consumption</u>
M^3/Year</td><td>Unbilled Metered Consumption</td><td rowspan="8"><u>Non-Revenue Water</u>
M^3/Year</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="6">Water Losses
M^3/Year</td><td rowspan="2"><u>Apparent Losses</u>
M^3/Year</td><td>Unauthorized Consumption ("stolen" water)</td></tr>
<tr><td>Metering Inaccuracies</td></tr>
<tr><td rowspan="4"><u>Real Losses</u>
M^3/Year</td><td>Leakage on Transmission Mains</td></tr>
<tr><td>Leakage and Overflow at Storage Tanks</td></tr>
<tr><td>Leakage on Distribution Mains</td></tr>
<tr><td>Leakage on Service Connections up to the point of Customer metering</td></tr>
</table>

Along with providing a structured approach to the issue of water balance form the perspective of a water loss control program, Figure 3-1 also reveals an important visualization of the volume of "non-revenue water" that makes up the total water balance.

Every unit of water volume has a cost associated with it. If that unit of water is not billed to a customer, then the cost of that unit of water must be borne by all the other customers that are billed. These ratios of revenue water to non-revenue water, or revenue water to **system input volume**, are important performance indicators when it comes to the financial sustainability of a water supply system.

3.3 Quantifying Water Losses and Non-Revenue Water

In Chapter 7 of this Manual of Practice, the user will be provided with the detailed guidelines and forms to conduct a **water balance audit** for a water supply system. In this chapter, it is the intent of the Manual to familiarize the user with the components of the water balance, as shown in Figure 3-1, and to describe a generalized approach to the quantification of water losses and non-revenue water. This generalized approach is explained in Table 3-1 below.

Table 3-1 Generalized Water Balance Calculation

Step	Action
1	Define System Input Volume, correct for known errors and enter in Col. A.
2	Define Billed Metered Consumption and Billed Unmetered Consumption in Col. D; enter total in Billed Authorized Consumption (Col. C) and Revenue Water (Col. E). Understandably, Billed Unmetered Consumption is an estimate based on consumption norms. These norms should be reconsidered periodically. *Billed Metered Consumption =* *Billed Metered Consumption + Billed Unmetered Consumption* *Revenue Water = Billed Metered Consumption*
3	Calculate the volume of Non-Revenue Water (Col. E) as System Input Volume (Col. A) minus Revenue Water (Col. E). Non-Revenue Water = System Input Volume – Revenue Water
4	Define Unbilled Metered Consumption and Unbilled Unmetered Consumption in Col. D; transfer total to Unbilled Authorized Consumption in Col. C. Here also, Unbilled Unmetered Consumption is an estimate based on consumption norms. Unbilled Metered Consumption = Unbilled Metered Consumption + Unbilled Unmetered Consumption
5	Add volumes of Billed Authorized Consumption and Unbilled Authorized Consumption in Col. C; enter sum as Authorized Consumption (top of Col. B). Authorized Consumption = Billed Authorized Consumption + Unbilled Authorized Consumption
6	Calculate Water Losses (Col. B) as the difference between System Input Volume (Col. A) and Authorized Consumption (Col. B). Water Losses = System Input Volume – Authorized Consumption
7	Assess components of Unauthorized Consumption and Metering Inaccuracies (Col. D) by best means available, add these and enter sum in Apparent Losses (Col. C). Apparent Losses = Unauthorized Consumption + Metering Inaccuracies
8	Calculate Real Losses (Col. C) as Water Loses (Col. B) minus Apparent Losses (Col. C). Real Losses = Water Losses – Apparent Losses
9	Asses components of real losses (Col. D) by best means available (night flow analysis, burst frequency/flow rate/duration calculations, modeling, etc.), add these and cross-check with volume of Real Losses in Col. C which was derived from Step. 8. Real Losses = Leakage on Transmission Mains + Leakage and Overflow at Storage Tanks + Leakage on Distribution Mains + Leakage on Service Connections up to the point of Customer metering

3.4 Calculation of Water Losses and Non-Revenue Water

The annual volume of water lost is an important indicator of water distribution efficiency, both in individual years, and as a trend over a period of years. High and increasing water losses are an indicator of ineffective planning and construction, and of low operational and maintenance activities.

In Chapter 1 of this Manual, water losses are defined as the sum of **apparent losses** and **real losses**. In this Chapter, the issues of apparent losses and real losses will be discussed further in the context of their impact on the water balance.

3.4.1 Apparent Losses

Apparent Losses are a function of unauthorized consumption and metering inaccuracies.
The influence of these subcomponents of apparent losses can be mitigated through a proper and constant management of the issue of unauthorized connections and in the running of an efficient maintenance system. The reduction of apparent losses is the least expensive solution to one component of the water loss management effort, and therefore, a utility should make every effort to have procedures and practices in place that minimize the volume of water that can be quantified as apparent losses.

Unauthorized consumption is normally the result of one of the following:

- Consumers are connected to the water system and are not recognized as customers of the water company

- Registered customers which by-pass the water meter and receive water that is not recorded as consumption.

The water company may use several approaches to reduce such losses. In conformity with the premise that every building unit in the service area receives water, the water company should check its records with the records of the civil status office (for identification of household customers); the records of other public services (such as the energy supply company); the records of the tax office (for identification of commercial and industrial customers); each of which may have a higher degree of accuracy as regards the population, building units, and businesses in the service area.

An additional measure is the conduct of physical inspections of the service area, especially on the new residential areas. These inspections should be undertaken on a regular basis, and performed according to an appropriate zoning of the service area. An approach requiring more effort is to conduct portable meter readings at the manhole where the customer's line connects to the supply main and compare these readings with the readings of the individual water meter installed on the same line.

3.4.2 Real Losses

Real losses are defined as the sum of leakage on transmission and/or distribution mains, leakage and overflow at storage tanks, and leakage on service connections up to the point of the customer's meter. The type of soil can influence the frequency of leaks and bursts, and the time lag between the occurrence of a leak and the visibility on the surface. However, correct selection and laying of pipe materials, as well as the application of modern leakage control methods can reduce these influences significantly.

Leakage management practice has demonstrated that it is impossible to eliminate real losses from a large distribution system. Therefore there must be some value of "**Unavoidable Annual Real Losses**" (UARL), which could be achieved at the current operating pressures if there were no financial or economic constraints. Under the conditions of a modernized distribution system, it is possible to employ infrastructure and pressure management options to reduce UARL.

Similarly, the losses resulting from overflows at service reservoirs can be reduced through undertaking management actions, such as installation of telemetry or altitude valves to avoid overflows.

3.5 Factors to Consider in Quantifying Water Losses

The best practice in management of water losses consists of a combination of continuous water balance calculations together with night flow measurements on a continuous or "as required" basis. The water balance, usually taken over a 12-month period, should include:

- a thorough accounting of all water into and out of a utility system, including inspection of system records;
- an ongoing meter testing and calibration program;
- due allowance for the time lags between production meter reading and customer meter reading

It is important to state that reliable metering of all water volumes must be an integral component of water supply, water demand management and loss determination. Metering of source meters for abstraction, treatment works production, imported and exported water, input volumes and inflows to sectorized distribution systems is essential for water balance calculations. Whenever actual metering is not possible, for example in activities such as fire fighting, flushing, etc., every effort should be made to estimate each component of water use accurately to determine realistic quantities for the water balance.

The water balance calculation quantifies volumes of total water into the system, authorized consumption (billed and unbilled, metered and unmetered) and water losses (apparent and real). Where continuous leak detection is not being practiced, the process may also include a benefit cost analysis for recovering excess leakage, leading to a leak detection program.

It is recognized that all water balance calculations are approximate to some degree, because of the difficulty of assessing all the components with complete accuracy. Best practice in the water industry is to assign confidence grades to each component of the water balance, incorporating both reliability and accuracy grading.

Exhibit B attached to this Manual provides an example of calculation of water balance components.

3.5.1 Component-Based Approach to Assessing Unavoidable Real Losses

In referring to Table 3-1, Step 9 of the process recommends that the volume of real losses calculated as the difference between total water losses and apparent losses should be checked, if possible, by assessing the individual components of real losses.

The following approach for the calculation of components of real losses, successfully used in a number of specific studies in different countries, considers real losses in three categories for modeling and calculation purposes:

- Background losses from undetectable leaks (typically low flow rates and long duration);
- Losses from reported leaks and bursts (typically high flow rates, short duration, moderate volumes);
- Losses from unreported bursts, (typically moderate flow rates but duration depending on the method and intensity of active leakage control);

Using this approach, it is possible to predict with reasonable overall accuracy, for each individual system, what the average UARL would be for various components of infrastructure at any specific pressure. Parameters which are required for these calculations are shown below in Table 3-2. Note that no allowance is given for service reservoir leakage or overflows, or for pipework located above ground.

Table 3-2 Parameters Required for Calculation of UARL

Component of Infrastructure	Background (undetectable) losses	Reported Bursts	Unreported Bursts
Mains	Length Pressure Min loss rate/km*	Number/year Pressure Average flow rate* Average duration	Number/year Pressure Average flow rate* Average duration
Service Connections Main to Edge of Street (Distribution Network)	Number Pressure Min loss rate/conn*	Number/year Pressure Average flow rate* Average duration	Number/year Pressure Average flow rate* Average duration
Service Connections after Edge of Street	Length Pressure Min loss rate/km*	Number/year Pressure Average flow rate* Average duration	Number/year Pressure Average flow rate* Average duration

* losses at some specific standard pressure.

3.5.2 Calculating Components of UARL

The parameter values used to calculate components shown in Table 3-2, above, for different sections of infrastructure are based on statistical analyses of international data, including 27 different water supply systems in 20 countries. The calculated values of these parameters of **UARL** for each component of infrastructure, are shown in Table 3-3 below.

Table 3-3 Calculated Components of UARL

Component of Infrastructure	Background Losses	Reported Bursts	Unreported Bursts	UARL Total	Units
Mains	9.6	5.8	2.6	18	Litres/km/mains/Day/ meter of pressure
Service Connections Main to Edge of Street (Distribution Network)	0.60	0.04	0.16	0.80	Litres/Connection/Day/meter of pressure
Service Connections after Edge of Street	16.0	1.9	7.1	25	Litres/km u.g. pipe/Day/ meter of pressure

The "**UARL Total**" values in the units shown above provide a rational and flexible basis for predicting UARL values for a wide range of distribution systems, taking into account all factors affecting real losses, i.e. continuity of supply, length of mains, number of service connections, location of customer meters on service connections and average operating pressure.

In the most basic form, the equation for the calculation of UARL in *litres/day* is:

UARL = (A x Lm + B x Nc + C x Lp) x P

Where

Coefficients for A, B, and C from Column "UARL Total" are:

A = 18
B = 0.80
C = 25

Lm (in km) is length of mains;
Nc is the number of service connections;
Lp (in km) is total length of service connections from the edge of the street to customer meters;
P (in m) is average operating pressure.

Alternatively, the equation for the calculation of UARL in *litres/service connection/day* is based on the following form of equation.

UARL = (A x Lm/Nc + B + C x Lp/Nc) x P

This approach recognizes separate influences of Real Losses from Lm, Nc, Lp and P when the system is pressurized.

3.5.3 Situations where UARL Calculations are Unlikely to be Valid

The basic assumption used in the UARL prediction may be may not be valid in situations where intensive active leakage control to locate unreported leaks is not possible, or not necessary. For example, in situations where pressures are significantly less than around 20 meters, sonic detection of hidden leaks may not be possible with some pipe materials and some depths of cover.

In some types of soil, where all significant leaks and bursts become rapidly visible at the surface, the values of Table 3-3 will over-estimate the attainable level of UARL, in the cases when there is good infrastructure, and rapid, good quality repair practice.

CHAPTER 4

4 PERFORMANCE INDICATORS

Performance indicators or performance measures have value to the water utility in two ways. When maintained systemically over time, they provide water utility management with a means of assessing progress in performance improvement of the utility. When shared with a group of utilities, they serve as a gauge as to how one water utility is doing in comparison to other comparable water utilities, so that the management can ask why differences exist and understand the practices of the other utilities that are achievingmore desirable performance .

Traditionally, when it came to water loss management, water utilities have applied performance indicators that reported losses as a percentage. However, since water utilities differ greatly in size, as well as in system and local characteristics, it is more relevant to make comparisons of performance in the management of water losses in terms of volume per year. When performance is measured in percentages, water utilities with lower demands will never be able to compete with those with larger demands. Instead, a performance indicator such as the volume of water loss per service connection per day is a more reliable and meaningful performance indicator.

When considering performance indicators related to water losses, it is appropriate to address both financial indicators and technical indicators.

4.1 Financial Performance Indicators

A good financial performance indicator should be expressed in cost terms. It can be calculated by placing appropriate monetary values, in local currency per cubic meter, on the annual volumes of:

- Unbilled Authorized Consumption,
- Apparent Losses, and
- Real Losses.

These three terms are the components of Non-Revenue Water discussed in Chapter 3 and shown in Figure 3-1.

When monetory values are considered, an appropriate value for Apparent Losses and Unbilled Authorized Consumption is usually the average <u>sale price of</u> water to customers. An appropriate value for Real Losses is the <u>unit cost of producing and pumping water,or the bulk water supply charge, whichever is higher</u>.

Since the sum of Apparent Losses, Unbilled Authorized Consumption, and Real Losses is equal to the volume of non-revenue water, then expressing this as a sum of the price orcost of their respective volumes results in the cost of Non-Revenue Water. This can then be simply expressed as a percentage of the annual operating costs of water supply:

$$\text{Non-Revenue Cost Ratio (\%)} = \frac{\text{Annual Cost of Non-Revenue Water}}{\text{Annual Operating Cost of the Water Supply System}} \times 100$$

Three additional financial indicators are presented below:

Unbilled Authorized Consumption Cost Ratio (%) = Annual Cost of Unbilled Authorized Consumption/ Annual Operating Cost of the Water Supply System.

Apparent Losses Cost Ratio (%) = Annual Cost of Apparent Losses/Annual Operating Cost of the Water Supply System.

Real Losses Cost Ratio (%) = Annual Cost of Real Losses/Annual Operating Cost of the Water Supply System.

This overview allows an individual water supplier to estimate what percentage of annual expenditure is attributed to each subcomponent of Non-Revenue Water.

4.2 Technical Performance Indicators

A good technical indicator measures the water utility's performance, taking into account both local influences and system design.

4.2.1 Influences on Real Water Losses

For each water supply system, there are several key local influences, which may constrain the possibilities for managing real water losses. These need to be recognized when selecting technical performance indicators that accurately measure the effectiveness of managing real losses. These factors may include:

- Number of service connections;
- Location of the customer meter on the service connection;
- Length of mains;
- Average operating pressure, when the system is pressurized;
- Percentage of time per year that the system is pressurized;
- Infrastructure condition, materials, frequencies of leaks and bursts;
- Type of soil and ground conditions, considering their influence on how quickly leaks and bursts will be detectable at the ground surface.

Research has clearly demonstrated that the overall leakage rates vary to a much greater extent than would be predicted by the theoretical 'square root' relationship between pressure and velocity (Bernoulli's Equation) This is because the effective area of some leakage paths varies with pressure. For large systems, the assumption of a square root relationship between pressure and leakage rate is an acceptable simplification.

4.2.2 Applying Technical Performance Indicators

When technical performance indicators are tested against the several key local factors that constrain management of real losses, "number of service connections" is a consistently useful technical performance indicator.

Basic technical performance indicators for water losses include:

- Technical Indicator for Real Losses (TIRL)

- Unavoidable Annual Real Losses (UARL) (see Chapter 3 for calculation)
- Infrastructure Leakage Index (ILI)

Each of these technical performance indicators is discussed in more detail below.

TIRL [expressed in *liters per connection/day in a* pressurized water system (w.s.p.)] is the technical performance indicator with the greatest range of applicability. It is calculated as follows:

$$\text{Technical Indicator for Real Losses (TIRL)} = \frac{\text{annual volume of Real Losses (l/day)}}{\text{number of service connections (no.)}}$$

TIRL may be influenced by operating pressure, location of customer meters, and low density of connections.

UARL is a prediction of real losses for any specific system if all infrastructure was in good condition (with active leakage control and expedient leak repair procedures). It takes account of length of mains, number of service connections, location of customer meters, continuity of supply, and average operating pressures (w.s.p.)
ILI is the ratio of TIRL to UARL, calculated for current pressures and continuity of supply (non-dimensional). ILI gives an indication of the current overall management of the infrastructure for leakage control.

The difference between TIRL and UARL represents the maximum potential for further savings in Real Losses (w.s.p). The concept of an ILI can be envisaged better from Figure 4-1 (see below) that shows the four components of leakage management. The large square represents the current annual volume of leakage tends to increase as the system grows older. However, this increase in leakage can be constrained by an appropriate combination of the four components of a successful leakage management policy. The small square represents the UARL - the lowest technically achievable vollume of real losses at the current operating pressure. The ratio of current annual real losses (the large square) to the UARL (the small square) is a measure of how well the three infrastructure management functions– repairs, pipe materials management, and active leakage control - are being controlled.

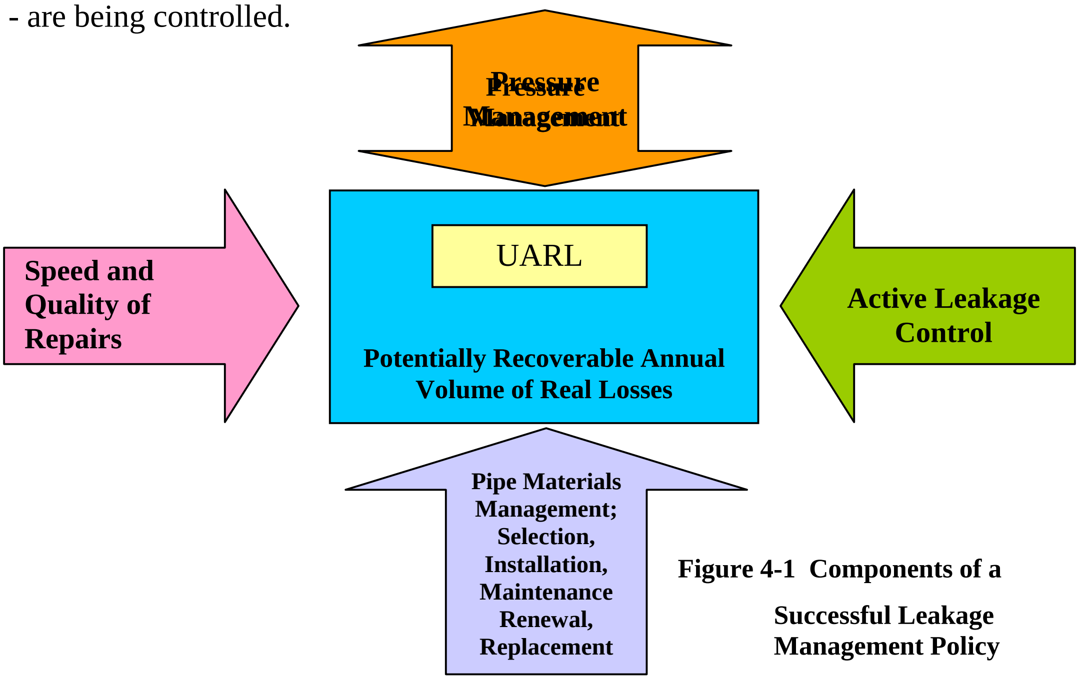


Figure 4-1 Components of a Successful Leakage Management Policy

The greater amount by which the ILI exceeds the value of 1.0, the greater the potential opportunity for further reduction of real losses by infrastructure management and maintenance, more intensive active leakage control, or speed and quality of repairs. Typically, it is only economical to achieve an ILI value close to 1.0, if water is very expensive, scarce, or both. Economic values of ILI depend on the system-specific marginal cost of real losses, and typically these lie in the range 1.5 – 2.5 for most systems, according to Western standards.

4.3 Example: Calculation of Performance Indicators

The following set of simple tables provides an example of how the water balance components, along with specific water system data, are used to calculate various technical and financial) performance indicators.

