California Department of Water Resources
The Resources Agency

American Water Works Association
California-Nevada Section

water conservation
guidebook no. 5

Water Audit and Leak Detection Guidebook

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- *Catalog of Water Conservation Materials*
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THE COVER PHOTO depicts how underground leaks can be detected and located by listening for the sounds of leakage on system contact points, such as hydrants, valves, and meters. This member of a leak detection crew is using sonic equipment to conduct an initial listening survey.

State of California
The Resources Agency

Water Audit and Leak Detection Guidebook

Fifth in a Series of Water Conservation Guidebooks for Use by Interested Organizations, Including Water Agencies, Waste Water Treatment Agencies, Government, and Service Groups

August 1986

(Revised June 1992)

Department of Water Resources
Water Conservation Office

American Water Works Association
California-Nevada Section

FOREWORD

An effective way to conserve water is to detect and repair leaks in municipal water systems. This controls loss of water that water agencies have paid to obtain, treat, and pressurize. Because water leaks from the system before it reaches the consumer, water agencies lose revenue and incur unnecessary costs.

The California Department of Water Resources (DWR) estimates that about 250,000 acre-feet of water leaks from municipal systems in California each year. DWR's experience in working with 60 local water agencies, whose water audits reveal leak detection projects to be cost effective, indicates that leaking water can be controlled at a cost averaging less than $50 per acre-foot, a cost usually less than what a water agency pays for the water.

A water audit and leak detection program has benefits in addition to the value of water control. Meter testing performed as a part of the water audit will frequently identify customer meters that inaccurately record water use. Recalibrating inaccurate meters will result in increased revenues to the water agency. Early detection of leaks will reduce the chances that the leaks will cause major property damage to the water agency or its customers. Better knowledge of the location of valves and mains will allow the water agency to react quickly when emergencies do occur.

The first two chapters of this Guidebook provide practical methods and sample forms for conducting a water audit. The audit enables one to determine if a leak detection project would be cost effective. The third and fourth chapters include instructions for the most efficient way to detect leaks.

This Guidebook is one of DWR's "how to" series on step-by-step ways to develop specific water conservation programs. The inside of the front cover lists other DWR water conservation publications. Water conservation assistance and training information can also be obtained from DWR District Offices which are listed inside the back cover.

This Guidebook, which is jointly sponsored by DWR and the California-Nevada Section, American Water Works Association (AWWA), reflects the wide participation, experience and cooperation among AWWA members and the Department.

David N. Kennedy, Director
Department of Water Resources

Michael J. McGuire, Chairman
California-Nevada Section
American Water Works Association

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DWR acknowledges all of the public water agencies that participated in the statewide water audit and leak detection program. These agencies field tested these procedures and provided comments and suggestions that contributed to the improvement of this Guidebook.

Additional thanks are extended to the many reviewers and supporters of this Guidebook through its development. Special contributors include: Ian Ballantine, Carl Buettner, John Curtis, Allen Deitemann, Max Ewington, Suzanne Kane, Alan Kenfield, William Kingston, Gordon Laverty, Paul McMann, Joseph Romano, Donald Vandekar and Dean Wheaden. The authors especially appreciate their time, patience, suggestions, and encouragement.

Water conservation efforts of DWR have been well supported by the American Water Works Association (AWWA), particularly by David Todd, Chairperson of the California-Nevada Section Water Conservation Committee.

AWWA's California-Nevada Section endorses the Water Audit and Leak Detection Guidebook and joins DWR in its publication. Thanks go to:

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SPECIAL NOTE

All photographs in this Guidebook were prepared by the staffs of Community Consultants, Inc. and the Department of Water Resources. We gratefully acknowledge their contributions to this effort.

INTRODUCTION

Purpose of the Guidebook

This Guidebook has been prepared to help water agencies reduce water and revenue losses. It includes techniques for conducting water audits and leak detection surveys of piped, pressurized, potable water distribution systems and provides:

- step-by-step procedures for conducting a comprehensive systemwide water audit to assess the delivery efficiency of a water distribution system;
- a worksheet and sample forms for each step of the water audit;
- specific techniques to identify, quantify, 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;
- alternative actions to correct identified problems in a water system;
- a tool to determine whether a leak detection project would 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 nonvisible underground leaks;
- forms to record information from surveying the distribution system, pinpointing leaks, estimating leak losses, and documenting costs of survey and repair; and
- a procedure and forms to evaluate the cost effectiveness of the leak detection project.