Table 1: Annual Input Volume to Water Balance is 38,000,000 m^3/year			
Re-group all components of Water Balance into one of the following:			
Billed Authorized Consumption (BAC)	Unbilled Authorized Consumption (UAC)	Water Losses Volume m^3/year	
		Apparent	Real
35,050,000	200,000	500,000	2,250,000

Table 2: Calculate Simple Financial Performance Indicators based on Valuation of Unbilled Water and Annual Cost of Operating Water Supply System						
Local Currency: USD Annual Cost of Operating Water Supply System = $US 45 million per Year						
Unbilled Volumes **From Table 1**	**m^3/year**	Unit value		**Valuation of Annual Losses**		% of Annual Operating Cost
		USD	m^3/year	USD	m^3/year	
UAC	200,000	2.7		540,000		**1.2**
Apparent Losses	500,000	2.7		1,350,000		**3.0**
Real Losses	2,250,000	0.15		337,500		**0.8**
Total Unbilled	2,950,000			2,227,500		**5.0**

Table 3: Calculate Average Daily Real Losses when system is pressurized, and Technical Indicator for Real Losses (TIRL)		
Annual Volume of Real Losses	2,250,000	m^3/year (from Table 1)
% of time system is pressurized	100	% of time per year
Average Daily Real Losses when system is pressurized	6,164	m^3/day when system is pressurized (w.s.p)
Number of Service Connections	57,510	
Technical Indicator Real Losses (TIRL)	107.2	liters/connection/day (w.s.p)

Table 4: Calculate Unavoidable Average Real Losses (UARL) and Infrastructure Leakage Index (ILI)				
Average Pressure (w.s.p.)			**35**	**Meters**
Density of Connections			39.4	connection per km of mains
Underground pipes if meters after edge of the street			633	km (at 11 m per connection)
Components of Unavoidable Average Real Losses (UARL)				
1485	Km mains	18	26,244	liters/day/m pressure (w.s.p.)
57,510	Connections	0.80	46,008	liters/day/m pressure (w.s.p.)
633	Underground pipes	25	15,825	liters/day/m pressure (w.s.p.)
Unavoidable Average Real Losses (UARL)			**88,077**	liters/day/m pressure (w.s.p.)
UARL at average pressure of 35 meters			**3,082,695**	liters/day (w.s.p)
UARL in same units as TIRL			**53.6**	liters/conn./day (w.s.p.)
Technical Indicator Real Losses (TIRL)			**107.2**	liters/conn./day (w.s.p.)
Infrastructure Leakage Index (ILI = TIRL/UARL)			**2.0**	

CHAPTER 5

5 PRESSURE MANAGEMENT AND REAL LOSS REDUCTION

Many water distribution systems are designed with minimum pressure requirements as design criteria, but not with maximum pressure limitations. The result is that there are many systems with service areas which are significantly over-pressured. Obviously, not all systems can tolerate pressure reduction and indeed many systems suffer from lack of pressure; however, there are still many utilities that are operating at pressures in excess of those required, which would benefit greatly from a pressure management scheme.

This chapter provides a summary overview of pressure management and its relationship to water loss. It also provides brief discussions of pressure management techniques that can be applied to a water supply system. Water utilities that feel that a pro-active pressure management program would benefit their systems are advised to do further research into the literature that exists on this subject and to speak with equipment suppliers of pressure control equipment.

5.1 Issues Related to Pressure, Leakage and Demand Management

The reduction of leakage is a subject which is on the minds of most water utility engineers and managers throughout the world. Pressure management is one of several actions that utility managers can consider to address leakage reduction. Recent studies and research have shown that both leakage volume and new leakage frequency are reduced greatly by the reduction and stabilization of pressure within a distribution system.

In addition to leakage reduction, pressure management can also contribute to demand management. This results from the fact that end users not only consume water by volume, but also by duration. For example, if a person normally takes five minutes to brush his teeth, and leaves the water running continuously for those five minutes, then less water will be consumed at a lower pressure. Although this does have an impact on revenues - less water used therefore less water sold - the reduced revenues are usually far outweighed by the savings in new capital expansion to provide the additional volume needed at the higher pressure.

5.2 Pressure Management and Efficient Distribution of Water

Pressure management is not only about pressure reduction but also in some cases about increasing pressure, sustaining pressure, surge control, and level management.

The implementation of pressure management schemes can assist utility operators in ensuring that reservoirs and storage tanks remain at realistic levels to meet demands. Level control also ensures that storage is not allowed to overflow during off-peak hours when system demand and headloss is low and pressures are highest. Reservoir overflows can form a large part of a utility's water loss, if not properly controlled.

Hydraulic impact, surge, and transient waves are caused by quick changes in system conditions. The abrupt opening and closing of valves in the systems by system operators or by large users will cause transient waves to travel backwards and forwards in the system, potentially causing damage at any week point. By applying simple pressure management schemes or pressure reducing devices, the negative effects of transient waves can be greatly reduced or eliminated.

5.3 Potential Concerns Related to Pressure Management Schemes

Although there are many proven benefits to a pressure management scheme, it can also be shown that a poorly implemented program may also cause problems of its own. When a utility is considering a pressure management scheme for the first time, it should consider the following issues:

- Fire flow needs
- Loss of revenue
- Reservoir filling

5.3.1 Fire Flow Needs

In any pressure management scheme to reduce water loss through leakage, care must be taken to always be aware of the water supply system needs during fire flow conditions. The need for the pressure management scheme to be able to adjust to the large flow demands for fire fighting is critical. Therefore the pressure management technology must be fail-proof in this regard.

5.3.2 Loss of Revenue

As far as the loss of revenue is concerned, systems with high leakage will almost always see a positive benefit from pressure management, even when assessed against the potential loss of revenue, due to reduction of pressure in residences and industry. Any lost revenue is included in the cost-to-benefit calculations as a cost against the project, just as installation and product costs are. This is also true for systems with lower losses and high costs to produce or purchase water. In situations where a loss of revenue cannot be tolerated, pressure management can be limited to nighttime hours, when legitimate consumption is at its lowest and system pressures are at their highest.

5.3.3 Reservoir Filling

Since operating a water supply systems at reduced system pressure can run the risk of not filling reservoirs at night, many pressure reduction programs concentrate on the smaller mains, therefore allowing reduction of losses in selected areas, while allowing normal system pressure in the larger trunk or transmission lines. This is particularly important in pumped systems, where the storage tanks balance on the system pressure; gravity systems are less affected in this way.

5.4 Types of Pressure Management Actions

Some of the most common forms of pressure management are discussed below.

5.4.1 Sectorization

Sectorization is one of the most basic forms of pressure management but it is also very effective. The distribution system is divided into sectors either naturally by isolating sectors from one another, or by physical valving to create isolated sectors. The sectors are usually selected to be quite large and often have multiple feeds, so they do not usually develop localized hydraulic problems because of valve closures. Gravity systems are usually sectorized by relative ground elevation, while pumped systems are usually sectorized based on the elevation of ground level or elevated storage tanks.

Sectorization in its simplest form does not require the implementation of costly automatic control values and controllers, but it is often not completely efficient without them. Many systems that have had sectorization schemes in place for many years are finding that it is cost-effective to implement more advanced controls in addition to the basic controls already in place.

5.4.2 Pump Control

Pump control is another method of controlling system pressure. For fixed speed pumps, the pumps are activated or deactivated depending on system demand. This method is effective if the reduced level of pumping (usually at night) can still maintain reservoir levels. Caution should be used in the throttling of upstream valves on fixed speed pumps as a pressure management technique, since it may cause the pumps to have to operate outside their design profile. Conversely, variable speed drives on pumps can provide a very effective system of pressure management.

5.4.3 Throttled Line Valves

Many system operators recognize the value of reducing system pressure and will partially close a gate or butterfly valve to create a headloss to reduce pressure. This method may seem quick and inexpensive, but it is least effective since the headloss created will change as system demand changes. What results is that at night when the distribution system needs the least pressure, the pressure will be higher, and during the day, when the distributions system needs the most pressure to supply demand, the pressure will be lower. This creates a classic case of an upside-down pressure zone.

5.4.4 Automatic Control Valves – Fixed Outlet

Automatic control valves are a traditional method of control and use a basic hydraulically operated control valve. The fixed-outlet control valve method is effective for areas with low head-losses, demands which do not vary greatly with the seasons, and uniform supply characteristics. Fixed outlet control in other areas may be inefficient, as outlet pressures have to be set high enough to meet minimum pressures during peak demand. As system demand falls, usually at night, the headlosses in the system fall and system pressure returns toward the static pressure, which in many cases is far in excess of that required to meet nighttime demand plus fire demand.

5.4.5 Overflow Control

Although not an issue of pressure management directly, it is important to consider level management in reservoirs, tanks and storage in the context of loss control and reduction. Water loss from overflows in storage facilities is too often overlooked as it is deemed not to be significant, and often tanks are in out-of-the-way locations and therefore overflows are not always evident.

Overflows can be controlled by manual pump control, automatic controls using sensors and computers, or by simple hydraulic control, using either altitude valves or ball valves. Utilities should routinely monitor the overflow pipes on their tanks and reservoirs to determine if they are experiencing overflows. If they are, they should take immediate action to determine the amount and frequency of overflows, and the cost-benefit of investing in some level of overflow control.

5.5 Pressure Monitoring

For any pressure management project, it is necessary to monitor the water supply system pressure, as a minimum, at the following points:

- *Supply Nodes* – points which supply a system or subsector of a system. Supply nodes may also be an outlet point from one zone to another. In some cases, it may be necessary to monitor bi-directional flows.

- *Storage Nodes* – includes any reservoir, tank, standpipe, or location where water is stored.

- *Critical Nodes* – points where supply may be at it weakest, such as a high level within the system or a point where there is high headloss in the supply pipe, or alternatively where a user cannot be left without supply such as a manufacturing facility or a hospital.

- *Estimated Average Nodes* – location that is chosen to be representative of average conditions within the system or zone.

Pressure should be measured on a continuous basis with a reasonably high resolution data logger.

CHAPTER 6

6 PURPOSE OF WATER AUDITS AND LEAK DETECTION

A water audit, followed by a leak detection program, can help water utilities reduce non-revenue water and make better use of water resources. The two following chapter of this manual include techniques for conducting water audits and leak detection surveys of piped, pressurized, potable water distribution systems. Major features of the manual are:

- Step-by-step procedures for conducting a comprehensive, system-wide water audit to assess the delivery efficiency of a distribution system.
- A worksheet and sample forms for each step of the audit.
- Specific techniques to identify, measure and verify all water sources, uses and losses.
- A procedure and form to calculate increased revenues as a result of testing and repair of large meters.
- Suggestions for correcting problems in a water system.
- A tool to determine whether or not a leak detection project will be cost-effective, the length of time needed to perform a leak detection survey, and what equipment is needed.
- Step-by-step procedures for conducting a comprehensive leak detection project to locate non-visible underground leaks.
- Forms to record information from surveying the distribution system, pinpointing leaks, estimating leak losses, and documenting costs of survey and repair.
- A procedure and forms to evaluate the cost-effectiveness of the leak detection project.

6.1 What Is a Water Audit ?

A water audit identifies how much water is lost and what that loss costs the utility. The overall goal of the audit is to help the utility select and implement programs to reduce distribution system losses.

To conduct a water audit, it is necessary to:

- Verify and update system maps.
- Test master and source meters.
- Verify and update source records for inflow, metered use (such as billing information), and unmetered use (including estimates for parks, community centres, government facilities, and fire fighting).
- Test residential, commercial, and industrial meters for accuracy.
- Inspect water measuring devices for proper sizing, installation and operation.
- Field-check distribution controls and system operating procedures.

Any of these tasks may be performed by utility staff, consultants, or both.

Water audits should be performed annually to help managers adjust priorities, monitor progress, identify new areas of system losses, and establish new maintenance goals. Updating a water audit is usually less expensive than the original audit. Utilities may also wish to consider a system of continuous monitoring to target leak detection efforts.

6.2 Cost of Water Audit

The cost of a water audit is the sum of in-house work and field work. Total cost depends on the size of the service area to be audited; the completeness, currency and accuracy of the utility's records, including meter-testing programs and records; and the extent to which utility staff or consultants are used to conduct the audit.

The most expensive task in a water audit is testing large meters. The audit's total field cost depends on the number of meters that must be tested to provide data for the entire system.

6.3 What Is Leak Detection?

Leak detection is a survey of the distribution system to identify leak sounds and pinpoint the exact locations of hidden underground leaks.

6.4 Cost of Leak Detection

The cost of leak detection includes the costs of equipment and personnel. A crew is needed to survey the system and personnel are also needed to pinpoint leaks, estimate water losses, and provide documentation. The cost of a leak detection crew depends on whether the utility uses its own staff, a consultant, or both.

Leak detection costs include a several to include: salaries for leak detection crews, the sue of consultants; the number of contact points to be surveyed, spacing of contact points to be surveyed, types of mains and services, accuracy of maps, and the type of leaks to be pinpointed.

Leak repair costs are not considered as direct cost of a leak detection program. Since leaks are continually discovered and repaired in the normal course of the utility's operations, leaks found by the leak detection program would eventually be repaired at some time in the future, sometimes under emergency conditions.

6.5 Benefits of Water Audits and Leak Detection Programs

Water audits and leak detection programs can achieve substantial benefits, including the following:

- **Reduced water losses.** Water audits and leak detection are necessary first steps in a leak-repair program.

- **Financial improvement.** A water audit and leak detection program can increase revenues from customers who have been undercharged, lower the total costs of wholesale supplies and reduce treatment and pumping costs. Repairing leaks saves money for the utility through reduced power costs to deliver water and reduced chemical costs to treat water.

- **Increased knowledge of the distribution system.** During a water audit, distribution personnel become more familiar with the distribution system, including the location of mains and valves. This familiarity helps the utility to respond quickly to emergencies, such as main breaks, and develop the missing technical documentation.

- **More efficient use of existing supplies.** Reducing water losses helps stretch existing supplies to meet increased needs. This could help defer the construction of new water facilities, such as new wells, reservoirs, or treatment plants.

- **Safeguarding public health and property.** Improved maintenance of a water distribution system helps reduce the likelihood of property damage and safeguards public health and safety.

- **Improved public relations.** Consumers appreciate maintenance of the water system. Field teams doing the water audit and leak detection, or repair and maintenance work, provide visual assurance that the system is being maintained.

- **Reduced legal liability.** By protecting public property and health, and providing detailed information about the distribution system, water audits and leak detection programs help protect the utility from expensive lawsuits.

- **Reduced disruption to customers.** More leaks are repaired on a planned basis rather than developing into major breaks that disrupt service.

CHAPTER 7

7 CONDUCTING A WATER AUDIT

This chapter outlines the basic steps involved in conducting a water audit (see Figure 7-1). Instructions for accomplishing each step are included. In some cases, more than one method is described for accomplishing a particular step, thus allowing for the various configurations of water systems. Each water supplier may choose the technique best suited to the system under study.

7.1 Before Starting

A number of decisions should be made before beginning a water audit. While discussion of all factors is beyond the scope of this book, three factors that influence the reliability of the study are discussed in the following paragraphs.

7.1.1 Water Audit Worksheet

A sample water audit worksheet is included in this chapter (Figure 7-2). This chapter describes each step of the audit, including what information is needed, how to get that information and how to enter it on the worksheet. Examples accompany the instruction to show how the data are gathered and how they are entered on the worksheet. Instructions for entering information on the worksheet appear in blue.

7.1.2 Set a Study Period

A water audit is a study over time. Choose a time period that allows analyses and evaluation of total system water use. One month or even six months is too short a time to give an overall picture of water flow through the system (see Figure 7-3). A 12-month study period is recommended. Most utility records are kept by the calendar or fiscal year; either system makes 12 months of data available. However, a calendar year is recommended to reduce the effects of lag time in meter reading and it is long enough to include seasonal variations. An example of annual water distribution is shown in Figure 7-3 below.

7.1.3 Choose a Unit of Measure

The same unit of measure should be used throughout the water audit. Choose a unit of measure that suits the utility and use the same unit of measure throughout the audit.

In this manual, the unit of measure is cubic meter (m3).

After establishing the water audit's official unit of measure, note the unit of measure used on each measuring device. Also note the conversion factor to be used when reading the device.

Figure 7-1 Basic Steps in Conducting a Water Audit

Before the Audit

A. Establish a worksheet
B. Set a study period
C. Choose an official unit of measure

The Audit

Task 1 – Measure the System Input Volume

1. Identify and map sources
2. Measure the water from each source
3. Adjust figures for total supply

→

Task 2 – Measure Unbilled Authorized Metered Consumption

1. Identify metered uses
2. Measure metered use
3. Adjust figures for metered use

→

Task 3 – Measure Unbilled Authorized UnMetered Consumption

1. Identify unmetered uses
2. Estimate unmetered use

→

Task 4 – Measure Water Losses

1. Identify potential water losses
2. Estimate losses by type

→

Task 5 – Analyze Audit Results

1. Identify recoverable leakage
2. Figure the value of recoverable leakage
3. Figure the cost of recovering leakage
4. Calculate the cost of leak detection

After the Audit

A. potential corrective measures
B. Update the audit. Analyze the value of non-revenue water and corrective measures
C. Evaluate
D. Update the master plan

Figure 7-2 Water audit worksheet

	WATER AUDIT WORKSHEET					
Utility:	Public Communal Company “Water and Sewer Works” Bar	Audit Study Period:		01 Jan 2003	to	31 Dec 2003
				Water Volume		
				Total		
Line	**Item**	**Subtotal**		**Cumulative**		**Units***
Task 1 -	**Measure the Supply**					
1	Uncorrected total water supply to the distribution system (total of master meters)					
				13,901,352		m3
2	Adjustment to total water supply					
2A	Source meter error (+ or -)	313,810				m3
2B	Change in reservoir and tank storage (+ or -)	3,142				m3
2C	Other contributions or losses	0				m3
3	Total adjustment to total water supply (add lines 2A, 2B, and 2C)					
				316,952		m3
4	Adjusted total water supply to the distribution system (add lines 1 and 3)					
				14,218,304		m3
Task 2 -	**Measure Authorized Metered Use**					
5	Uncorrected total metered water use	12,332,833				m3
6	Adjustments due to meter reading lag time (+ or -)					
		757				m3
7	Metered deliveries (add lines 5 and 6)			12,333,590		m3
8	Total sales meter error and system-service meter errors (+ or -)					
8A	Residential meter error	508,493				m3
8B	Large meter error	113,448				m3
8C	Total (add lines 8A and 8B)			621,941		m3
9	Corrected total metered water deliveries (add lines 7 and 8C)					
				12,955,531		m3
10	Corrected total unmetered water (subtract line 9 from line 4)					
				1,262,773		m3
	* Units of measure must be consistent throughout the worksheet.					

Line	Item	Subtotal	Water Volume Total Cumulative	Unit*
Task 3 -	**Measure Authorized Unmetered Use**			
11A	Firefighting and firefighting training	36,718		m3
11B	Main flushing	6,057		m3
11C	Storm-drain flushing	1,893		m3
11D	Sewer cleaning	2,461		m3
11E	Street cleaning	6,624		m3
11F	Šchools	0		m3
11G	Landscaping in large public areas:			
	Parks	151,416		m3
	Golf courses	454,248		m3
	Cemeteries	11,356		m3
	Playgrounds	20,441		m3
	Highway median strips	2,461		m3
	Other landscaping	1,893		m3
11H	Decorative water facilities	0	(metered)	m3
11I	Swimming pools	0	(metered)	m3
11J	Construction sites	0	(metered)	m3
11K	Water quality and other testing (pressure-testing pipe, water quality, etc.)	0	(metered)	m3
11L	Process water at treatment plants	265		m3
11M	Other unmetered uses	0		m3
12	Total authorized unmetered water (add lines 11A through 11M)		695,833	m3
13	Total water losses (subtract line 12 from line 10)		566,940	m3

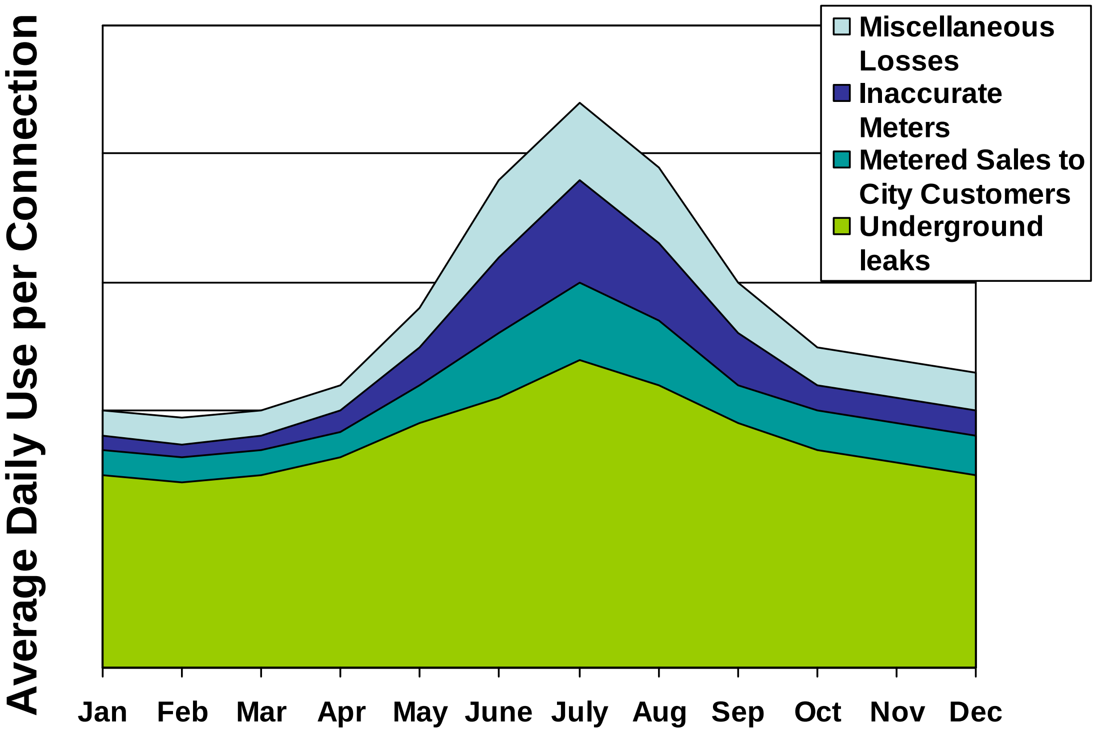
* Units of measure must be consistent throughout the worksheet.

			Water Volume	
			Total	
Line	**Item**	**Subtotal**	**Cumulative**	**Unit***
Task 4 -	**Measure Water Losses**			
14A	Accounting procedures errors	44,024		m3
14B	Unauthorized connections	1,249		m3
14C	Malfunctioning distribution system controls	0		m3
14D	Reservoir seepage and leakage	265		m3
14E	Evaporation	37,021		m3
14F	Reservoir overflow	0		m3
14G	Discover leaks	82,825		m3
14H	Unauthorized use	0		m3
15	Total identified water losses (add lines 14A through 14H)			
			165,384	m3
Task 5 -	**Analyze Audit Results**			
16	Potential water system leakage (subtract line 15 from line 13)			
			401,556	m3
17	Recoverable leakage (multiply line 16 by 0.50)			
			200,778	m3
Line	**Item**	**€ / m3 (Euro per Unit of Volume)**		
18A-B	Cost savings			
18A	Cost of water supply	0.15		€ / m3
18B	Variable operation and maintenance costs	0.03		€ / m3
19	Total costs per unit of recoverable leakage (add lines 18A and 18B)			
		0.18		€ / m3
Red	**Item**	**Euro per year**		
20	One-year benefit from recoverable leakage (multiply line 17 by line 19)			
		36,140		€ / year
21	Total benefits from recovered leakage (multiply line 20 by 2)			
		72,280		€ / year
22	Total costs of leak detection project	19,850		€ / year
23	Benefit-to-cost ratio (divide line 21 by line 22)			
		3.64		

Prepared by:	Title :
	Date :

* Units of measure must be consistent throughout the worksheet

Figure 7-3 One calendar year is recommended for the audit study period



7.2 Instructions for Water Audit Worksheet filling

7.2.1 Task 1 – Measure the System Input Volume

This task tells how much water enters the distribution system and where it comes from.

Step 1-1 Identify and Map Sources

1-1A Identify Sources. Identify all water sources that supply the distribution system, including interconnections with other systems and intermittent sources or emergency supplies. Make a list of these sources.

1-1B Map the System. Find an existing map of the distribution system. The map should show the principal mains of the entire delivery system. A scale of 1:5,000 makes the map legible and easy to work with.

If no map of the distribution system exists, use aerial photos or a municipal map and draw the distribution mains on a transparent overlay. If no suitable map can be found, a hand-drawn one can be used.

1-1C Plot the Sources. First, choose a symbol to represent each type of water source, including aqueduct turnouts: wells; surface diversions, such as lakes, streams or reservoirs; interconnections;

and emergency sources. Then, draw the symbol on the map according to where the source is located.

Step 1-2 Measure the Water from Each Source

1-2A Identify Measuring Devices. Visit each source and note what type of measuring device is used (for example, meter, Parshall flume, weir, or stream gauge). Note basic information about the measuring device, including the type, identification number, frequency of reading, type of recording register, unit of measure (and conversion factor, if necessary), multiplier, date of installation, size of conduit, frequency of testing and date of last calibration. Using that information, create a table similar to Table 7-1.

Table 7-1 Source Measuring Devices for the Water Company

Source Information	Water Sources		
	Source 1	**Source 2**	**Source 3**
Type of Measuring Device	Venturi	Propeller	Venturi
Identification # /Serial #	0000278-A	8759	OC-16
Frequency of Reading	Daily	Weekly	Daily
Type of Recording Register	Dial	Dial	Builder Type M
Units Registers Indicate			
Multiplier (if any)	1.0	1.0	100.0
Date of Installation	1993	1987	1998
Size of Conduit			
Frequency of Testing	Annual	2 Years	4 Years
Date of Latest Calibration	22/07/95	16/11/99	30/06/02

1-2B Record Total Water from Each Source. Record how much water was produced by each source for each month and for the entire audit period (see Table 7-2).

Table 7-2 Total Water Supply for Water Company (uncorrected)*

Month*	Sources (1000 m3)			
	Source #1	**Source #2**	**Source #3**	**Total**
January	0	130.34	104.27	234.61
February	0	195.51	65.17	260.68
March	0	260.68	0	260.68
April	130.34	130.34	0	260.68
May	265.57	97.76	0	363.33
June	299.78	0	81.46	381.24
July	303.04	0	84.72	387.76
August	325.85	0	89.61	415.46
September	293.27	32.59	32.59	358.45
October	130.34	32.59	07.76	260.69
November	130.34	0	130.34	260.69
December	130.34	0	97.76	228.10
Yearly Total	2,008.87	879.81	783.68	3,672.36**

* Study period is one calendar year.

** Note that this is an uncorrected figure; if necessary, it will be adjusted.

Most meters have some type of register, or totalling device. Registers may be round-reading or direct-reading. Round-reading registers have a series of small dials with pointers, registering volume in tens, hundreds, thousands, and ten thousands. Direct-reading registers have one large sweep hand for testing and a direct-reading dial that shows total units of volume.

Calculate the total water produced from all water sources during the study period. Enter the amount on Line 1 of the worksheet.

Step 1-3 Adjust Figures for Total Supply

Figures for the total water supply, based on readings from source meters and measuring devices, are raw data. The raw data must be adjusted for a number of factors, including (1) meter inaccuracies, (2) changes in reservoir and storage levels, (3) non-metered sources, and (4) losses that occur before water reaches the distribution system. These adjustments are made in the steps described below; they are recorded on lines 2A, 2B, and 2C on the worksheet.

1-3A Verify Meter Accuracy. Although most production sources are measured by meters, some are measured by other devices, such as Parshall flumes or weirs. Supply figures (like those used in Table 2-2) are based on readings of these measuring devices. Any error in any measuring device must be discovered and corrected; incorrect supply data invalidates the entire water audit.

To be sure meters are accurate; compare the results of meter tests to applicable standards of measurement. If a meter measures incorrectly and the error exceeds the standard for its category, repair and recalibrate the meter to function within standard limits. If a meter has not been tested within the last 12 months, test the meter.

- ***Possible causes of meter error.*** If source meters are inaccurate, inspect each one in the field. Normal wear Is not the only cause of inaccurate meter readings. Check to be sure the meter is the right type and size for the application and that it is installed correctly. Check the size against manufacturers' recommended ranges. Be sure the meter is level; most meters are not designed for sloped or vertical operation. Inspect the meter to see if hard-water encrustation is interfering with its measurement.

  Also check to verify that the proper registers were selected and installed correctly. Have an employee other than the regular meter reader make a special reading of master meters, or have an employee accompany the meter reader to verify sample readings. Check to be sure the meter is read correctly, recorded correctly, and the correct conversion factor is used.

- ***Check venturi meters.*** Check venturi meters for blockages in the throats of the meters. Test the primary device with a pitot rod. Testing the meter with a pitot rod shows whether or not the installation is adequate for nonturbulent flows. The meter's primary device should be tested at different flow ranges. If pressure deflection for appropriate flows is adjusted without checking the venturi itself, the meter may still record flows erroneously.

- ***Testing meters.*** There are four ways meters may be tested. Meter testing methods are listed here in order of effectiveness, with the most effective first.

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

2. Compare meter readings with readings of a calibrated meter installed in series with the original meter.
3. Record meter readings for a given flow over a specified time period. Remove the meter and replace it with a calibrated meter. Record readings from the calibrated meter for the same flow over the same period; compare the readings.
4. Test the meter at a meter testing facility.

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

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

1-3B Adjust Total Supply Totals. Adjust the monthly and annual supply data from Table 7-2 for meter error. To do this, divide the uncorrected metered volume (UMV) by the measured accuracy of the meter (a percentage expressed as a decimal) and subtract the UMV as follows:

$$\frac{\text{Uncorrected Meter Volume}}{\text{Percent Accuracy}} - \text{Uncorrected Meter Volume} = \text{Corrected Meter Volume} \quad \text{(Eq. 7-1)}$$

Table 7-3 shows how to adjust the supply totals from Table 7-2 to yield the adjusted measurements.

Table 7-3 Total Water Supply for Water Company (adjusted for meter error)

Source	Yearly Total Uncorrected UMV	Meter Accuracy (percent) MA	Meter Error Calculation $\frac{UMV}{MA} - UMV$	Meter Error m3	Corrected Metered Volume m3
1	2,008.87	95	(2,008.87/0.95)-2,008.87	+105.73	2,114.60
2	879.81	100	(879.81/1.00) – 879.81	+00.0	879.81
3	783.68	103	(783.68/1.03) – 783.68	-22.83	760.85
Total Adjustment				**+82.90***	

* Note: The new total is not recorded on the worksheet – the "total adjustment due to meter error" is.

Enter the total adjustments due to meter error on line 2A of the worksheet.

1-3C Adjust Reservoir and Tank Storage. If source meters are located upstream of reservoirs and storage tanks, then stored water must be accounted for in the water audit. Generally, water flowing out of storage is replaced; as the “replacement” water flows from the source into storage, it is measured as supply into the system. If the reservoirs have more water at the end of the study period than at the beginning, then the increased storage is measured by the source meters but not delivered to consumers. Such increases in storage should be subtracted from the metered supply.

Conversely, if there is a net reduction in storage, then the decreased amount of stored water should be added to the metered supply. Table 7-4 shows how to calculate the change in storage volume.

Table 7-4 Changes in Reservoir Storage (m3)

Reservoir	Start Volume	End Volume	Change in Volume
Apple Hill	32,350	36,270	+3,920
Eagle Mountain	278,100	240,600	-37,500
Rock Road	978,400	318,400	-660,000
Tall Tree Village	187,300	55,300	-132,000
Total Change in Reservoir Storage			**-825,580***

*Note: *Decreases* in storage are *added* to the supply; storage *increases* are *subtracted* from the supply.

Enter the total changes in reservoir and tank storage on Line 2B of the worksheet.

1-3D Other Adjustments. Some water supplies may be subject to other types of contributions or losses. For example, there may be an additional source that enters the water supply system between the source meter and the finished water system. This could result from infiltration into an open channel. Likewise, losses may be introduced through an unlined or open channel. These additions or losses should be accounted for as "other contributions or losses" on the worksheet.

Enter other contributions or losses on Line 2C on the worksheet.

Remember: Always use the same unit of measure.

Add lines 2A, 2B, and 2C; enter the sum on line 3 of the worksheet.

Add line 3 to line 1; enter the sum on line 4 of the worksheet.

7.2.2 Task 2 – Measure Authorized Metered Consumption

Authorized water is any water used for all uses approved by the utility. Most authorized consumption is metered, but some is not. Metered water, usually sold to consumers, includes industrial, commercial, residential, agricultural, governmental, and other uses. Unmetered water is used for irregular or mobile public purposes, such as street cleaning or fire fighting. All unmetered uses should have meters installed, if possible.

This task tells how much water goes to metered deliveries. The next task discusses unmetered deliveries.

Remember: To be accurate, the water audit must be consistent. Be sure to use the same 12-month study period and the same unit of measure for studying consumption as was used to study supply.

Step 2-1 Identify Authorized Metered Consumption

2-1A Identify Authorized Metered Accounts. Identify all users who should have meters. Accounts can be identified by meter serial number, connection number, assessor's parcel number, street address, or account number. Assign each account to a meter-reading route.

Be sure to include all accounts for which data on metered use are available, even if the account is not billed. Remember, also, to take into account water provided to other agencies.

2-1B Describe Meters. For all active accounts, list meters according to identification number and size of meter. Sort meters by type of use, including industrial, commercial, residential, agricultural, wholesale transfers, and other. This can help to identify accounts that represent larger volumes of sales and, therefore, greater potential earnings (see Table 7-5).

Table 7-5 Water Consumption by Meter Size

Meter Size	Number of Meters	Percent of Total Meters	Percent of Total Consumption
5/8	11,480	94.10	70.1
¾	10	0.08	0.1
1	338	4.40	2.8
1 ½	124	1.00	2.8
2	216	1.80	11.7
3	15	0.12	6.4
4	7	0.05	2.0
6	6	0.05	2.5
Total	12,196	100.00	100.00

Check carefully to be sure all information is correct. Consider the possibility of accounting procedure errors, improper computer programming, incorrect meter reading, and unauthorized use. When data on metered use are unavailable or incorrect, water losses are possible. Task 4 gives methods for estimating potential water losses due to incorrect data on metered use.

Step 2-2 Measure Authorized Metered Consumption

2-2A Figure Total (uncorrected) Water Consumption for Each Size of Meter. Add the water consumption for all accounts and connections for each size of meter by month (or other billing period) and for the entire study period (see Table 7-6).

Calculate the total water consumed through all meters during the audit period. Enter the amount on Line 5 of the worksheet.

Remember: Use the same unit of measure that was used for measuring supply in Task 1.

2-2B Adjust for Lag Time in Meter Readings. Corrections must be made to metered use data when the source-meter reading dates and the customer-meter reading dates do not coincide with the beginning and ending dates of the audit study period.

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

- **Source meters.** No correction is made for source meters, because their reading usually occurs on the days that the study period begins and ends. If the last reading (December 31) was a day late (January 1), then the water supplied for January 1 should be subtracted from the total water use read.

- **Customer meters.** Because customer meter readings do not coincide neatly with the study period, a correction must be made. The best way to account for changes in the number of customers and in use patterns is to prorate water use for the first and last billing within the study period.

  The first billing period has only 10 days that actually occur in the study period. Yet the billing information represents 31 days of use. If sales for that December 11 through January 10 period are 125.690 m3, the amount applicable to the study period is

  $$125.690 \text{ m3} \times \frac{10 \text{ days}}{31 \text{ days}} = 45.545 \text{ m3} \qquad \text{(Eq 7-2)}$$

  Thus, only 45.545 m3 of the use read on January 10 applies to the study period.

  At the end of the study period, there are 21 days not included in the billing data collected on December 10. Use for the last 21 days in December is obtained from the following month's billing. If sales for that month are 138.773 m3, the amount applicable to the study period is

  $$138.773 \text{ m3} \times \frac{21 \text{ days}}{31 \text{ days}} = 94.007 \text{ m3} \qquad \text{(Eq 7-3)}$$

  Thus, 94.007 m3 is added to the use read on December 10.

Table 7-6 Total Authorized Metered Water Consumption (m3)

Month	Residential	Industrial	Commercial	Agriculture	Total
January					
February					
March					
April					
May					
June					
July					
August					
September					
October					
November					
December					
Total					

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

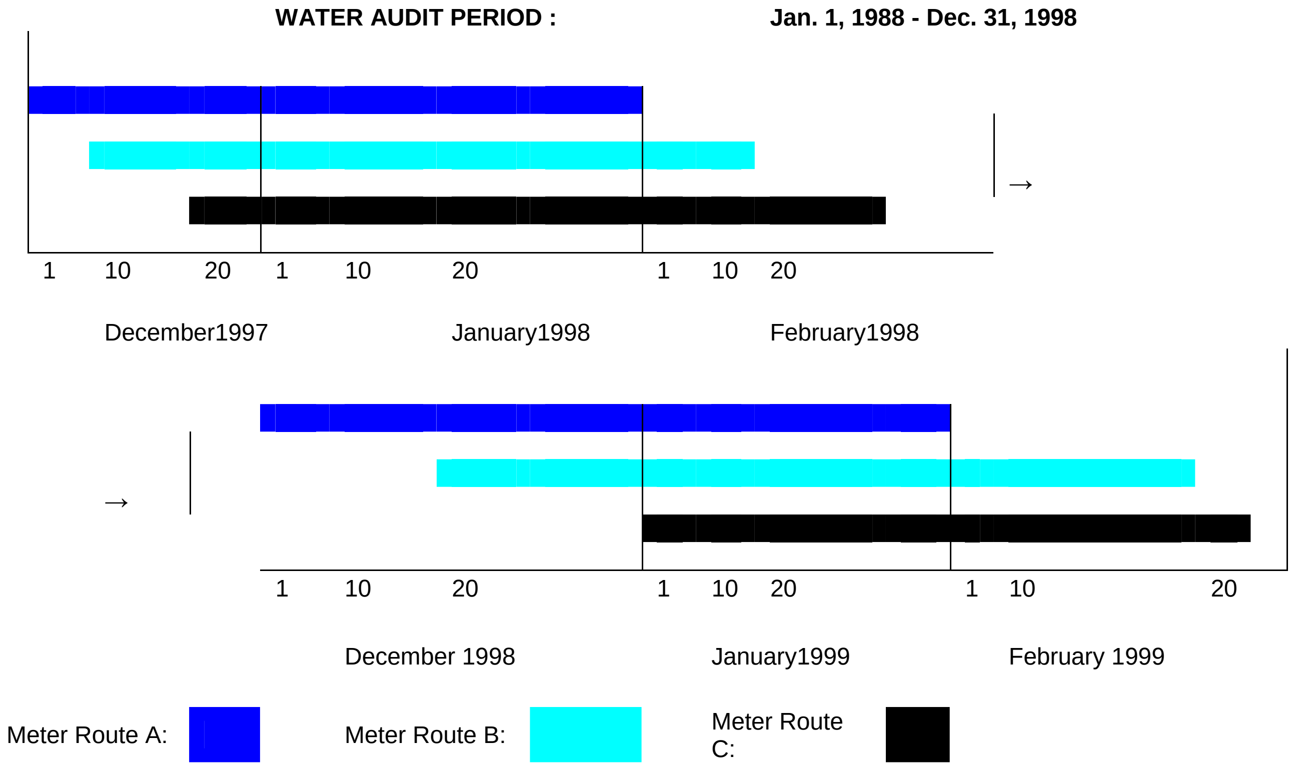
  A meter lag correction can involve a number of steps. In our example, County Water Company has three meter routes, each with its own reading date. The study period is one calendar year, and the consumption is prorated for each meter route or book. Meters are read bimonthly: route A on the first of month, route B on the 10^{th} of the month, and route C on the 20^{th} of the month (see Figure 7-4).

The uncorrected total metered use (from step 2-2A, Table 7-6) is based on bills issued during the study period. But, because of the bimonthly billing schedule, these bills would not include all water used during the year. Some water shown as used in the first billing period (issued in February) actually occurred in the preceding December. The last set of bills, issued in November and December, would not include water used in December. Two corrections need to be made. First, water used in the month proceeding the study period must be subtracted from consumption figures. Second, water used in the final month of the study period must be added.

Figure 7-4 shows how to adjust sales figures for meter lag time. Many utilities combine accounting and billing procedures into a computerized format to make this procedure easier and quicker.

Prorate water sales figures to adjust for lag time in meter reading.
Enter the net adjustment on Line 6 of the worksheet.
Add all metered deliveries.
Enter the sum on Line 7 of the worksheet.

Figure 7-4 Detailed Meter Lag Correction



The December through January billing period is 62 days long.

Route	Data Read	Sales (m3)	Adjustment (mil m3)
A	2/ 1/98	15,142	31/62 = 7,571
B	2/10/98	12,493	21/62 = 4,231
C	2/20/98	13,627	11/62 = 2,418

Total adjustment to eliminate 1997 sales from study period…- 14,220 m3.

This amount appeared on the February billing, but the water was used the previous Dec.

Route	Data Read	Sales (m3)	Adjustment (m3)
A	2/ 1/99	4.2	31/62 = 15,899
B	2/10/99	3.3	21/62 = 12,492
C	12/20/99	3.9	11/62 = 14,763

Total adjustment to add 12/98 sales to study period …….….+ 14,800.

This amount did not appear on the final bill for the year; it is prorated from the bill on which it appears.

Net adjustment ……………………..………………………… + 580 m3.

Step 2-3 Adjust Figures for Authorized Metered Consumption

Because there are so many customer meters, it is not practical to inspect and test every one each year. Instead, annual inspections and testing should include all meters greater than 50 mm in diameter, along with a random sampling of smaller meters.

2-3A Check for Proper Installation. Review the utility's practices on meter selection, sizing, and installation to see whether or not present practices permit accurate operation. If they do not, revise the practices as necessary so that meters will operate correctly.

Commercial and industrial meters produce a much larger share of revenue per account than do residential meters. Commercial and industrial accounts should be inspected for proper selection, sizing, and installation. In addition, inspect and test all large meters before they are used. Not all new meters are accurate.

2-3B Test Residential Meters. Test a random sample of residential meters – 50 to 100 is a good number. Residential meters may be tested on a test bench or sent to the factory or a consultant for testing. Many utilities are involved in *meter replacement programs*. For those utilities, to calculate meter error for the entire system, the random sample of meters must include some of the meters being replaced. Test a representative sample of the new residential meters before putting them to use.

2-3C Calculate Total Sales Meter Error. Total sales meter error includes meter errors from all meter sizes, including residential, commercial, and industrial.

- ***Calculate residential meter error.*** Residential meters are tested for low, medium, and high flows. The results, expressed as a percentage of accuracy, are used to calculate the total meter error at average flow rates. Tables 7-7 through 7-9 demonstrate how to use existing meter test data to calculate total residential meter error. The data in the table are based on Table 7-6.

- ***Calculate large meter error.*** Tables 7-10 through 7-12 show how to use existing meter test data to calculate total large meter error. The mean registration data in Table 7-10 are used to calculate the meter error for large meters.