Benefits of Water Audits and Leak Detection

- Reduced Water Losses - Conducting a leak detection project will identify and locate water system leakage. Upon repair of the leaks, water savings will result. Savings are also realized in reduced power costs to deliver water and reduced chemicals to treat water.
- Financial Improvement - A water audit and leak detection project can increase revenues from customers who have been undercharged, lower costs of wholesale supplies, and reduce treatment and pumping costs.
- Increased Knowledge of the Distribution System - The added familiarity of the distribution system gained during a water audit and leak detection project helps a utility to respond more quickly to emergencies such as main breaks.

- More Efficient Use of Existing Supplies - Reducing water losses will help stretch existing supplies to meet increased needs. This could help defer the construction of new water facilities, such as a new well, reservoir, or treatment plant.

- Reduced Property Damage - Improved maintenance of a water distribution system can reduce the likelihood of property damage and better safeguard public health and safety.

- Improved Public Relations - The public appreciates seeing that its water systems are being maintained. Field teams carrying out water audit and leak detection tasks and doing repair and maintenance work make a favorable impression.

- Reduce Legal Liability - Conducting a water audit and leak detection project provides better information for protection against expensive lawsuits.

Definition of a Water Audit

A water audit is a thorough examination of the accuracy of water agency records and system control equipment. Water managers can use audits to determine their water distribution system efficiency. The overall goal is to identify, quantify, and verify water and revenue losses. This allows the water utility to select and implement programs to reduce water and revenue losses. Such examinations should be performed annually to update the results of earlier audits.

Cost of a Water Audit

The cost of a water audit is the sum of in-house work and field work. Total costs depend on the following variables:

- the size of the service area to be audited

- the completeness and up-to-date accuracy of the water agency's in-house and field records, including meter testing programs and records

- the extent to which in-house staff or consultants are used to conduct the audit

- variations in costs for in-house staff or consultants to conduct all or a portion of the audit

Typical water audit activities include:

- verifying and updating system maps

- master/source meter testing

- verifying, quantifying, and updating: water source inflow records; metered use records, such as billing and accounting information; and unmetered use records, such as estimates of water use for parks, community centers, government facilities, and firefighting

- o testing residential, commercial, and industrial sales meters for accuracy

- o inspecting water measuring devices for proper sizing, installation, and operation

- o field checking distribution controls and system operating procedures

Any of the above activities could be conducted by in-house staff or consultants or both.

The most expensive item for a water audit is large meter testing. Large meter tests range in costs from $150 to $500. Residential meter tests average $25 to $50 each. The total field cost depends upon the number of source/master meters and sales meters that must be tested to provide current data for the entire system.

Water agencies participating in the State of California's water audit and leak detection grant program reported costs of water audits. These costs ranged from $2,000 to over $15,000 depending on the accuracy of information already on hand, the complexity of the agency, and other variables.

Definition of a Leak Detection

Leak detection is the systematic method of using listening equipment to survey the distribution system, identify leak sounds, and pinpoint the exact locations of hidden underground leaks.

Cost of a Leak Detection

The costs for a leak detection project include costs for leak detection equipment and the leak detection crew to survey the system and costs of pinpointing leaks, estimating water losses, and documentation.

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

Costs for leak detection crews depend upon whether an agency uses its own staff, a consultant, or a combination of the two. Leak detection costs are normally expressed in dollars per mile of main surveyed. In California, these costs range from $75 to $300 per mile of main. Costs for consultants range from $250 per mile of main to $500 per mile of main.

The variables for leak detection costs include wage rates for leak detection teams, 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.

Equipment costs are shown in Appendix J.

CHAPTER 1. THE WATER AUDIT

Water losses, whether due to leakage, theft, underbilling of customers, or faulty system controls, represent monetary losses to the water agency. This is water that the agency has already paid to obtain, treat, and pressurize. However, because it is lost, the water produces no revenue. Outlined here are steps management can take to correct the unproductive elements in the water supply system.

Analyze the Value of Water Losses and Corrective Measures

Evaluations of corrective measures should be based on the costs, feasibility, and savings that result. Once the water audit has been completed, the agency will have sufficient data to determine where the greatest water losses are occurring. This information will give the agency the data necessary to set priorities. In setting priorities, the manager will also wish to incorporate local constraints. These, of course, are unique to each agency and therefore are not specified.

Answers to the following questions will indicate which corrective actions should be carried out.

- Where are losses occurring within the system?
- How much water is lost in each problem area identified?
- What corrective measures are needed to reduce the water loss?
- What will be the cost of reducing the water loss?
- What savings and benefit:cost ratios will result from reducing the water loss?
- When can the corrective measures be implemented?

Evaluate Potential Corrective Measures

Examples of corrective measures to be evaluated are:

- Perform a leak detection survey and leak repair program.
- Replace mains with history of serious leaks.
- Exercise valves annually.
- Implement corrosion control procedures.

Update the Water Audit Annually

Once a water agency has conducted a comprehensive water audit, annual updates provide data to help managers decide how to adjust priorities and monitor progress made on system maintenance. Equally important, the update can identify new areas of system losses to establish new annual maintenance goals. Updating a water audit will usually be less expensive than the original audit.

Periodically Update the Master Plan

The agency's master plan is a valuable planning tool which can be used to set priorities and schedule corrective actions to maintain its water distribution system. Managing a water distribution system requires current information on the system's delivery capacity, maintenance, and water quality. An updated master plan includes the following items associated with water audit and leak detection programs:

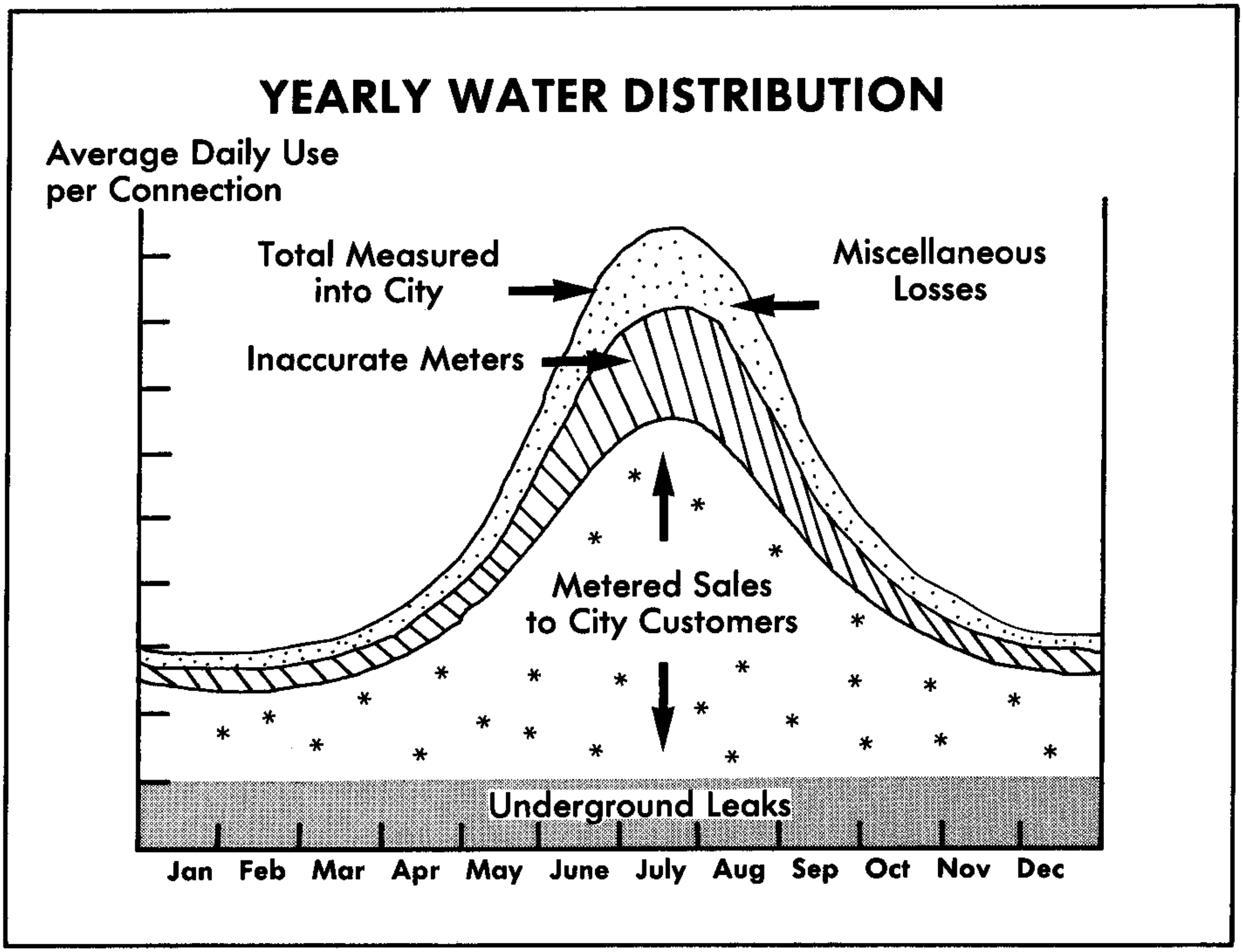
- problem areas and areas of potential water savings identified in a water audit
- an analysis of water and cost savings achieved by corrective actions
- a feasibility analysis of corrective actions based on cost and organizational constraints
- an analysis of improved water system efficiencies resulting from past and proposed corrective actions
- an analysis of the possibility that greater system efficiencies can defer expansion of the delivery system
- projected water needs
- an implementation schedule that identifies when specific corrective actions will be taken
- updated maps showing physical relationships and characteristics of the system