  One the benefits of a water audit is the potential increase in revenue resulting from testing and repairing large meters (performed as part of the audit). One can estimate the amount of revenue to be gained by repairing the meters.

- ***Calculate total sales meter error.*** Total sales meter error includes meter errors from all meter sizes.

Total sales meter error = residential meter error + large meter error.

Using the data given in Tables 7-6 through 7-11, the total sales meter error for the Water Company is

$$508{,}493 \text{ m3} + 113{,}448 \text{ m3} = 621{,}941 \text{ m3} \qquad \text{(Eq 7-4)}$$

Add Lines 8A and 8B on the worksheet.
Enter the sum on Line 8C.
Add Lines 7 and 8C on the worksheet.
Enter the sum on Line 9.
Subtract Line 9 from Line 4.

7.2.3 Task 3 – Measure Authorized Unmetered Consumption

The volume of unmetered water must be carefully estimated to produce an accurate audit. This task includes descriptions of ways to measure water used for unmetered purposes. In selecting the best procedure for a given situation, consider the difficulty of gathering information; the degree of precision necessary; the availability of measuring equipment and skilled personnel; and the need for hiring consultants, buying more equipment, or training employees. When it is evident that a particular water use is very low, a rough estimate could replace a complete, detailed calculation.

It is recommended that all users be metered, even if the customer is not billed for the use.

Procedures for Estimating Consumption

Most authorized unmetered water use can be estimated using either the batch or discharge procedure. Which procedure is best for a given use depends on how the water is applied. In some cases, the best way to estimate use is to adapt consumption figures from similar, metered facility.

- **Batch procedure.** When water is transported in a tank truck or container of some sort, use the batch procedure. Multiply the volume of the tank or other container by the number of times it is filled from the distribution system. Careful record keeping is necessary for accurate estimates.

- **Discharge procedure.** When water is applied directly from a pipe, as in a sprinkler system, use the discharge procedure. Multiply the rate of water discharge by the total time it flows. This yields the volume of water delivered from the distribution system. The discharge rate may vary and the application period will vary in length and frequency. Again, careful record keeping is necessary for accurate estimates.

- **Comparison procedure.** For some facilities and areas, such as schools, swimming pools, construction sites, or golf courses, consumption figures may be adapted from similar facilities, provided they are alike in size, hours and type of use, landscaping, and most other details. Any differences must be accounted for. For example, at a construction site, work habits are important. If the crew at a metered site turns off water between uses, while the crew at unmetered site lets the water run continuously, the borrowed consumption figures will have to be adjusted considerably.

Remember: No matter what procedure is used, be sure to use the same unit of measure used for other parts in the audit.

Table 7-7 Weighting Factors for Flow Rates Related to Volume Percentages for 1/2" and ¾" Water Meters *

Percent of Time	Range (l/s)	Average (l/s)	Percent Volume**
15	Low 0.032-0.063	0.047	2.0
70	Medium 0.063-0.631	0.347	63.8
15	High 0.631-0.946	0.789	34.2

* Based on information from Tao, Penchin, "Statistical Sampling Technique for Controlling the Accuracy of Small Meters," *Journal AWWA*, 6:269 (1982).

** Percent volume refers to the proportion of water consumed at the specified flow rate, as compared to the total volume consumed at all rates. In this example, only 2.0 percent of the total water consumed occurs at the low-flow range of approximately 0.032-0.063 l/s.

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

Table 7-8 Meter Testing Data from a Random Sample of 50 meters for Water Company

Test Flow Rates (liters per second)	Mean Registration (percent)
Low Flow 0.016	88.8
Medium Flow 0.126	95.0
High Flow 0.946	94.0

Table 7-9 Calculation of Residential Water Meter Error

% Volume* (V)	Total Sales Volume** (Vt) (000 m^3)	Volume at Flow Rate (Vf) (%V x Vt) (000 m^3)	Meter Registration (R)*** (%)	Meter Error (ME) ME=Vf/0.01R)-Vf (000 m^3)	Meter Error (ME) (000 m^3)
2.0	8,778	176	88.8	[(176 / 0.888) – 176]	22
63.8	8,778	5,600	95.0	[(5,600 / 0.95) – 5,600]	295
34.2	8,778	3,002	94.0	[(3,002 / 0.94) – 3,002]	192
				Total	**508**

* From Table 7-7.
** Based on Residential Water Sales data in Table 7-6.
***From Table 7-8.

Table 7-10 Volume Percentages for Large Meters for Water Company*

Flow Rates	Percent of Volume Delivered
Low	10
Medium	65
High	25

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

Table 7-11 Meter Test Data for Large Meters for Water Company

Meter ID Number	Size (mm)	Meter Type	Date of Install	Maker	Test Date	Mean Registration at Various Flow Rates (% of Registration)		
						Low	Medium	High
XYZ001	80	Turbine	6/83	Insa	10/02	89	85	100
X00ZAA	3	Turbine	6/83	Insa	10/02	70	88	98
NB123	100	Displace	7/80	-	10/02	95	99	102
NB456	150	Compound	9/77	Insa	10/02	98	92.5	102
AA002	6	Propellar	5/66	Insa	10/02	98	98	103
Sum of Mean Registrations						450	462.5	505
Mean Registration for five meters tested						90	92.5	101

Table 7-12 Calculation of Large Water Meter Error

% Volume* (V)	Total Sales Volume** (Vt) (000 m^3)	Volume at Flow Rate (Vf) (%V x Vt) (000 m^3)	Meter Registration (R)*** (%)	Meter Error (ME) ME=Vf/0.01R)-Vf (000 m^3)	Meter Error (ME) (000 m^3)
10	1,850	185	90.0	[(185 / 0.90) - 185]	21
65	1,850	1,202	92.5	[(1,202 / 0.925) – 1,202]	97
25	1,850	462	101.0	[(462 / 1.01) - 462]	-5
				Total	**113**

* From Table 7-10
** From Table 7-6
*** From Table 7-11

Step 3-1 Identify Unbilled Authorized Unmetered Consumption

Many water utilities provide some authorized, but unmetered, use of water. This is typically labelled as, “Authorized Unmetered Consumption“. Most often, unmetered consumers are scattered throughout the service area at public buildings, open-space public areas, and special facilities designed to protect the public. Unmetered consumption may include fire fighting and training; flushing mains, storm drains, and sewers; street cleaning; schools; landscaping/irrigation in large public areas; wintertime bleeders; decorative water facilities; swimming pools; and construction sites. Water used for water quality and other testing, as well as process water at treatment plants, is also included in this category.

When conducting the following audit, check to be sure these uses are unmetered. If they are metered, they should be handled as metered use, as discussed in Task 2.

Step 3-2 Estimate Authorized Unmetered Consumption

To estimate total authorized unmetered consumption, break down the total into various uses.

3-2A Fire Fighting and Training. This is defined as water drawn from hydrants, fire – sprinkler systems, and other water sources dependent on the piped water distribution system. It may be used for fire suppression, testing fire equipment, flushing sprinkler systems, or hazardous-materials reduction performed by public-safety employees and volunteers. This category excludes water drawn from ponds, rivers, or other water supplies not connected to the piped water distribution system.

To estimate this use, check fire department records on training, flushing, and fire suppression. Many fire departments use more water for training than for fighting fires. Where flow meters on standby fire systems show water use, the maintenance superintendent of the building may have fire or test records.

Some fire departments require a "run-report" whenever a unit responds to a call. A survey of run reports for all fire calls made during the audit study period in the water service area should yield an excellent estimate of the amount of water used by the fire department. Remember to eliminate calls to locations where the water used came from water supplies not connected to the distribution system.

Estimates of other fire fighting uses, such as sprinkler systems (including their testing), require calculation of the flow of the system and the duration of operation. For this calculation, the discharge procedure is used. To acquire the raw data needed for the calculation, survey and inspect meters at schools, stores, apartments, industrial sites, lumberyards, warehouses, and other similar locations. The more complete the survey, the more accurately the final estimate will reflect water used in testing, and in leaky or incorrectly connected sprinkler systems.

In our example, there are four fire companies in the service area. Non of them make run reports. However, their logs show a total of 10 structural fires and a 5-day wildfire (for which water was airlifted from an open reservoir,) plus 8 days (48 work hours) of training in which water was used. Estimates of water use are 24,605 m3 for fire fighting and 12,113 m3 for training. Water used for fighting the wildfire is not included because it was not drawn from the distribution system.

Add fire-department use and other use to determine total use for fire fighting and training. Enter the sum on Line 11A of the worksheet.

3-2B Flushing Mains. This water is vented from the distribution system, frequently to storm drains, to clean the system of contaminants and debris.

Many utilities with standard flushing procedures maintain logs that include the location of the main or blow off, and the length of time it flowed. Some utilities meter the amount the amount of water released. (If this use is metered, the total should be included in the uncorrected total metered water use in Task 2.)

Estimating water used for flushing mains requires a series of discharge estimates. For each location flushed, multiply the flow rate by the duration of the discharge. For instance, 3.15 l/s released for 30 min yields 6 m3. If the discharge rate is not constant, calculate the volume by figuring the area under a curve (see Figure 7-5).

In our example, mains were flushed through relief valves and hydrants on 18 occasions (54hours total), accounting for about 6,057 m3.

Enter the total volume used for flushing mains on Line 11B of the worksheet.

3-2C Flushing Storm Sewers. This is water from the distribution system discharged through fire hydrants to flush and clean storm drains, culverts, or catch basins.

To estimate water used for flushing storm drains, contact the department responsible for the work. Ask for logs and cleaning activity, including the number of trucks used, their capacities, how frequently they were filled, and portable meter readings. Use the discharge method, if water is supplied directly from the piped distribution system. If water is transported by truck, use the batch method.

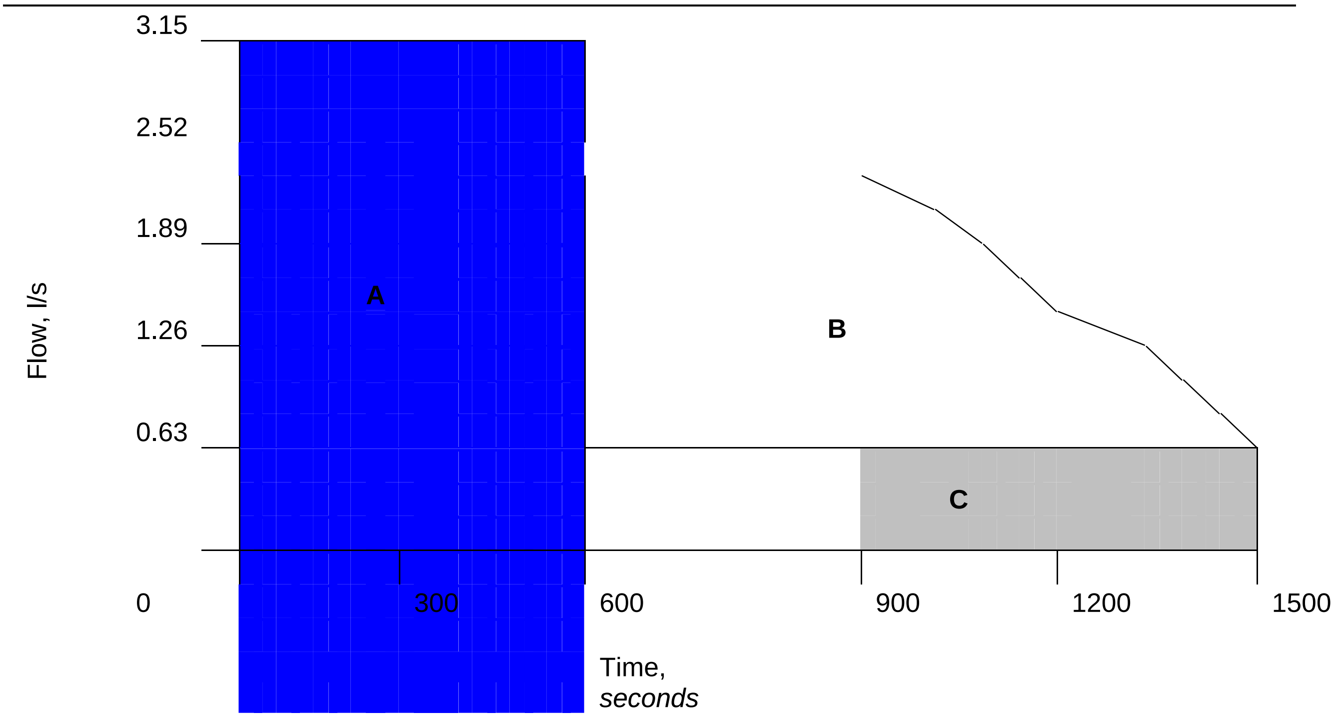
The discharge flow was constant for 10min at 3.15 l/s, then uniformly reduced to 0.63 l/s over the next 15 min, and then was shut off.

Volume A = 3,150 l/s x 600 s = 1.89 m3
Volume B = 0,5 x (3.15 – 0.63) l/s x (1500 – 600) s = 1.13 m3
Volume C = 0.63 l/s x 900 s = 0.57 m3
Total volume = 3.6 m3

In our example, the department of waste water treatment estimated about 1,893 m3 of water was used to clear debris from storm drains.

Enter the total volume used for flushing storm drains on Line 11C of the worksheet.

Figure 7-5 Calculation of Water Volume from Variable-Rate Discharge



3-2D Flushing Sanitary Sewers. This is water from the distribution system discharged through fire hydrants to flush and clean sanitary sewers. This category also includes water used in sewerage treatment plants for treatment processes and maintenance. This water should be metered and kept track of accordingly.

Use the procedure described in Step 3-2C, for flushing water.

In our example, the department of waste water treatment estimated about 60 days work using its sewer water jet cleaning equipment and releases from hydrants for an estimated 2,461 m3 of water.

Enter the total volume used for flushing sanitary sewers on Line 11D of the worksheet.

3-2E Street Cleaning. This water is used to clean roadways. It may be released directly from fire hydrants or sprayed from trucks, sweepers, or other equipment. It includes water used for the cleaning of park walkways, boat ramps, bus stops, parking areas, and bike paths.

Estimates are usually made with the batch method. Check with the local street department to find out the number of trucks or other equipment used, their capacities, how many days they were used during the study period, and how many times a day they were filled. Also identify the types of equipment used to wash recreational vehicle ramps and paths, and the frequency of their use. Table 7-13 shows how to calculate total street-cleaning estimates.

Volumes used in direct cleaning from hydrants must be estimated using the discharge procedure.

Table 7-13 Estimate of Water Volumes Used by Tank Trucks

Vehicle	Capacity (m3)	Number of Refills per Day	Number of Days Used per Year	Volume per Vehicle per Year (m3)
A	1	5	200	757
B	2	10	150	2,839
C	8	2	200	3,028
			Total Annual Use	**6,624**

Enter the total volume used for street cleaning on Line 11E of the worksheet.

<u>3-2F Schools.</u> Water is used in schools for domestic sanitation, heating, and air conditioning. The designation may also apply to school yards and playgrounds that are supplied by school water services.

Estimate unmetered school use by comparing them with metered schools having similar landscaped areas and use characteristics, including the number of students and faculty, hours of use, and recreational facilities.

In our example, all schools are metered, so there is no unmetered use; a zero is entered on the worksheet.

Enter the total volume used for unmetered schools on Line 11F of the worksheet.

<u>3-2G Landscaping in Large Public Areas.</u> This water is used to irrigate parks, golf courses, cemeteries, playgrounds, highway median strips, and similar areas.

As with schools and other public areas, the easiest method of estimating this total water use may be to compare use with metered landscaped areas having similar use, watering schedule, size, and plant growth.

If records have been kept, it may be possible to calculate the actual amount of water applied to the landscaped areas. This would include runoff from misapplied watering. Ask the people who maintain the areas for information on the frequency and duration of watering. Remember that watering schedules vary at different times of the year.

For median strips and other landscaped areas watered by tank trucks, use the batch procedure for estimating volume.

For unmetered sprinkler systems, the discharge method can be used. Essential factors are (1) the discharge rate at each supply pipe to an irrigate area, and (2) the total amount of time water is applied at each area. Obviously, time-controlled irrigation systems make the calculation easier. When figuring the amount of time water that is applied, remember to use the total time the service is discharging, rather than the period for one lateral. Figure 7-6 demonstrates how to estimate the volume used for landscape irrigation. Figure 7-7 gives the landscape irrigation figures for the example Water Company.

Enter the total volume used for each category of unmetered landscaping on the lines under line 11G of the worksheet.

Figure 7-6 Estimate of Private Landscape Watering

EXAMPLE ESTIMATE OF PRIVATE LANDSCAPE WATERING

A single 50 mm service provides irrigation water to 1,8 ha park at the rate of 10 l/s. Each of three laterals provides equal amounts of water and is controlled by a common timer.

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

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

How much water is applied from My through September?
Here's how to work out the answer:

The service supplies 10 l/s. It operates 6 hours each day the park is watered. During those 6 hours 10 l/s x 6 hours = 216 m3 of water applied.

The number of watering days must now be calculated:

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

Total ………………………………………………………………….. 99 days

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

216 m3/day x 99 days = 21,384 m3 *

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

Figure 7-7 Estimate of Public Landscape Irrigation

EXAMPLE OF ESTIMATED PUBLIC LANDSCAPE IRRIGATION

Landscaping in large public areas is not metered. Three estimating methods were used.

1. Parks, Playgrounds, and Cemeteries.

For parks, playgrounds and cemeteries comparisons were made with Mayfair City parks (USA), playgrounds and cemeteries which are metered. Landscape was irrigated 18,707 m3/ha for parks and playgrounds and 14,030 m3/ha for cemeteries.

Type of Area	Total Area in Service District (ha)	Annual Water Rate (m3/ha)	Total Yearly Water Use m3
Park	8	18,707	151,416
Playground	1.1	18,707	20,441
Cemetery	0.8	14,030	11,356

2. Golf Courses

Water use for 25 ha municipal golf course was estimated by measuring the rate of flow and determining the length of watering periods.

Typical water application: 10 h/day
250 days/year
50.5 l/s

(10 h/day) x (3,600 s/h) x (250 days/year) x (50.5 l/s) = 454,250 m3

3. Median strips

Highway median strips are watered by a large tanker truck carrying 1,892 m3, refilled 10 times a day, used 130 days a year.

(1.89 m3) x (10) x (130) = 2,600 m3/year

4. Miscellaneous

A 10 ha memorial park is watered, but specific quantities are not recorded. Water use is estimated at 1,893 m3 and included as "Other" on the worksheet.

<u>3-2H Decorative Facilities.</u> This water is used for cleaning and maintaining water quality in pools, fountains, and other decorative facilities.

The major causes of water loss from open-air, standing bodies of water are evaporation, water drained from a pool during maintenance, water used for cleaning, and leaks.

Evaporative loss. Appendix D explains how to calculate evaporative loss.
Pool drainage. To estimate water loss from pool drainage, use the following equation:

$$V \times F = V w \qquad \text{(Eq 2-5)}$$

Where :

V = volume of pool at the time it is drained (the volume of the pool when full minus the amount that is likely to have evaporated)

F = frequency of pool draining

Vw = volume of water loss due to drainage

Cleaning. To estimate the water lost in cleaning, ask maintenance workers about pool volumes and the frequency and flushing.

For an unmetered source, ask how much time maintenance work requires after the pool is drained. Ask if the hose or refill pipe is left running during that time. Determine flow rates for the appropriate outlet, refill pipe, or hose, and calculate the volume used. If the source is a hose bib from a metered facility, no further calculation is needed.

Leaks. To estimate leakage, subtract the average amount that should be lost to evaporation from the normal water volume. The difference is leakage.

Add water lost to evaporation, drainage, cleaning, and leaks. Add losses by type of facilities (for example, parks, or buildings) within the service area. In our example, the Water Company has no unmetered decorative facilities.

Enter the total volume used on Line 11H of the worksheet.

<u>3-2I Swimming Pools.</u> Here, water is used to maintain volume and water quality, including cleaning filters, decks, and walkways, and operation of sanitary and drinking water facilities associated with swimming pools. If concessionaires tap into unmetered water intended for the pool, that use should be included, also.

Many pools are metered. In that case, their use is already counted as a metered use, under Task 2. If they are not metered, estimate the volume of use from information provided by operations and maintenance staff. Useful estimates can be made by comparing water use with metered pools of similar size and use.

In our example, the Water Company has no unmetered swimming pools.

Enter the volume used for all unmetered pools on Line 11I of the worksheet.

<u>3-2J Construction Sites.</u> Water is delivered, principally through hydrants, to trucks for controlling road dust, site preparation, landscaping, temporary domestic use, and materials processing (for example, mixing concrete).

To estimate total use, use consumption data from metered construction sites for similar projects. Data may be obtained from regulatory water agencies. Compare the practice of shutting off supply at unmetered sites with the practices at metered sites and compensate for the difference.

It is recommended that all contractors be required to use a portable meter and report the readings.

In our example, the Water Company has no unmetered construction sites.

Enter the total volume used for unmetered construction site uses on Line 11J of the worksheet.

<u>3-2K Water Quality and Other Testing.</u> This water is used to test distribution system output to meet public health standards and to test meters and new mains.

Estimate water used by contracting operations staff to determine testing frequency as well as duration and volumes of water used. Amounts probably vary with each user.

In our example, the Water Company uses less than 2 m3/year for testing. The amount is so small it is disregarded.

Enter the total volume used for unmetered testing on Line 11K of the worksheet.

3-2L Process Water at Water Treatment Plants. This is water lost – not recycled – after washing filters or draining sedimentation basins at source water treatment plants. If the meter is located after the treatment plant, rather than before the plant, disregard this factor.

Estimate the water use by contacting plant operations staff and checking records.

In our example, operators for the Water Company do not keep specific records. It is estimated that a total of 265 m3 is released to waste after filter backwash each year.

Enter the total volume used for process water on Line 11L of the worksheet.

<u>3-2M Other.</u> An unmetered use may not fit any categories described here. In that case, determine the best means for estimating the total volume used.

In our example, there are no miscellaneous unmetered uses.

Enter the total volume other uses on Line 11M of the worksheet.

Add all authorized unmetered water uses (Lines 11A through 11M).
Enter the sum on Line 12 of the worksheet.

7.2.4 Task 4 – Measure Water Losses

As we have seen, most water that passes through a distribution system is accounted for, that is, records show how much is used for what purpose. This water is termed authorized consumption, either metered or unmetered. On the other hand, some water use is neither metered nor authorized. This water is considered lost from the system.

This task will show how to estimate the water that is lost to the system. In this regard, this task will consider both Apparent Losses and Real Losses.

The lost water does not produce revenue and is not available for beneficial uses. To determine how much water is lost by the system, subtract the volume of authorized, unmetered water from the corrected total unmetered water.

Subtract Line 12 from Line 10.
Enter the difference on Line 13 of the worksheet.

Step 4-1 Identify Potential Water Losses

Most water losses can be attributed to the following causes:

- accounting procedure errors
- unauthorized connections
- malfunctioning distribution-system controls
- reservoir seepage and leakage
- evaporation
- reservoir overflow
- unauthorized water use
- discovered leaks
- other leaks

The total volume of water lost to unknown leaks can be determined by first accounting for all other losses and subtracting them from the total water loss.

Step 4-2 Estimate Losses

The step identifies types of water losses and methods of estimating their volume.

4-2A Accounting procedure error. Water may seem to be lost from the system because of overlapping billing cycles (see discussion of meter lag time), misread meters, improper calculations, or computer- programming errors. These types of losses are paper mistakes that can be identified by careful, step-by-step review of record keeping and the computer process. For example, if the water meter registers in other units than those shown on the water bill, an incorrect conversion factor would introduce an error.

The entire billing and accounting procedure, from meter reading to printing billing statements, should be reviewed. In some agencies, the accounting and billing functions are scattered among several departments or organizational units. Such a fragmented arrangement can lead to miscommunication and error.

The task of reviewing billing and accounting can be simplified by checking a representative sample of accounts. A sampling of accounts from each meter-route book should be checked for accuracy. To do this, perform the following steps:

1. Determine the number of accounts to be checked from each book or route.

2. Choose a random sample of accounts to be checked. for the discrepancy.

3. Check meter readings. Have an employee other than the regular meter reader read meters for the identified accounts, or send another employee to accompany the meter reader to verify the readings. Both readings should be taken on the same day, if possible. The purpose is to determine whether or not the register is read and recorded properly and if the conversion factor is used properly. Compare the water-use volume for both meter readings. Calculate the billing manually.

4. Compare the total water use with total billed amounts. They should agree. If they don't, find out the reason for the discrepancy.

5. If meter-book readings show a substantial difference from billed amounts, review the normal billing process step by step, line by line.

In the example, four meter readers were accompanied on their rounds for a half-day each. This procedure sampled about 800 connections. In addition, the billing department's computer procedures were reviewed. The utility discovered that 0.5 percent of the 10,200 residential meters were inoperable or misread. The water loss was estimated at 863 m3 per year for each inaccurate meter reading. The following equation shows the total water loss for the 1-year audit study period.

0.005 x 12,200 x 863 m3 = 44.013 m3 (Eq 7-6)

Enter the total loss due to accounting errors on Line 14A of the worksheet.

4-2B Unauthorized Consumption: Identify active connections when unauthorized water use is not included in the accounting and billing process. Unauthorized use of water is usually accidental. For example, taps may be made to unmetered fire lines in a building (the installer may have been unaware that the lines are reserved for fire control); connections classified as inactive may be in use; or meters may not be read or the readings may not be entered into the accounting system. Occasionally, unauthorized water use may be deliberate. A customer may tap into the main or someone else's service to avoid paying for water. Good billing software should disclose improper practices, both deliberate and accidental.

The first step in measuring water lost to unauthorized connections is to determine which accounts are active and which are inactive. Connections listed as inactive should be confirmed. For some inactive accounts, the meter is removed or locked in the "off" position. If meters have not been deactivated, the meter reader should check the inactive connections periodically to see if they have been used. Telephone calls or visits to the premises may help meter readers keep abreast of changes in the use of these connections.

To identify unauthorized use, compare all active and inactive accounts with all locations that could receive water. One way to do this is to write the meter-identification numbers on the distribution system map and check that each parcel has a meter. A second method is to use an aerial photograph to identify places of water use and, where possible, correlate them with account numbers on a map. A third method is to check each meter-identification number against the assessor's parcel number. Any parcel without an account number should be investigated. (Keep in mind that some water uses may not have an account number or may not be metered.) A fourth method involves the measurement of flow into the suspected facility. A portable metering device is installed on the feed main upstream of the facility's meter. The flow is measured and recorded for a 24-h period. Results are compared to readings of the facility's meter discrepancy between the two amounts reveals that either the facility's meter is registering inaccurately or that water is being diverted through a bypass.

In our example, one small shop was using water illegally at an annual rate of 1,249 m3/year.

Enter the total volume of illegal connections on Line 14Bof the worksheet.

4-2C Malfunctioning Distribution System Controls. Water loss may result from improper application, malfunctioning, or improperly set system controls. These cases fall under Apparent Losses and/or Real Losses.

The basic steps for determining the volume of loss remain the same: determine (1) the rate of loss; (2) the length of time during which the loss occurred; and (3) the frequency of loss.

Valves. Valves are the controlling devices in a water distribution system. They are used for both isolation and control functions. Isolation valves are usually manually operated, while control valves function automatically. Many valves have indicators that show the position of the valve; valves without indicators can be retrofitted. Indicators make it easy to inspect valves to be sure they are positioned properly.

All control valves fail sooner or later. Each installation that uses automatic system controls should be inspected to determine whether or not the valve is working. Also, check to see that the valve has been set properly and whether or not its size and design are suitable for its intended purpose.

Different kinds of valves must be checked for different problems.

- **Altitude control valves.** Altitude control valves can cause a tank or reservoir to spill if the valve is broken or set improperly. The valve is normally set to prevent the tank from overflowing.

- **Pressure-relief valves.** If the pressure-relief valve is set too low for the system's range of pressures, then each time the pressure reaches the high range the valve will cause water to spill. Sometimes an unnecessary spill occurs because a pressure-regulating valve has been readjusted but the pressure-relief valve was not reset.

- **Pressure-reducing, pressure-sustaining, and pressure-maintaining valves.** If any one of these valves is improperly set, it can cause an altitude-control valve, a pressure-relief valve, or a surge-control valve to spill water.

- **Surge-relief valves.** If these valves are set too low, they can spill water as a blow-off to the atmosphere or into a tank or drain or back to the suction well of a pump.

- **Pump-discharge valves.** When the pump-discharge valve fails, it acts like a check valve that is partially open. This may allow water to discharge from the distribution system down the well.

In this example, the Water Company uses an updated system schematic to methodically check all controls. All operated correctly.

Enter the total loss from malfunctioning distribution system controls on Line 14C of the worksheet.

4-2D Reservoir Seepage and Leakage. This represents the loss from linings, bottoms, or walls of storage tanks or ponds. Water loss is estimated by closing the inflow and outflow of the reservoir and noting the change in storage level over several days. From this information, the rate of seepage can be calculated. Because water may leak only at certain elevations, the seepage test should be performed several times at successively lower surface-water elevations.

In our example, each of the Water Company's closed reservoirs was individually valved off from the system for 24 hours. One tank showed a change in elevation. The loss was calculated to be 0.727 m3/day, or 265 m3/year.

Enter the total loss from reservoir seepage and leakage on Line 14D of the worksheet.

4-2E Evaporation. Most reservoirs that store treated water are covered and lined, which reduces evaporation significantly. Some clear wells and reservoirs are open to the atmosphere and subject to evaporation. Losses can be calculated by measuring the surface area and applying the proper evaporation data for the area.

In our example, Crystal Lake is an open reservoir with 2 hectares of surface area. Estimated evaporation in excess of rainfall is 1,830 mm/year. Total annual loss is

1.83 m x 20,235 m2 = 37,006 m3/year (Eq 7-7)

Enter the total volume lost to evaporation on Line 14E of the worksheet.

4-2F Reservoir Overflow. This is an element of Real Losses. This occurs most often because the altitude control valve is faulty or missing. To calculate total loss, both the periods of overflow and the overflow discharge rate must be determined. (Overflow does not include water discharge to the distribution system.) If discharge is not directly measured (for example, by a stream gauge below the discharge point), reservoir overflow is calculated by subtracting reservoir outflow to the distribution system from the inflow to the reservoir. For open reservoirs, evaporation losses should be deducted from the reservoir inflow before attempting to calculate overflow.

In our example, no reservoirs overflowed.

Enter the total lost to reservoir overflow on Line 14F of the worksheet.

4-2G Discovered Leaks. Real losses from leaks that are found and repaired can be measured to determine the rate of loss and the total volume lost during the life of the leak. Methods of estimating leak rates, with tables, are described in Chapter 8.

In our example, four leaks were repaired. Two were large leaks believed to be short-lived (30 days), due to their disruptive nature. The other two were assumed to have been active the entire year until their discovery. Leak rates were not estimated in the field. The rates were estimated from the size of the hole in the pipe, using Greeley's formula as shown in Table 7-14. All mains involved operated at 3.5 b.

Table 7-14 Rate of Leak Losses

Diameter of Hole (")	Total Loss (m3/day)	Number of Days Leak Existed	Loss (m3)
1"	920	30	27,506
1"	920	30	27,596
¼"	58	180	10,357
¼"	58	300	17,261
		Total Loss from all leaks	**82,809**

Enter the total loss from discovered leaks on Line 14G of the worksheet.

4-2H Unauthorized Water Use. This is an element of Apparent Losses. Most unauthorized water use occurs when individuals vandalize fire hydrants to fill water trucks. Comparing construction permits with temporary-use billings show where large amounts of water are being taken without metering and billing.

In this example, there was no unauthorized water use.

Enter the volume lost to unauthorized water use on Line 14H of the worksheet.
Add all the identified water losses (Lines 14A through 14H).
Enter the sum on Line 15 of the worksheet.

7.2.5 Task 5 – Analyze Audit Results

Audit results may indicate loss problems resulting from faulty metering, unauthorized taps, leaking mains reservoirs, or leaking mains and services. To determine which corrective efforts are cost-effective, first estimate the value of the recoverable leakage and the cost of recovering it. If the value of the recoverable water exceeds the cost of recovering it, then carry out a metering and unauthorized tap program, and leak detection and repair program.

This section shows how to figure the benefits and costs of a leak detection survey.

Step 5-1 Identify Recoverable Leakage

Not all leakage is recoverable. To determine what portion may be recovered, first find out how much leakage there probably is, then figure what percentage of that can be recovered.

5-1A Potential Leakage. Generally, more water is lost than can be accounted for. This missing water is called potential leakage. It is easily calculated by subtracting identified losses from total losses.

Subtract Line 15 from Line 13.
Enter the difference on Line 16 of the worksheet.

5-1B Recoverable Leakage. Not all leaks can be detected and repaired. Experience indicates that about 25 to 75 percent of all potential losses can be recovered. To calculate the recoverable leakage, multiply the potential leakage by 0.50.

Multiply Line 16 by 0.50.
Enter the total on Line 17 of the worksheet.

Step 5-2 Figure the Value of Recoverable Leakage

Saving water saves money. What cost savings would be achieved if the leakage was prevented? There are two types of cost savings: (1) the cost of purchasing the water and (2) variable operations and maintenance costs associated with storing, treating, and delivering the water. Both of these costs vary with the amount of water going into the distribution system. Both exclude fixed costs. The cost savings equal the value of recoverable leakage.

5-2A Purchase Cost. This is what it costs the utility to buy water from another water supplier. Recovering leakage reduces the amount of water purchased. Usually, the most effective cost reduction results from reducing the amount of water purchased or produced from the most expensive source of supply.

In our example, the purchase price of water is 15 Euro/m3.

Enter the cost per unit of water from the utility's most expensive supply on Line 18A of the worksheet.

5-2B Operations and Maintenance. Operations and maintenance costs are paid to treat and pressurized water in the system. If the utility pumps water from its own wells, then recovering leakage will reduce the amount of energy needed for pumping.

NOTE: Only operation and maintenance costs that vary with the amount of water delivered are to be included here. Fixed costs that do not vary with the amount of water delivered should not be included.

In our, example, 0.02915 Euro/m3 is spent to purchase power, while 0.00324 Eur/m3 is spent on water treatment. Variable operations and maintenance costs total 0.03 Eur/m3.

Enter the unit costs of variable operations and maintenance on Line 18B of the worksheet.

5-2C Total Cost per Unit. The total cost per unit is the sum of costs for purchase and costs for operations and maintenance.

Add Lines 18A and 18B. Enter the sum on Line 19 of the worksheet.

Step 5-3 Figure the Cost to Recover Leakage

This step is accomplished in two parts.

5-3A One-Year Benefit. To determine the benefit of leak repair over one year, multiply the recoverable leakage by the unit cost of recoverable leakage.

Multiply Line 17 by Line 19.
Enter the product on Line 20 of the Worksheet.

5-3B Two-Year Benefit. The average lifetime of a leak before it requires repair is estimated to be two years, depending largely on pipe and soil conditions and the extent of a leak detection program. The total benefit, then, accrues over those two years. To compute total benefits from recoverable leakage, multiply the 1-year benefit by 2.

Multiply Line 20 by 2.
Enter the product on Line 21 of the worksheet.

In some situations, it may be appropriate to include additional benefits from increased leak detection and repair. For example, a more active detection program may allow investments in new resources or delayed construction of a treatment plant, resulting in substantial financial savings from deferred capital spending.

Step 5-4 Calculate the Cost of Leak Detection

The cost of conducting a leak detection survey can be estimated by preparing a leak detection and repair plan. Chapter 8 provides suggestions for how to prepare the plan. Prepare the plan now to get an idea of the cost for leak detection.

Enter the costs for leak detection on Line 22 of the worksheet.

NOTE: The cost of leak repair is not included. Since leaks are continually discovered and repaired in the normal course of utility operations, leaks found in the leak detection program would be repaired eventually. If leaks are repaired as part of the leak detection program, the utility avoids expense of repairing them as they are discovered accidentally. Savings on future repair costs are often overlooked when estimates of savings from leak detection are made, but they can be nearly as great as the cost of repairing leaks as part of the program. The real cost of repairing leaks in a program is generally very small.

For example, when the average life of the leak is 24 months and the real interest rate is 3 percent, benefits from avoided future costs amount to 94 percent of the cost of repairing leaks at the time of the leak detection program. In other words, the real cost is only 6 percent of the cost of repairing the leaks found in the program. To simplify the calculation, the cost of repairs has been assumed to be 0.

To determine the benefit-cost ratio, divide total benefits from recoverable leakage by the total costs of the leak detection program.

Divide Line 21 by Line 22.
Enter the total on Line 23 of the worksheet.

If the benefit-cost ratio is greater than 1.0, then the benefits of leak detection are greater than the costs, and the program should be implemented.

7.3 AFTER THE AUDIT

Outlined here are steps management can take to correct the unproductive elements in the water supply system.

Analyze the Value of Losses and Corrective Measures

Evaluations of corrective measures should be based on cost, feasibility, and savings. The water audit tells the utility where the greatest losses occur. This information allows the utility to set priorities. In setting priorities, managers need to incorporate local constraints.

The choice of corrective actions is influenced by a number of factors, including the following:

- Where losses occur
- How much water is lost in each problems area
- What action is needed to reduce water loss
- The cost of reducing water loss
- Savings that will result from reducing water loss (based on the benefit-cost ratio)
- Timetable for implementing the measures

Evaluate Potential Corrective Measures

Corrective measures include performing a leak detection survey and leak repair program, replacing mains that have a history of serious leaks, exercising valves annually, and implementing corrosion-control procedures.

Based on our example of the Water Company, the following recommendations might be made: conduct a leak detection program; test customer meters when received from the manufacturer; check accounts for stopped meters; recommend that public parks, playgrounds, cemeteries, and golf courses be metered; have the leak repair crew measure leak discharge when leaks are uncovered; and perform water audits annually.

Update the Audit

Annual updates provide information to help managers adjust priorities and monitor progress made on system maintenance. Equally important, the update can identify new areas of system losses; this helps managers establish new annual maintenance goals. Updating a water audit is usually less expensive than the original audit.

In some cases, it may be worthwhile to install permanent flow meters in distribution zones. Continuous monitoring allows detection teams to be sent to areas of highest leakage and provides clear results of detection and repair.

Update the Master Plan

The utility's master plan can be used to set priorities and schedule corrective actions to maintain the distribution system. Managing a distribution system requires current information on the system's delivery capacity, maintenance, and water quality. An update master plan, supplemented by a water audit and leak detection program, supplies the current information by providing the following:

- Identification of problem areas and areas of potential water savings
- Analysis of water and cost savings achieved by corrective action
- Feasibility analysis of corrective actions based on cost and organizational constraints
- Analysis of improved water system efficiencies resulting from past and proposed corrective actions
- Analysis of greater system efficiencies versus expansion of resources, treatment plant, or distribution system
- Project water needs
- An implementation schedule for corrective actions
- Updated maps showing the system's physical relationships and characteristics

CHAPTER 8

8 LEAK DETECTION

8.1 Overview

Only three decades ago, utility managers in developed countries believed that demand should be managed through tariff adjustments, such devices as declining block pricing and that any effort to encourage consumer conservation could adversely affect utility budgets. The only exception to this view was controlling demand during crises such as droughts. Since then, changes in public attitude regarding the environment and resource conservation have shifted the perspective of utilities on demand issues. Today, controlling leakage and promoting the use of efficient plumbing fixtures are a fundamental part of utility programs.

Of the many options available for conserving water, leak detection is a logical first step. If a utility does what it can to conserve water, customers will tend to be more cooperative in other water conservation programs, many of which hinge on individual efforts. A leak detection program can be highly visible, encouraging people to think about water conservation before they are asked to take action to reduce their own water use. Leak detection is an opportunity to improve services to existing customers and to extend services to the population not served.

8.1.1 Types of Leaks

Water takes the path of least resistance; it may or may never surface. Therefore there are two basic types of leaks: visible and non-visible. Visible leaks can be seen emerging from the ground or pavement. The source of the leak may be a considerable distance away from the area where it is observed. Many visible leaks are reported by water customers. Non-visible leaks may percolate into the surrounding ground or may enter storm drains, sewers, stream channels, or old abandoned pipes. Most of them are estimated to have an average life of two years, depending mostly on soil and pipe conditions and the extent of a leak detection program.

Based on where they occur, leaks can be divided into six categories. Leaks may be located on the main line, a service line, a residential meter box, residential service or at a valve, or random cracks/breaks or joints in water mains.

8.1.2 Causes of Leaks

In most cases, the largest portion of unaccounted-for water is lost through leaks in the mains. There a re many possible causes of leaks, and often a combination of factors leads to their occurrence. The material, composition, age, and joining methods of the distribution system components can influence leak occurrence. Another related factor is the quality of the initial installation of distribution system components. Water conditions are also a factor, including temperature, aggressiveness, and pressure. External conditions, such as stray electric current; contact with other structures; and stress from traffic vibrations, frost loads, and freezing soil around a pipe can also contribute to leaks.

8.1.3 Cost of Leaks

First of all, water leaks result in a loss of water resources. As water leaks, it creates an underground cavity. This increases the potential for damage to overlying property. Another effect of water leakage is reduced pressure in the supply system. Raising pressures to make up for such losses increases energy consumption. This rise in pressure makes leaking worse and has adverse environmental impacts.

8.1.4 Benefits of Leak Detection and Repair

The economic benefits of leak detection and repair can be easily estimated. For an individual leak, the amount lost in a given period of time, multiplied by the retail value of that water will provide an indication of the financial loss related to that leak. Remember to factor in the costs of developing new water supplies and other “hidden” costs.

Some other potential benefits of leak detection and repair that are difficult to quantify include:

- Increased knowledge about the distribution system, which can be used, for example, to respond more quickly to emergencies and to set priorities for replacement or rehabilitation programs.
- More efficient use of existing supplies and delayed capacity expansion;
- Improved relations with both the public and utility employees;
- Improved environmental quality;
- Increased firefighting capability;
- Reduced property damage, reduced legal liability, and reduced insurance because of the fewer main breaks; and reduced risk of contamination.

All water utilities will benefit from a water accounting system that helps track water throughout the distribution system and identifies areas that may need attention, particularly large volumes of unaccounted-for water.

8.2 Leak Detection Methods

Listening for the leak itself is the direct method of detection. This is performed by a distribution system worker wearing listening equipment. There are other methods of leak detection, including zone flow measurement and the water audit. Rather than pinpoint leaks, these methods indicate whether or not water is leaking and give a general idea of where the leak might be.

8.2.1 Water Audit

A water audit is an efficient way to determine the total volume and value of water leaking from a distribution system. The final part of the water audit is the preparing of a leak detection and repair plan, which outlines the equipment, type of crew, method of surveying and pinpointing leaks, and the costs involved.

8.2.2 Zone Flow Measurements

This method can be uses as an extension of the water audit or, in some cases, as a leak detection method. Its purpose is to determine whether or not a sector or zone of a water system is experiencing major leakage. To effectively conduct a zone flow measurement program, a utility must maintain good maps, have valves located at zone-control points, and provide a tap in the main for a pitot rod attached to a recording device.

To measure a zone, close valves to isolate sections of the water system and allow flow through a single line. Record the flow for 24-hours. Compare the average hourly rate to the minimum night time hourly rate. The resulting ratio may indicate leakage if the ratios is over 0.40 and there are no large industrial or commercial night time water users in the area.

8.2.3 Audible Leak Detection

An important goal of leak detection is to find exactly where a leak is located. Typically, the louder the noise, the closer you are to the leak. Small leaks under high pressure usually make more noise than larger leaks under low pressure. In fact, many large leaks make almost no sound whatsoever. Audible leak detection uses electronic listening equipment to detect the sounds of leakage. Pressurized water forced out through a leak loses energy to the pipe wall and to the surrounding soil area. This energy creates audible sound waves that can be sensed and amplified by electronic transducers or, in some cases, by simple mechanical devices. The sound waves are evaluated to determine the exact location of the leak. During the leak detection survey, a trained operator conducts an initial listening survey of the entire distribution system and records all suspect sounds. Later, areas are rechecked. If sounds can still be heard, leaks are pinpointed.

8.3 Conducting a Leak Detection Survey

Leak detection is a process of elimination and discovery. The goal is to eliminate the contact points where leak sounds are not heard and discover the contact points where leaks can be heard. A contact point is any suitable connection to the water main that transmits sound vibrations. This can be a fire hydrant, service stop, valve, or probing rod.

Preparing for the Detection Survey

Before conducting a leak detection survey, review the specifics of the distribution system, including the following:

- results of the water audit: How much water is lost from the system?
- mains and services: types, ages, diameters, joints, installation methods, inspections, leak histories, and operating pressures
- meters and meter-box assemblies: types, brands, and sizes of meters; ages; types of installations; meter shutoffs; couplings; and meter reading frequency
- valves: locations, types, left- or right-handed, number of turns to exercise, and how often exercised
- hydrants: types, sizes, locations, flushing frequencies, and unmetered usage
- pressure-reducing valves, pressure-sustaining valves, and pressure-relief valves: locations and how often they are exercised
- blowoffs and air-release valves: locations and how often they are exercised

• distribution system maps: What is shown on maps, how current is the information, and how often is the information updated?

Many utilities survey their distribution networks systematically according to zones, or areas outlined on maps. Other utilities use meter routes because the routes are well thought out and minimize distances in covering the system. However, using meter routes requires familiarity with the system layout.

Leak Detection Equipment

Crew members should have leak detection equipment, including sonic listening equipment with a high-frequency listening probe and a low-frequency ground microphone for pinpointing leaks. When using the ground microphone on turf areas, a "thumb tack" helps provide better-quality sounds. A thumb tack is a flat, metal, horizontal plate attached to a strong, metal, vertical spike. See appendix E to obtain the *AWWA Sourcebook* for leak detection suppliers and consultants. Crew members should also have safety equipment, including safety vests, traffic cones, and barricades.

Tools to measure flow rates should be provided, including a stopwatch, bucket, measuring cup, pressure gauge, and measuring tape or ruler.

Working tools, such as meter-box lid lifters, valve-cover lifters, valve keys, curb-stop keys, small bailing cans or small manual pumps, chalk (keel) or spray paint, pipe locators, and wrenches for tightening meter-spud nuts, should also be provided.

Selecting Team Members

Each leak detection team member should have a keen sense of hearing, ability to discern different sounds, familiarity with water meters and the distribution system, a sense of responsibility, and ability to estimate leak flows, complete leak forms, and work independently.

One person can conduct the initial listening survey, although more may be needed for safety purposes.

Planning the Survey

When planning how the leak survey will be conducted, consider the following:

- What type of noise problems exist within the system?
- What effect will traffic have on the survey?
- What type of protection is required for the leak crew?
- What time of day or night will be most effective to conduct the listening survey?
- What time will be most effective to pinpoint suspected leaks? (Some utilities concentrate on the initial listening phase for several days and pinpoint leaks at the end of the week.)
- Is the crew a compatible group that will work together?
- How will the crew's tasks be divided?
- What is the most effective route to follow in the initial listening survey?
- Which are the most effective leak survey and pinpointing forms, and how are these records to be completed?
- How will leak detection crews communicate and work with repair crews to ensure effectiveness and resolve dry holes?

Leak Detection and Repair Plan

Prepare a leak detection and repair plan. A sample plan is shown in Figure 8-1, and a blank form is included in Appendix A.

Team Training

Train team members before conducting a leak detection survey. This will build crew members' confidence and help to ensure that the survey is accurate. Training can be arranged through manufacturers of the equipment to be used—either by attending their training seminars or by on-the-job training as part of the equipment purchase. Training may also be available from consultants, from utilities with existing leak detection programs, or from the state.

Equipment Tune-up

Before conducting the survey, leak detection staff should familiarize themselves with the equipment to be used. Consult the instruction manual and review the instructions. Check the equipment to be sure batteries are charged and worn-out batteries are replaced, electrical and physical connections are tight, and controls work properly. Check to see if the basic leak sound can be heard by testing the equipment on a hose bibb, first with water running and then with no water running.

Have team members practice with the particular pieces of equipment they will use during the survey. All team members should become familiar with the unique background sound of their particular listening instrument; what a quiet sound is (when no leak or water use is present); what water use sounds like (by opening a hose bibb on a customer's service line); the sound when a faucet is dripping; the sound when sprinklers are in use in the area; and the sound when the meter is turning.

Figure 8-1 Sample plan for leak detection and repair

SAMPLE LEAK DETECTION AND REPAIR PLAN

Name of Utility : **Water Works Pljevlja** Date: **7/18/1999**

A Area to be Surveyed

A - 1 Using the results of the water audit, show on a map which areas in the distribution system will be surveyed. Indicate which areas have the higher potential for recoverable leakage. Consider records of previous leaks, type of pipe, age of pipe, soil conditions, high pressures, ground settlement, and improper installation procedures.

Describe each area to be surveyed under item B-2 of this plan

A - 2 Total length of main to be surveyed in km : 233.6

When calculating the kilometers of main, include the total length of pipe and exclude service lines. If only a portion of the system is being surveyed, calculate the benefit-to-cost ration to reflect only the portion included in the survey.

A - 3 Average number of km of main surveyed per day: 3.2

The average survey crew can survey about two miles of main per day. Items to consider include distances between services, traffic and safety conditions, and number of listening contact points. Explain if more than three miles per day are surveyed.

A - 4 Number of working days needed to complete survey (divide line 2 by line 3): 73

B Procedures and Equipment

B - 1 Describe procedures and equipment you will use to detect leaks.

Experience shows that the best results are obtained by listening for leaks at all system contact points (such as water meters, valves hydrants, and blowoffs).

Purchase leak detection equipment.
Attend manufacturer's training seminars and state training.
Conduct initial listening survey on all contact points.

B - 2 Describe why the areas noted on the map in step A-1 have the greatest potential for recovering leakage:

Area 1 - Downtown - old ductile-iron mains.
Area 2 - Steel mains over 40 years old.
Area 3 - Reminder of systems.

B - 3 If you will not be listening for leaks at all system contact points, describe your plan for effectively detecting leaks:

The crew will listen for leaks at all contact points.

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

Will use low-frequency ground microphone to listen over pavement surfaces.
Consultant's correlator will be used in difficult situations.

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

The leak detection crew and the repair crew will jointly excavate all leaks for the first three weeks and resolve any dry holes thereafter.

B - 6 Describe the methods you will use to determine the flow rates for excavated leaks of various sizes.

Bucket-and-stopwatch method will be used on small leaks.
For larger leaks, the diameter of the hole and the pressure will be measured.
The Greeley formula will be used to calculate the volume of large leaks based on measurements taken.

C Staffing

C - 1 How many agency staff will be used? 2

Staff costs including wages and benefits:

	€ / h	€ / day
Person 1	13.77	110.18
Person 2	10.02	80.12
TOTAL	23.79	190.30

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

Cost of consultant staff:

	€ / h	€ / day
Person 1	25.04	200.3
Person 2	0	0
TOTAL	25.04	200.30

D	**Leak Detection Survey Costs**			
		days	€ / day	€
D -1	Agency-crew costs	73	190.30	13,892
D - 2	Consultant-crew costs	15	200.30	3,005
D - 3	Vehicle costs	73	1.92	140
D - 4	Other			0
D - 5	Total survey costs			17,037
E	**Leak Detection Budget**			€
E -1	Cost of leak detection equipment			2,043
E - 2	Leak detection team training			320
E - 3	Leak detection survey costs			17,037
E - 4	Total leak detection costs			19,400

F	**Leak Survey and Repair Schedule**	
	Indicate realistic, practical dates.	
F - 1	When will the leak survey begin?	August 1, 1999
E - 2	When will the leak survey be	December 15, 1999
E - 3	When will leak repairs begin?	August 15, 1999
E - 4	When will leak repairs be completed?	January 10, 2000

Prepared by: Petar Petrović	Title: Technical Manager
	Date : 7/18/1999

LEAK DETECTION PROCEDURES

This section describes, in general terms, how to conduct a leak detection survey. The leak detection daily log (see Figure 8-2) can be used to record the results of the survey, and a blank form is provided in appendix A.

Initial Listening Survey

The objective of the initial listening survey is to listen for leak sounds on contact points in the distribution system. Use the high-frequency contact microphone to listen for leak sounds on all meters, valves, hydrants, blow-offs, air-release valves, and other contact points. Note the address of all locations where water use, meter sounds, or possible leak sounds exist. This initial search through each area of the system can be conducted quickly.

Sound travels a long distance on metallic mains, so listening at contact points allows the listener to hear the sounds of leakage along the length of the main between the points. Sound travels less distance on nonmetallic mains, such as PVC, and a little extra effort may be required during listening surveys. If sound does not carry the entire length of the pipe from one contact point to the next, then the leak detection staff needs to listen over the main itself with a ground microphone.

A number of factors influence how far sound will travel along nonmetallic lines, including system pressure and pipe diameter. The sensitivity of listening equipment also limits the length of pipe along which sounds can be heard.

To determine whether it is necessary to listen directly over mains in addition to contact points, perform the following test:

1. Listen over the main with a ground microphone.
2. Have a co-worker turn on a hose bib at a customer's service.
3. Determine how far away along the main the sound of water escaping from the hose bib can be heard.

If the distance between contact points is greater than the distance that the sound travels along the main, then use the ground microphone to listen over the main at appropriate intervals between 3 and 5 meters.

Interference. A number of sounds can interfere with leak detection equipment.

Sounds from customer use inside a dwelling include use of showers, toilets, washing machines, pumps, and meters. Even the sound of people talking may be picked up by listening equipment.

Sounds from outside a dwelling can be caused by aircraft, wind and rain, street traffic, interference from power lines or transformers, radio broadcasting, or lawn watering.

Sounds from water noises usually come from adjacent leaks, valves, or turbulence. All of the sounds may be transmitted through leak detection equipment, making it difficult to isolate and identify leak noises.

Faulty equipment, loose electrical connections, improper training, or system pressure less than 1 atmosphere can also obscure or modify leak noises.

Figure 8-2 Sample log for leak detection survey

LEAK DETECTION SURVEY DAILY LOG

Name of Water Utility: Public Utility "Water Works" Pljevlja   Date : 12/15/1999

Leak Detection Team Members: Janko Janković, Đorđe Đorđević

Manufacturer and Models of Equipment Used: F.S.C. Model L-100

Area Surveyed: 7

Map reference: Water Distribution Map   Page & Coordinates: 6

Street and Block Numbers:

Leak Nr.	Location or Address of Suspected Leak	Agency or Customer (A or C)	Leak Pinpointed (Y or N)	Leak to Be Rechecked (Y or N)	Leak Repaired (Y or N)	Not a Leak (Date)
12	Njegoševa 25	A	Y	N	Y	
13	Proleterska 18	A	Y	N	Y	
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						

	Meters	Hydrants	Valves	Test Rods	Other
Indicate Number of Listening Points Used	483	43	88	0	0

Kilometers of Main Surveyed: 7.17

Survey time: 8 h

To be rechecked: 9 (number)

Number of Leaks Suspected: 8

Number of Leaks Pinpointed: 0

Pinpointing time: 0 h

Remarks:

Found a 50/50 percentage between stem packing leaks and small service meter leaks.

Also found two customer sprinkler system leaks.

Customers were informed.

Re-listening to Suspect Sounds

Return to each location noted in the initial listening survey. Using the high-frequency contact microphone, listen again for the sounds heard earlier. If the location is quiet, there is no leak. If sounds are heard, check to see if the meter is running; a running meter indicates water use. If sounds can still be heard when there is no water use, a leak probably exists. That leak must be pinpointed.

Pinpointing Leaks

The objectives of pinpointing leaks are (1) to determine whether the leak sound is leakage, water use, or some other noise; and (2) to determine the leak's exact location.

Return to the suspected location and again listen for the leak sound. Inspect the area, paying attention to both sight and sound. Use a sonic amplifier, if possible. What might be a leak sound may actually be caused by a pressure-reducing valve, electrical transformer, or other interference.

Review detailed distribution system maps and locate pressure reducers, forgotten valves, or other system apparatus that might make the suspect sound. If when inspecting the area, another possible cause of the sound is found, try to isolate and identify the sound, or quiet it temporarily. For example, a customer pressure-reducing valve can be isolated by shutting off the customer service and then bleeding the pressure off the system by opening the customer's hose bibb. (Be sure to check with the customer before shutting off the service.)

If the leak noise is heard on a water meter (see Figure 8-3), listen carefully for leak sounds on both sides of the meter. Determine if the sound is louder on the customer side or the utility side of the meter. Look for obvious signs of customer use, such as sprinklers operating. In this case, the meter may be heard turning, even if the meter hand is not moving. Then, check the meter indicator for movement; the leak may be in the area of the meter box.

If it is difficult to identify which side of the meter the leak is on, notify the customer that the service will be shut off for a few minutes. Close the angle stop and bleed off system pressure from the customer's line by opening the hose bibb. If the leak sound stops, the leak is either within the meter box, on the customer's service line, or in the dwelling. If the noise continues, the leak is on the agency side of the meter.

If the leak is on the customer side of the meter, leave a doorhanger (see Figure 8-4) notifying the customer that there may be a leak in the service line, interior plumbing, or water-using fixtures.

Figure 8-3 Listening for leak noise at meter

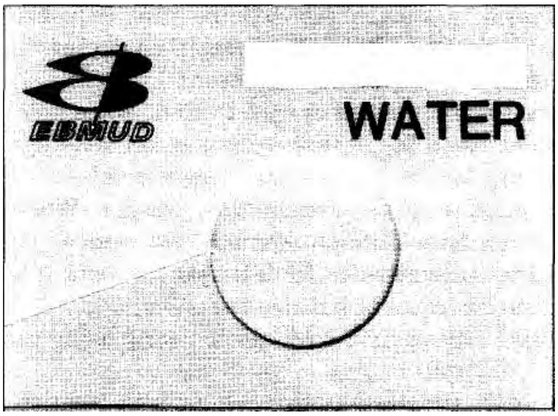
Methods for pinpointing leaks. If a leak is on the main or the service line, the leak sound may be detectable on adjacent service meters, valves, or hydrants. Listen for sounds of leakage on services adjacent to the suspected meter and determine where the sound is the loudest. Pinpointing the exact location can be accomplished by using the ground microphone or the correlator method.

Ground-microphone method. The objective of this method is to find the location of the loudest leak sound over the main or service line.

The first step is to determine the exact location of the main or service. An electronic pipe locator can be used to locate the buried main or service line. Precisely mark the location of the main or service line on the pavement. Locate other nearby pipes from which the sound might be coming.

Ground microphones are either monophonic or stereophonic, depending on the manufacturer. Stereo models can discern differences in intensity between two microphones, but most models have only one microphone.

When using the ground microphone for pinpointing leaks, remember to set the volume relatively low at the beginning, so loud sounds will not be uncomfortable.



ADDRESS

CITY ________________

DATE ________________

TIME ________________

Water Works Pljevlja is "listening" to its water mains and service connections with electronic leak detection equipment. As part of this survey, customer house plumbing system* are "listened to" at the meter.
The detectors have picked up the sound of running water on your plumbing system, which could mean that you have leaks in your plumbing. In order to conserve water and to prevent high water bills, please check your house for leaks or running water, using the checklist on the reverse side of this card

C-93 * 6/86

Courtesy Public Company “Water Works Pljevlja”

HOME
LEAK
DETECTION

1. □**TOILETS - Leaks may be seen or heard.**
   a. **Water level high and running into overflow.**
   b. **Plunger - ball not seating properly or deteriorated.**
   c. **Float valve not operating properly.**
2. □**LEAKY FAUCETS OR VALVES – (inside or outside).**
   a. **Washers need replacing.**
   b. **Faucet left running.**
3. □**HOT WATER TANK leaking.**
4. □**WET SPOT on lawn or unusual surface water indicates possible leak.**
5. □**SPRINKLER SYSTEM left running.**
6. □**WASHING MACHINE OR DISHWASHER left running.**
7. □**AUTOMATIC SHUTOFF for swimming pool in bad condition.**

If you do find leaky plumbing or fixtures, please make necessary repairs or call a plumber right away. For additional information please call the Water Works Pljevlja, 12 Petra Petrovica street, Pljevlja.

Customer Service closed Saturdays, Sundays & Holidays

Figure 8-4 Doorhanger notifying residential customer of possible plumbing leaks

Keep the volume adjustment at the same level throughout each pinpointing sequence. If uncomfortably loud sounds are heard, reduce the volume for safety, then survey the points again to locate the loudest leak sounds.

Use the ground microphone to listen for leak sounds every 1.5 to 3 m. Write notes on the sound intensities. If the equipment has a meter, write down meter readings. The strongest signal usually indicates the location of the leak. Be careful not to change the setting of the volume or other controls during this process. Where possible, avoid comparing sounds at points with different surface and compaction characteristics. If this is unavoidable, make allowance for the fact that the same leak sound is quieter at a loosely compacted surface than at a dense one.

After pinpointing the leak, verify its location with a second listening using the ground microphone.

Correlator method. The objective of this method is to pinpoint leak locations using an acoustic leak correlator, or microprocessor, to analyze leak sounds (including those inaudible to the human ear) that travel through the water column and along the pipe wall. These sounds can be picked up, for example, at valves, hydrants, and curb stops. Direct contact with exposed mains or probe rods also can be used.

The correlator method is used in place of or as verification of the previously described ground-microphone method. It is used before drilling or excavating. The correlator method does not rely on the presence of surface sound as does the ground-microphone method. Common noise interference, such as wind, traffic, and ambient system noise, do not affect the leak correlator. The depth of the main, type of cover, and surface conditions are generally not factors to be considered.

To use the leak correlator, the leak sound must be detectable at two or more contact points, and pipe locations and configurations must be accurately determined. The linear pipe distance between the contact points, and pipe materials and diameters are entered into the correlator. Two electronically amplified microphones, connected to and powered by portable electronic preamplifier outstations, are attached to the selected contact points. The leak sound picked up by the microphones and amplified by the outstations is then transmitted to the correlator by a radio housed within the outstation (Figure 4-5).

Figure 8-5 Preamplifier outstation

The leak correlator is essentially a two-channel microprocessor that measures the time delay of a leak noise between two contact points. Although the leak sound's characteristics vary due to such factors as pipe material, diameter, size and nature of the orifice or fissure, system pressures, ground conditions, and other factors, the leak sound velocity (V), or speed with which the leak sound travels along the pipe, remains constant.

As previously mentioned, if the sound of the leak can be detected at two contact points, the leak correlator can determine the leak's position. A simple example is shown in Figure 4-6, where the leak is on a main between two sounding points, A and *B,* at a distance *D* apart.

The leak is at a point halfway between *C* and *B.* The leak correlator determines the delay in arrival time taken by the leak sound to travel from *C* to *A,* the distance *N.* This delay is the time difference *Td* for the leak sound to reach *A* versus its arrival time at *B.*

Referring to Figure 8-6,

$$D = 2L+N$$

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

$$D = 2L + VTd$$

The value D is measured in the field and velocity V is either selected from the leak correlator's memory, or can be computed manually by the operator. The difference in arrival time Td of the leak sound at A and B is automatically established by the correlator through the cross-corre/ation process. This time the difference is directly related to the sound velocity of the pipe under investigation.

The leak location results appear on the correlator's display, or results can be printed, as shown in Figure 8-7. The operator then measures the indicated distances from the contact points.

While correlators once required permanent vehicle installation, most are now laptop computers with internal rechargable 12-volt direct current (VDC) power supplies (Figure 8-8) and simple to operate.

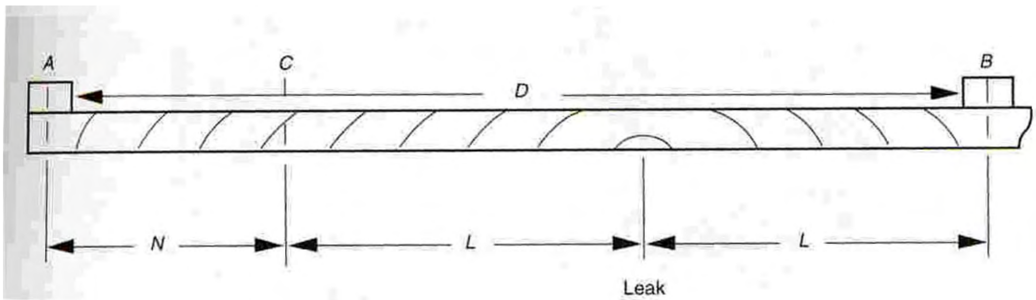
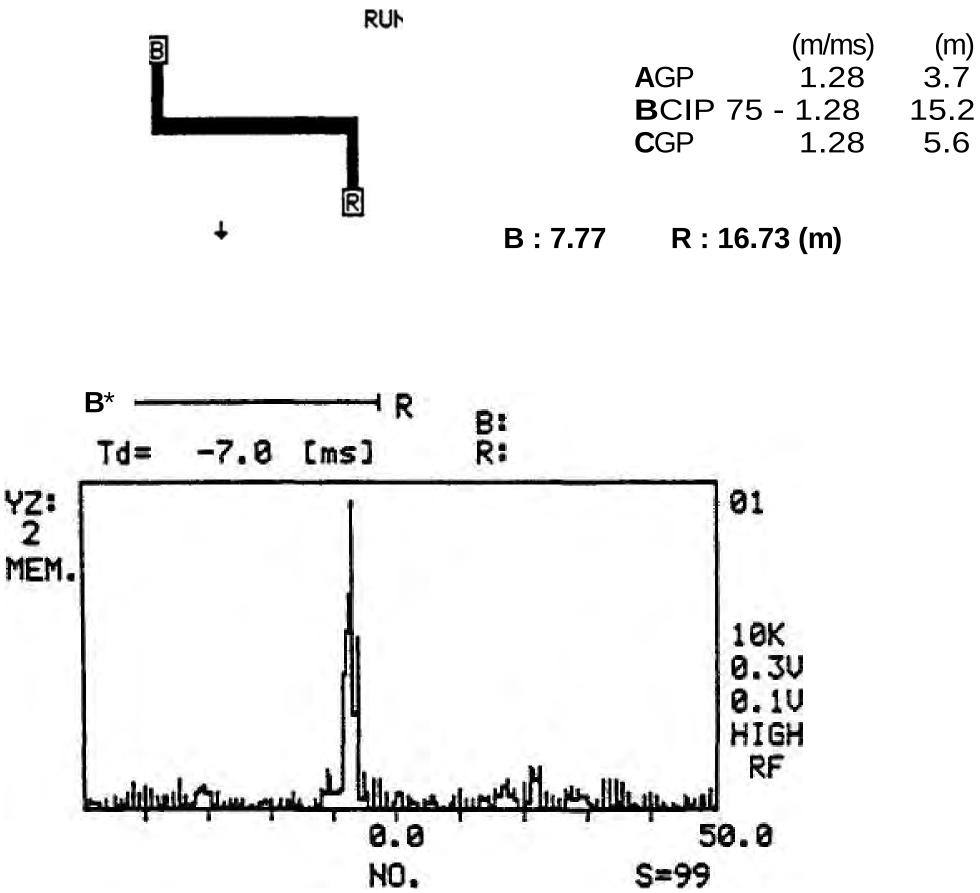


Figure 8-6 Determining the position of a leak using a leak correlator (see text for definitions of variables)



Note: The spike on the chart indicates the position of the leak between blue and red transducers.

Figure 8-7 Typical paper-tape output of leak location using correlator

Figure 8-8 Portable laptop leak correlator

A leak correlation system is a package of electronic equipment and accessories, commonly consisting of the following items:

- a laptop microprocessor with internal rechargeable 12-VDC power supply, display screen, internal preamplifier, two-channel internal radio receiver, and stereo headphone
- two electronic amplifier outstations with internal rechargable 12-VDC power supply, internal radio transmitters, microphones, and stereo headphones
- battery charger kit
- manual and test tape with stereo lead

Commonly available accessories include the following:

- cases for carrying items and added protection
- microphone attachment accessory kit
- portable electronic survey tool that serves as a backup outstation
- measuring wheel
- hydrophone sensor package
- stereo recorder with harness
- training tapes
- ground-microphone system
- printer
- pipe locator

Probe method. This is a method to double-check findings using the ground-microphone or correlator method. Drill a small hole through the pavement over the suspected leak taking care not to damage the pipe. Insert a metal rod with a T-handle into the hole and use a high-frequency sonic microphone to listen again for the sound of leakage. Additional holes through the pavement or ground may be drilled as necessary. In unpaved areas, the probe can be used as an extension to listen directly on the buried pipe (see Figure 8-9).

NOTE: For safety and to prevent interruption of service, contact other utilities for clearance before starting to drill. Many areas have a one-call, underground-protection center to clear all utilities at once.

After pinpointing the leak, mark the pavement above the exact location of the leak. Record all information on the leak detection log and turn in work orders for repair.

Nonpersonnel acoustic leak survey. The use of acoustic listening instruments is a proven procedure for identifying and localizing hidden leakage. However, research organizations and practical experience have demonstrated that acoustic listening only on valves and hydrants or the ground surface leads to many leaks being overlooked. Consequently, for effective leakage-reduction programs using acoustic survey, soundings must also be performed on all service connections.

The major disadvantages of this approach include the following factors:

- labor intensive
- high skill levels required
- difficult to maintain efficient performance
- low daily coverage rates
- service line location often difficult and slow

- limited success on nonmetallic pipes

Figure 8-9 Using extension to listen for leak sounds on fire hydrant

Acoustic leak survey results can be optimized by using nighttime operations, uninterrupted listening, and extended listening periods.

Statistical noise analyzer. The statistical noise analyzer makes leakage control possible for areas that cannot be identified as having leaks due to excessive interference. The system includes a hydrophone sensor typically attached at hydrants, measurement taps, or chlorination taps. This sensor is connected by cable to a hand-sized acoustic data processor.

The statistical noise analyzer is designed for nonpersonnel acoustic operations during the night. Because the system listens for a continuous two-hour period at a single contact point, it is more effective at monitoring leak sounds than personnel surveying techniques.

Units are temporarily installed within the distribution system at varying intervals up to approximately 1,500 ft. They are typically preprogrammed to begin listening around 2:00 a.m. When activated, the system monitors noise measured on the distribution system and stores results in twenty-four 5-min analysis periods until monitoring is complete (4:00 a.m.).

The statistical variance of this noise is determined by the presence or absence of leakage. The "noise signature" obtained at each monitoring point confirms the presence or absence of leakage and indicates the relative location.

Installation and data collection is usually performed during daily operations. The data can be downloaded in the field for immediate or later evaluation by technicians or engineering staff. The unit can then be reprogrammed and installed at a new location for the next night's sounding operation.

Most software provides an overall 2-h graph, a 3-D graph, and 24 individual 5-min graphs.

This method of leakage identification and location includes the following benefits:

- Low deployment cost. The unit can be installed during daytime hours and picked up the following day for positioning in other areas.
- Minimal training to set up. Deployment is simple and can be performed with little training.
- Easy data collection. Interrogation is by personal computer and can be performed in the field, or data can be stored for later analysis by appropriate technical personnel.
- High acoustic sensitivity. Hydrophone sensors are used to directly contact the pressurized water.
- Nighttime listening. Provides the benefits of nighttime listening without the labor costs.
- Unlike personnel listening, there is no timing of the listening step, concentration and distractions are not factors, and trained skills are more easily transferred.

When the system is installed in visible areas, security and equipment protection is maintained by placing the units in locked security housings.

In addition to progressive acoustic leak survey operations, the units can also be deployed for

- specific areas of difficulty for extensive analysis
- advanced known leak investigation
- extended daily monitoring of special event or special concern areas
- investigation of piping sections that have had repairs
- inspection of new installations
- permanent monitoring of trunk mains or any piping section where daily monitoring is desirable

The statistical noise analyzer's application lends itself to distribution system operations from small rural systems to large municipalities, as well as industrial and commercial water systems.

Tracer gas method. Occasionally situations occur where leaks cannot be detected or pinpointed by traditional electrosonic or correlation methods. These types of leaks often occur as hydrostatic test failures during construction. They are usually small and occur more frequently with nonmetallic pipe materials. Tracer gas has proven effective for detecting and pinpointing leaks in these situations.

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

For detection using hydrogen gas, it is not necessary to dewater the main because the mixture (less than 5 percent) is injected in a liquid form into the water. The gas mixture is a standard mixture of 5 percent hydrogen in nitrogen, purchased already mixed from a gas supplier. CAUTION: **the actual blending of hydrogen and nitrogen is a highly hazardous operation that should only be undertaken by the gas supplier.** Do not handle hydrogen gas in any form other than ready-mixed to 5 percent hydrogen in nitrogen, or less. Any hydrogen-nitrogen mixture containing less than 5.7 percent hydrogen is nonflammable (ISO 10156).

As the liquid exits the leak, it returns to a gaseous form. Walking directly over the test section of pipe, the operator uses a specialized instrument that continuously senses the atmosphere at grade. The instrument is highly sensitive and can detect minor seepages of gas to atmosphere.
When gas is detected at the surface, the instrument's various sensitivity settings can quickly verify and pinpoint the leak location. If the surface over the pipe is covered with asphalt or concrete, or soil conditions include frost, it may be necessary to place test holes directly over the pipe, normally at 3 m intervals along the pipe run, to allow the helium to vent to atmosphere through the cover.

Excavating the leak. The survey crew and the repair crew should work together to uncover the leak. If the hole is dry, the survey crew can relisten to the sound and help the repair crew locate the leak. A leak may be missed because it is on the bottom of the pipe or a few inches away and no sign of dampness or water is visible. By working together, both the survey and repair crews can share knowledge and experience that make locating the leak easier.

Uncovering leaks requires careful excavation to avoid other pipes, other utilities, or both. Be sure to check with other utilities before starting to dig.

Table 8-1 Drips per second converted to liters per minute

Drips per second	Liters per minute
1	0.023
2	0.045
3	0.068
4	0.091
5	0.114

NOTE: Five drips per second amounts to a steady stream.

Table 8-2 Cups per minute converted to liters per minute

Cups per Minute (120 ml)	Liters per Minute
0.25	0.061
0.50	0.117
0.75	0.178
1.00	0.235
1.50	0.356
2.00	0.473
2.50	0.591
3.00	0.712
3.50	0.829
4.00	0.946

MEASURING AND ESTIMATING LOSSES FROM DISCOVERED LEAKS

As part of detection and repair, leaks should be measured to determine the rate of loss and the total volume lost during the life of the leak. There are three ways to do this: use a container of known volume and a stopwatch, use a hose and a meter, or calculate losses using modified-orifice and friction-loss formulas.*

Bucket-and-Stopwatch Method

The bucket-and-stopwatch method is as simple as its name.

Hold a container against the leak for a predetermined time period. Measure the time with a stopwatch. Measure the water captured with a measuring cup or other container of known volume. Then convert time and volume to liters per minute (see Tables 8-1 and 8-2).

Use time intervals that are easy to deal with. Catch the leaking water for 1 min, then the volume collected is the per-minute flow. For other time periods, see the following:

Time in seconds:	6	10	15	30	
Multiply volume in liters by:	10	6	4	2	to get liters per minute.

Table 8-2 provides the conversion from cups per minute to liters per minute. To convert liters per minute to million liters for a 2-year time period (the average lifetime of a leak), use the following:

$$\text{A leak of 1 l /min for 2 years} = \frac{(60\text{ min/h})(24\text{ h/day})(365\text{ days/year})(2\text{ years})}{1{,}000{,}000\text{ l}}$$

$$= 1.051\text{ mil l} \qquad \text{(Eq 8-1)}$$

Large, spraying leaks can be measured by draping an enveloping device (such as a large canvas, rain jacket, or inverted pail) over the leak and diverting the water into a container.

Hose-and-Meter Method

This is the most direct method of measuring leaks, but it requires some mechanical effort. Connect a hose to the leak and direct the flow through a meter. Then, simply read the meter.

Calculation Method

This is the simplest method to perform in the field, but it requires calculations. The method is often helpful for large leaks where the flow is too great to measure and the main must be valved off. It requires measuring the size and shape of the hole and determining the line pressure. A pressure gauge or a hand-held pitot blade could be used to determine the pressure of the water coming from the leak or a nearby fire hydrant. This method also uses some assumptions regarding the shape of the hole, which may introduce error.

*Greeley, D.S. "Leak Detection Productivity," Reference Number 1981, Water/Emergency & Management, Des Plaines, 111. (1981).

Table 8-3 Leak losses for circular holes under different pressures*

Diameter of hole cm	Area of hole cm2	Leak losses (l / s) Water Pressure (atmospheres) 1,37	2,73	4,10	5,46	6,83	8,19	9,56	10,92	12,29	13,65
0,25	0,05	0,067	0,095	0,117	0,135	0,151	0,165	0,178	0,191	0,202	0,213
0,51	0,20	0,269	0,381	0,467	0,539	0,602	0,660	0,713	0,762	0,808	0,852
0,76	0,46	0,606	0,857	1,050	1,212	1,355	1,485	1,604	1,715	1,819	1,917
1,02	0,81	1,078	1,524	1,867	2,155	2,410	2,640	2,851	3,048	3,233	3,408
1,27	1,27	1,684	2,381	2,916	3,368	3,765	4,124	4,455	4,763	5,051	5,325
1,52	1,82	2,425	3,429	4,200	4,849	5,422	5,939	6,415	6,858	7,274	7,667
1,78	2,48	3,300	4,667	5,716	6,600	7,380	8,084	8,732	9,335	9,901	10,436
2,03	3,24	4,311	6,096	7,466	8,621	9,639	10,559	11,405	12,192	12,932	13,631
2,29	4,10	5,456	7,715	9,449	10,911	12,199	13,363	14,434	15,431	16,367	17,252
2,54	5,07	6,735	9,525	11,666	13,470	15,060	16,498	17,820	19,050	20,206	21,299
2,79	6,13	8,150	11,525	14,116	16,299	18,223	19,962	21,562	23,051	24,449	25,771
3,05	7,30	9,699	13,716	16,799	19,397	21,687	23,757	25,660	27,432	29,096	30,670
3,30	8,56	11,382	16,097	19,715	22,765	25,452	27,881	30,115	32,195	34,147	35,995
3,56	9,93	13,201	18,669	22,865	26,402	29,518	32,336	34,927	37,338	39,603	41,745
3,81	11,40	15,154	21,431	26,248	30,308	33,886	37,120	40,094	42,863	45,463	47,922
4,06	12,97	17,242	24,384	29,864	34,484	38,555	42,234	45,618	48,768	51,726	54,524
4,32	14,64	19,465	27,527	33,714	38,929	43,524	47,679	51,499	55,055	58,394	61,553
4,57	16,42	21,822	30,861	37,797	43,644	48,796	53,453	57,736	61,722	65,466	69,007
4,83	18,29	24,314	34,385	42,113	48,628	54,368	59,557	64,329	68,771	72,942	76,888
5,08	20,27	26,941	38,100	46,663	53,882	60,241	65,991	71,279	76,200	80,822	85,194

*Calculated using Greeley's formula (see Eq 8-2).

Table 8-4 Leak losses for joints and cracks*

Area of Joint or Crack Length cm	Width cm	Leak Losses (l / s) Water Pressure (atmospheres) 1,37	2,73	4,10	5,46	6,83	8,19	9,56	10,92	12,29	13,65
2,54	0,08	0,2	0,3	0,3	0,4	0,4	0,5	0,5	0,6	0,6	0,6
2,54	0,16	0,4	0,6	0,7	0,8	0,9	1,0	1,1	1,1	1,2	1,3
2,54	0,32	0,8	1,1	1,4	1,6	1,8	2,0	2,1	2,3	2,4	2,5
2,54	0,64	1,6	2,3	2,8	3,2	3,6	3,9	4,3	4,5	4,8	5,1

*For leaks emitted from joints and cracked service pipes, an orifice coefficient of 0.60 is used in the following equation:

$$Q = (0.853)\{A\}(\sqrt{P})$$

Where: Q = flow, in liters per second (l/s);

A = the area, in square centimeters (cm2);

P = the pressure, in atmospheres (atm.)

For losses from such items as pipes or broken taps, assume an orifice coefficient of 0.80 and calculate flow in liters per second from the formula

$$Q = (1.138)(A)(\sqrt{P}) \qquad \text{(Eq 8-2)}$$

Where:

Q = flow, in liters per second
A = the cross-sectional area of the leak, in square centimeters (cm2)
P = pressure, in atmospheres (atm.)

If a hole in a pipe were circular, then the area would be $A = 3.14\ r^2$. Measure the diameter of the hole (to get the radius) and determine the pressure in the pipe.

For relatively small holes, leak rates are calculated by assuming a circular hole and several pressures. Tables 8-1 and 8-2 show calculated leak rates for typical meter-box leaks. Table 8-3 covers circular leaks, and Table 8-4 covers joints and cracks.

DETERMINING LEAK DETECTION EFFECTIVENESS____________________

After repairing leaks, record all information regarding excavation, flow rates, and repair on the leak repair report (see Figure 4-10). This helps with future repair projects and provides information to be used in evaluating benefits of the *leak-detection project.*

An important and often neglected post survey step is determining whether or not the project was a cost-effective water conservation measure. To determine if it was cost-effective, the agency must evaluate the completed leak detection project.

The Leak Detection and Repair Project Summary (see Figure 8-11) includes information needed for this evaluation.

Looking Beyond Leak Detection

Detecting leaks is only the first step in eliminating leakage. Leak repair is the more costly step in the process. Repair clamps, or collars, are the preferred method for repairing small leaks, whereas larger leaks may require replacing one or more sections of pipe. On average, the savings in water no longer lost to leakage outweigh the cost of leak detection and repair. In most systems, assuming detection is followed by repair, it is economical to completely survey the system every one to three years. Instead of repairing leaking mains, some argue it is preferable to replace more leak-prone, generally older pipes. Selecting a strategy depends upon the frequency of leaks in a given pipe and the relative costs to replace and repair them.

Deciding whether to emphasize detection and repair, versus pipe replacement, depends upon site specific leakage rates and costs. In general, detection and repair result in an immediate reduction in lost water, whereas replacement will have a longer-lasting impact to the extent that it eliminates the root cause of leaks. The most important factor in a leak detection and repair program is the need for accurate, detailed records that are consistent over time and easy to analyze. Records concerning water production and sales, and leak and break costs and benefits, will become increasingly important as water costs, and leak and break damage costs increase, and as leak detection and rehabilitation programs become more important.

Figure 8-10 Leak repair report

LEAK REPAIR REPORT

Utility:	Public Communal Company "Water and Sewer Works" Bar	Date:	1/11/2003
W.O.No:	2356	Foreman:	Miloš Milošević

LEAK IDENTIFICATION

		Map Reference:	Water Distribution System
Refer to:	Leak Discovery Report	Page and Coordinates:	6
Discovery Date:	1/10/2003	Leak No.:	197

Location (include street name and number): Vladimira Rolovića 15, Bar

FOR MAIN AND SERVICE LATERAL LEAKS ONLY

Sketch a map of the site including:

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

If Main of Service Leak, Attach Three Photos:

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

Leak Found? Yes (Yes/No)

TYPE OF LEAK

Main Line Leak		Meter Leak		Joint Leak	
Service Lateral Leak		Counter Leak		Other Leak	
Fire Hydrant Leak		Valve Leak			

Describe: *automatic flushing device*

DESCRIPTION OF REPAIR

Damaged part was: **x** Repaired; ___ Replaced

If replaced, what material was used?

If repaired, what repairs were made?		Repair time:	4h	
Leak Clamp				
Welded		Crew Size:	2	(persons)
Other				
Repacked Valve		Equipment Used:		Backhoe
Recaulked Joint				Dumptruck
Other (describe)				

Repair Costs:			Size of Leak:		
Material	8.60	€	Measured:	0.22	l / sec
Labor	88.40	€	Estimated:		l / sec
Equipment	9.20	€			
Other	0.77	€	Method Used:		
Total	106.97	€	Timed 10 l bucket with stopwatch		

DESCRIPTION OF DAMAGE FOR MAINS AND SERVICES

What part was damaged?
- Pipe Barrel ____
- Joint ____
- Flange Nuts, Bolts, Tie Rods ____
- Valve ____
- Other ____

Type of Break
- Split ____
- Hole ____
- Circumferential split ____
- Broken Coupling ____
- Service
- Pulled ____
- Cracked at Corporation Stop ____
- Cracked Pipe ____
- Other (describe) ____

In your opinion, what caused the damage? ____

Estimated Age of Leak in Months 48
How determined? ____
Diameter of Main or Lateral (mm) ____
Depth to Top of Pipe (m) ____

Pipe Material:
- Galy Iron ____
- Black Iron ____
- Cast Iron ____
- Ductile Iron ____
- Steel ____
- Copper ____
- ACP ____
- P.V.C ____
- Polybutylene ____

System Pressure ____

How Determined ____

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

Original Metal Remaining: ____ (mm)
Deterioration is on: ____ Outside ____ Inside

Min. Thickness of Good Thickness: (mm) : ____

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

Number of Previous Leak Repairs: ____
Last Repair Date: ____

Cause of Leak: ____

In your opinion, should pipe be replaced? Yes ____ No ____ Do not know ____
If yes, explain extent: ____

FOR EXCAVATIONS, INDICATE GROUND CONDITIONS

Type of Soil:
- Rocky ____
- Clay ____
- Adobe ____
- Other ____
- Sandy ____
- Hard Pan ____
- Loam ____

Existing Bedding:
- Gravel/ Sand ____
- Native Soil ____
- Pea Gravel ____
- Other ____

Type of Cover: Type
- Concrete ____
- Asphalt ____
- Soil ____
- Other ____

Figure 8-11 Leak detection and repair project summary

LEAK DETECTION AND REPAIR PROJECT SUMMARY

Water Utility: The Public Communal Company "Water and Sewer Works" Bar

Date: 12/15/1999

Report Prepared by: Petar Petrović

LEAK DETECTION SURVEY

Total number of days Leak Surveys were Conducted:	65	First Survey Date:	7/10/1999
		Last Survey Date:	11/4/1999
Number of Listening Points:			
Meters	13,786	Valves	2,505
Hydrants	1,067	Test rods	0
Other			
Number of suspected leaks:	175	Number of pinpointed leaks:	7
Length of mains surveyed (m)	210,743	Survey time:	469 h
		Pinpointing time:	2 h

Average survey rate = $\frac{\text{Length of main surveyed x 8}}{\text{Total survey and pinpointing hours}}$ = m / day 3,579

Total number of visible leaks reported since survey started, from other sources (not discovered during leak detection surveys): 0

LEAK REPAIR SUMMARY

First Leak Repair Made:	7/11/1999	Last Leak Repair Made:	11/5/1999
Number of Repairs Needing Excavation:	27	Total Water Losses from Excavated Leaks	12.83 l/s
Number of Repairs Not Needing Excavation:	148	Total Water Losses from Nonexcavated Leaks	0.05 l/s
Total number of Repaired Leaks	175	Total Water Losses	12.88 l/s

Excavated Leak Repair Costs:		Nonexcavated Leak Repair Costs:	
Materials	539.00 €	Materials	317.04 €
Labor	3371.12 €	Labor	1737.18 €
Equipment	432.35 €	Equipment	191.57 €
Other	26.95 €	Other	64.31 €
Subtotal	4369.42 €	Subtotal	2310.10 €

Total Repair Costs:	
Materials	856.04 €
Labor	5108.30 €
Equipment	623.92 €
Other	91.26 €
TOTAL	6679.52 €

LEAK DETECTION PROJECT COST-EFFECTIVENESS

Step 1 Calculate the value of water recovered (Vwr) from all repaired leaks.

Vwr = Total Leakage Recovered in l/s x Leakage Time x (l / s) Leakage Unit of Measurement, Wc (€ / m3)

Wc * (€ / m3) = water purchase price x operating costs per unit of water

* Line 19 of Water Audit Report

Vwr = l/sec 12.88 x 60min x 24h x 730 days x € / m3 0.50

Vwr = € 6,770

Step 2

Determine the total cost of the leak detection survey.

Equipment	1,852.00	€
Training	308.00	€
Survey costs	19,981.00	€
Total	22,141.00	€

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

Benefit: Cost Ration = Value of water recovered / Total cost leak detection survey

= 0.31

For planning future leak detection efforts, you can calulate average survey costs per m'.

Step 4 Determine average survey costs per meter of main surveyed (€ / m)

Cost/m = Total cost of leak detection survey / Total number of meters surveyed

= 0.11 € / m

In addition to assisting with decisions about rehabilitation and replacement, the leak detection and repair program can further other water utility activities, including:

Inspecting hydrants and valves in a distribution system.
Updating distribution system maps.
Using remote sensor and telemetry technologies or ongoing monitoring and analysis of source, transmission, and distribution facilities.

Remote sensors and monitoring software can alert operators to leaks, fluctuations in pressure, problems with equipment integrity, and other concerns; and inspecting pipes, cleaning, lining, and other maintenance efforts to improve the distribution system and prevent leaks and ruptures from occurring. Utilities might also consider methods for minimizing water used in routine water system maintenance.

Finally, detecting and repairing leaks is only one water conservation alternative; others include: meter testing and repair/replacement, rehabilitation and replacement programs, installing flow reducing devices, corrosion control, and water pricing. All these methods should be used, as effectively as possible, in order to use water conservation as a viable long-term supply alternative, which results in considerable capital savings and avoidance of environmental degradation.

ANNEX A

GLOSSARY OF TERMS FOR WATER BALANCE AUDIT COMPONENTS AND CALCULATIONS

Apparent Losses Cost Ratio is the ratio, expressed as a percentage, of the annual cost of apparent losses of water over the annual operating cost of the water supply system.

Authorized Consumption is the volume of metered and/or unmetered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorized to do so for commercial and industrial purposes. It also includes water exported.

Infrastructure Leakage Index (ILI) is the ratio of the Technical Indicator for Real Losses (TIRL) to the value of Unavoidable Annual Real Losses (UARL) calculated for current pressures and continuity of supply. ILI is a non-dimensional performance indicator of the current overall management of the infrastructure for leakage control purposes.

Non-Revenue Cost Ratio is the ratio, expressed as a percentage, of the annual cost of non-revenue water over the annual operating cost of the water supply system.

Real Losses Cost Ratio is the ratio, defined as a percentage, of the annual cost of real losses of water over the annual operating cost of the water supply system.

Unbilled Authorized Consumption Cost Ratio is a percentage equivalent of the annual cost of unbilled authorized consumption of water divided by the annual operating cost of the water supply system.

System Input Volume is the volume of water input to a transmission system or a distribution system, or both. It is equal to the sum of Water Produced and Water Imported (a positive value)/ Exported (a negative value).

Technical Indicator for Real Losses (TIRL), expressed in liters per connection per day, is equal to the Annual Volume of Real Losses divided by the number of service connections.

Unavoidable Annual Real Losses (UARL) is a prediction of what the real losses would be for any specific system if all infrastructure was in good condition, with active leakage control, and expedient leak repair procedures. It takes into account the length of mains, number of service connections, location of customer meters, continuity of supply, and average operating pressures (w.s.p.) between 20 and 100 meters.

Unbilled Authorized Consumption Cost Ratio is the ratio, expressed as a percentage, of the annual cost of unbilled authorized consumption of water over the annual operating cost of the water supply system.

Water Imported / Exported is the volume of bulk water supply transferred across operational boundaries.

Water Losses are the difference between System Input Volume and Authorized Consumption.

Water Produced is the volume of water treated for input to water transmission mains or directly to the distribution system.

Water Balance Audit is a process of determining how much water is lost in a water supply system, and how much that loss of water costs the utility.

Real Losses are the sum of leakage on transmission and/or distribution mains, leakage and overflows at storage tanks, and leakage on service connections up to the point of the customer's meter.

Apparent Losses are the sum of Unauthorized Consumption and metering inaccuracies.

Water Demand is the total amount of water that all authorized consumers of the water supply system need, plus the amount used by Unauthorized consumers and that lost to system defects.

ANNEX B

WATER AUDIT AND THE RELATED CALCULATIONS FORMS

This Annex cosists of the following forms used for water auditing and the related calculations:

- WATER AUDIT WORKSHEET
- SAMPLE LEAK DETECTION AND REPAIR PLAN
- LEAK DETECTION SURVEY DAILY LOG
- LEAK REPAIR REPORT
- LEAK DETECTION AND REPAIR PROJECT SUMMARY AND LEAK DETECTION PROJECT COST-EFFECTIVENESS

Note : Chapter 7 contains the instructions on filling the water audit worksheet in. Chapter 8 contains the instructions on filling other forms in.

WATER AUDIT WORKSHEET

Utility:

Audit Study Period: to

Line	Item	Subtotal	Water Volume Total Cumulative	Units*
Task 1 -	**Measure the Supply**			
1	Uncorrected total water supply to the distribution system (total of master meters)		______	______
2	Adjustment to total water supply			
2A	Source meter error (+ or -)	______		______
2B	Change in reservoir and tank storage (+ or -)	______		______
2C	Other contributions or losses	______		______
3	Total adjustment to total water supply (add lines 2A, 2B i 2C)		______	______
4	Adjusted total water supply to the distribution system (add lines 1 i 3)		______	______
Task 2 -	**Measure Authorized Metered Use**			
5	Uncorrected total metered water use	______		______
6	Adjustment due to meter reading lag time (+ or -)	______		______
7	Metered deliveries (add lines 5 and 6)		______	______
8	Total sales meter error and system-service meter errors (+ or -)			
8A	Residential meter error	______		______
8B	Large meter error	______		______
8C	Total (add lines 8A and 8B)		______	______
9	Corrected total metered water deliveries (add lines 7 and 8C)		______	______
10	Corrected total unmetered water (subtract line 9 from line 4)		______	______

*Units of measure must be consistent throughout the worksheet

Line	Item	Subtotal	Water Volume Total Cumulative	Unit*
Task 3	**Measure Authorized Unmetered Use**			
11A	Firefighting and firefighting training	______		______
11B	Main flushing	______		______
11C	Storm-drain flushing	______		______
11D	Sewer cleaning	______		______
11E	Street cleaning	______		______
11F	Schools	______		______
11G	Landscaping in large public areas:			
	Parks	______		______
	Golf courses	______		______
	Cemeteries	______		______
	Playgrounds	______		______
	Highway median strips	______		______
	Other landscaping	______		______
11H	Decorative water facilities	______	(metered)	______
11I	Swimming pools	______	(metered)	______
11J	Construction sites	______	(metered)	______
11K	Water quality and other testing (pressure-testing pipe, water quality, etc.)	______	(metered)	______
11L	Process water at treatment plants	______		______
11M	Other unmetered uses	______		______
12	Total authorized metered water (add lines 11A through 11 M)		______	______
13	Total water losses (subtract line 12 from line 10)		______	______

*Units of measure must be consistent throughout the worksheet.

Line	Item	Subtotal	Water Volume Total Cumulative	Unit*
Task 4	**Measure Water Losses**			
14A	Accounting procedures errors	______		______
14B	Unauthorized connections	______		______
14C	Malfunctioning distribution system controls	______		______
14D	Reservoir seepage and leakage	______		______
14E	Evaporation	______		______
14F	Reservoir overflow	______		______
14G	Discover leaks	______		______
14H	Unauthorized use	______		______
15	Total identified water losses (add lines 14A through 14H)		______	______
Task 5	**Analyze Audit Results**			
16	Potential water system leakage (subtract line 15 from line 13)		______	______
17	Recoverable leakage (multiply line 16 by 0.50)		______	______

Line	Item	€ / m3 (Euro per Unit of Volume)	
18A-B	Cost savings		
18A	Cost of water supply	______	______
18B	Variable operation and maintenance costs	______	______
19	Total costs per unit of recoverable leakage (add lines 18A and 18B)	______	______

Line	Item	Euro per year	
20	One-year benefit from recoverable leakage (multiply line 17 by line 19)	______	______
21	Total benefits from recovered leakage (multiply line 20 by line 2)	______	______
22	Total costs of leak detection project	______	______
23	Benefit-to-cost ration (divide line 21 by line 22)	______	

Prepared by:	Title:
	Date:

*Units of measure must be consistent throughout the worksheet

SAMPLE LEAK DETECTION AND REPAIR PLAN

Name of Utility : _ Date:

A Area to be Surveyed

A - 1 Using the results of the water audit, show on a map which areas in the distribution system will be surveyed. Indicate which areas have the higher potential for recoverable leakage. Consider records of previous leaks, type of pipe, age of pipe, soil conditions, high pressures, ground settlement, and improper installation procedures.

Describe each area to be surveyed under item B-2 of this plan

A - 2 Total length of main to be surveyed in km : __________

When calculating the kilometers of main, include the total length of pipe and exclude service lines. If only a portion of the system is being surveyed, calculate the benefit-to-cost ration to reflect only the portion included in the survey.

A - 3 Average number of km of main surveyed per day: __________

The average survey crew can survey about two miles of main per day. Items to consider include distances between services, traffic and safety conditions, and number of listening contact points. Explain if more than three miles per day are surveyed.

A - 4 Number of working days needed to complete survey (divide line 2 by line 3): __________

B Procedures and Equipment

B - 1 Describe procedures and equipment you will use to detect leaks.

Experience shows that the best results are obtained by listening for leaks at all system contact points (such as water meters, valvesm hydrants, and blowoffs).

B - 2 Describe why the areas noted on the map in step A-1 have the greatest potential for recovering leakage:

B - 3 If you will not be listening for leaks at all system contact points, describe your plan for effectively detecting leaks:

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

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

B - 6 Describe the methods you will use to determine the flow rates for excavated leaks of various sizes.

C Staffing

C - 1 How many agency staff will be used? __________

Staff costs including wages and benefits:

	€ / h	€ / day
Person 1	__________	__________
Person 2	__________	__________
TOTAL	__________	__________

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

Cost of consultant staff:

	€ / h	€ / day
Person 1	__________	__________
Person 2	__________	__________
TOTAL		

D	**Leak Detection Survey Costs**	days	€ / day	€
D -1	Agency-crew costs	______	______	______
D - 2	Consultant-crew costs			
D - 3	Vehicle costs	______	______	______
D - 4	Other	______	______	______
D - 5	Total survey costs			______
E	**Leak Detection Budget**			€
E -1	Cost of leak detection equipment			______
E - 2	Leak detection team training			______
E - 3	Leak detection survey costs			______
E - 4	Total leak detection costs			______
F	**Leak Survey and Repair Schedule**			
	Indicate realistic, practical dates.			
F - 1	When will the leak survey begin?	______		
E - 2	When will the leak survey be	______		
E - 3	When will leak repairs begin?	______		
E - 4	When will leak repairs be completed?	______		

Prepared by:	Title:
	Datum :

LEAK DETECTION SURVEY DAILY LOG

Name of Water Utility: ____________________ Date : ____________

Leak Detection Team Members: ____________________

Manufacturer and Models of Equipment Used: ____________________

Area Surveyed: ____________________

Map reference: ____________________ Page & Coordinates: ____________

Street and Block Numbers: ____________________

Leak Nr.	Location or Address of Suspected Leak	Agency or Customer (A or C)	Leak Pinpointed (Y or N)	Leak to Be Rechecked (Y or N)	Leak Repaired (Y or N)	Not a Leak (Date)
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						

	Meters	Hydrants	Valves	Test Rods	Other
Indicate Number of Listening Points Used					

Kilometers of Main Surveyed ____________ Survey time ____________ h

To be rechecked ____________ (number)

Number of Leaks Suspected ____________

Number of Leaks Pinpointed ____________ Pinpointing time ____________ h

Remarks:
Found a 50/50 percentage between stem packing leaks and small service meter leaks.
Also found two customer sprinkler system leaks.
Customers were informed.

LEAK REPAIR REPORT

Utility: _ Date:

W.O.No: _ Foreman:

LEAK IDENTIFICATION

Map Reference: ____________

Refer to: ____________ Page and Coordinates: ____________

Discovery Date: ____________ Leak No.: ____________

Location (include street name and number):

FOR MAIN AND SERVICE LATERAL LEAKS ONLY

Sketch a map of the site including:

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

If Main of Service Leak, Attach Three Photos:

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

Leak Found? ____________ (Yes/No)

TYPE OF LEAK

Main Line Leak	____________	Meter Leak	____________	Joint Leak	____________
Service Lateral Leak	____________	Counter Leak	____________	Other Leak	____________
Fire Hydrant Leak	____________	Valve Leak	____________		

Describe: ____________

DESCRIPTION OF REPAIR

Damaged part was: ____________ Repaired
____________ Replaced

If replaced, what material was used? ____________

If repaired, what repairs were made?

- Leak Clamp ____________
- Welded ____________
- Other ____________
- Repacked Valve ____________
- Recaulked Joint ____________
- Other (describe) ____________

Repair time: ____________

Crew Size: ____________ (persons)

Equipment Used: ____________ Backhoe
____________ Dumptruck

Repair Costs:

Material	____________	€
Labor	____________	€
Equipment	____________	€
Other	____________	€
Total	____________	€

Size of Leak:

Measured: ____________ l / sec

Estimated: ____________ l / sec

Method Used: ____________

DESCRIPTION OF DAMAGE FOR MAINS AND SERVICES

What part was damaged?
- Pipe Barrel ______
- Joint ______
- Flange Nuts, Bolts, Tie Rods ______
- Valve ______
- Other ______

Type of Break
- Split ______
- Hole ______
- Circumferential split ______
- Broken Coupling ______
- Service Pulled ______
- Cracked at Corporation Stop ______
- Cracked Pipe ______
- Other (describe) ______

In your opinion, what caused the damage? ______

Estimated Age of Leak in Months ______
How determined? ______
Diameter of Main or Lateral (mm) ______
Depth to Top of Pipe (m) ______

Pipe Material:
- Galy Iron ______
- Black Iron ______
- Cast Iron ______
- Ductile Iron ______
- Steel ______
- Copper ______
- ACP ______
- P.V.C ______
- Polybutylene ______

System Pressure ______

How Determined ______

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

Original Metal Remaining: ______ (mm)
Deterioration is on: ______ Outside ______ Inside
Min. Thickness of Good Thickness (mm): ______

Is there evidence of previous leak or repairs in same general area? ______ Yes ______ No
Number of Previous Leak Repairs: ______
Last Repair Date: ______

Cause of Leak: ______

In your opinion, should pipe be replaced? Yes ______ No ______ Do not know ______
If yes, explain extent: ______

FOR EXCAVATIONS, INDICATE GROUND CONDITIONS

Type of Soil:
- Rocky ______
- Clay ______
- Adobe ______
- Other ______
- Sandy ______
- Hard Pan ______
- Loam ______

Existing Bedding:
- Gravel/ Sand ______
- Native Soil ______
- Pea Gravel ______
- Other ______

Type of Cover:
- Concrete ______
- Asphalt ______
- Soil ______
- Other ______

LEAK DETECTION AND REPAIR PROJECT SUMMARY

Water Utility: Date:

Report Prepared by: ______________________

LEAK DETECTION SURVEY

Total number of days Leak Surveys were Conducted: __________ First Survey Date: __________

Last Survey Date: __________

Number of Listening Points:

Meters __________ Valves __________

Hydrants __________ Test rods __________

Other __________

Number of suspected leaks: __________ Number of pinpointed leaks: __________

Length of mains surveyed (m) __________ Survey time: __________ h

Pinpointing time: __________ h

$$\text{Average survey rate} = \frac{\text{Length of main surveyed x 8}}{\text{Total survey and pinpointing hours}} = \quad \text{m / day}$$

Total number of visible leaks reported since survey started, from other sources (not discovered during leak detection surveys): __________

LEAK REPAIR SUMMARY

First Leak Repair Made: __________ Last Leak Repair Made: __________

Number of Repairs Needing Excavation: __________ Total Water Losses from Excavated Leaks __________ l/s

Number of Repairs Not Needing Excavation: __________ Total Water Losses from Nonexcavated Leaks __________ l/s

Total number of Repaired Leaks __________ Total Water Losses __________ l/s

Excavated Leak Repair Costs:			Nonexcavated Leak Repair Costs:		
Materials	__________	€	Materials	__________	€
Labor	__________	€	Labor	__________	€
Equipment	__________	€	Equipment	__________	€
Other	__________	€	Other	__________	€
Subtotal	__________	€	Subtotal	__________	€

Total Repair Costs:		
Materials	__________	€
Labor	__________	€
Equipment	__________	€
Other	__________	€
TOTAL		€

LEAK DETECTION PROJECT COST-EFFECTIVENESS

Step 1 Calculate the value of water recovered (Vwr) from all repaired leaks.

Vwr = Total Leakage Recovered in l/s x Leakage Time x (l / s) Leakage Unit of Measurement, Wc (€ / m3)

Wc * (€ / m3) = water purchase price x operating costs per unit of water

* Line 19 of Water Audit Report

Vwr = l/sec ______ x 60min x 24h x ______ days x € / m3 0.50

Vwr = € ______

Step 2 Determine the total cost of the leak detection survey.

Equipment	______	€
Training	______	€
Survey costs	______	€
Total	______	€

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

Benefit: Cost Ration = Value of water recovered / Total cost leak detection survey

= ______

For planning future leak detection efforts, you can calulate average survey costs per m'.

Step 4 Determine average survey costs per meter of main surveyed (€ / m)

Cost/m = Total cost of leak detection survey / Total number of meters surveyed

= ______ € / m