CHAPTER 2. CONDUCTING A WATER AUDIT

This chapter outlines specific steps and techniques for carrying out an audit of a water delivery system. More than one method is presented for some steps. The choice of methods is left to each agency.

TABLE 1
STEPS IN A WATER AUDIT

Task 1: Quantify the Water Supply	
Step 1.	Identify All Water Sources
Step 2.	Quantify Water from Each Source
Step 3.	Verify and Adjust Source Quantities
Task 2: Quantify Authorized Metered Water Use	
Step 1.	Identify Metered Uses
Step 2.	Quantify Metered Uses
Step 3.	Verify and Adjust Metered Use Quantities
Task 3: Quantify Authorized Unmetered Uses	
Step 1.	Identify Authorized Unmetered Uses
Step 2.	Estimate Authorized Unmetered Uses
Task 4: Quantify Water Losses	
Step 1.	Identify Potential Water Losses
Step 2.	Estimate Losses by Type of Loss
Task 5: Analyze the Water Audit Results and Consider Corrective Measures	



1. Yearly water distribution (courtesy of Community Consultants Inc.)

Introduction to the Water Audit Worksheet

Example 1, "Water Audit Worksheet," on page 9 is used to record the results of the step-by-step computations involved in auditing a water delivery system. In Chapter 2, instructions directing you to enter information on certain lines of the worksheet are emphasized by arrows in the margins.

The Water Audit Worksheet is presented here to simply familiarize you with the computational process and the types of data you will need. The audit of your system will provide actual data for your own agency.

Appendix A on page 83 is a Sample Completed Water Audit Report and Leak Detection and Repair Plan which includes a worksheet using data from the examples in this chapter.

EXAMPLE 1
WATER AUDIT WORKSHEET

For the Water District: ______________________________

LINE	ITEM	WATER VOLUME Subtotal	Total Cumulative	UNITS*
1	Uncorrected Total Water Supply to the Distribution System (Total of Master Meters)		________	________
2	Adjustments to Total Water Supply			
2A	Source Meter Error (+ or -)	________		________
2B	Change in Reservoir and Tank Storage (+ or -)	________		________
2C	Other Contributions or Losses (+ or -)	________		________
3	TOTAL Adjustments to Total Water Supply (+ or -) (Add Lines 2A, 2B, and 2C.)		________	________
4	ADJUSTED TOTAL Water Supplied to the Distribution System (Add Line 1 and Line 3.)		________	________
5	Uncorrected Total Metered Water Use	________		________
6	Adjustments Due to Meter Reading Lag Time (+ or -)	________		________
7	Subtotal: Metered Deliveries (Add Lines 5 and 6.)		________	________
8	TOTAL Sales Meter Error and System Service Meter Errors (+ or -)		________	________
9	CORRECTED TOTAL Metered Water Deliveries (Add Lines 7 & 8.)		________	________
10	CORRECTED TOTAL Unmetered Water (Substract line 9 from Line 4.)		________	________

* The units of water measurement must be consistent throughout the worksheet. Their selection (e.g., acre-feet, millions of gallons, hundred cubic-feet) is left to the user.

LINE	ITEM	WATER VOLUME Subtotal	WATER VOLUME Total Cumulative	UNITS
11	Authorized Unmetered Water Uses			
11A	Firefighting & 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	______		______
11I	Swimming Pools	______		______
11J	Construction Sites	______		______
11K	Water Quality and Other Testing (pressure testing pipe, water quality, etc.)	______		______
11L	Process Water at Treatment Plants	______		______
11M	Other Unmetered Uses	______		______
12	TOTAL Authorized Unmetered Water (Add Lines 11A through 11M.)		______	______

LINE	ITEM	WATER VOLUME Subtotal	Total Cumulative	UNITS
13	TOTAL Water Losses (Substract Line 12 from Line 10.)		________	________
14	Identified Water Losses			
14A	Accounting Procedure Errors	________		________
14B	Illegal Connections	________		________
14C	Malfunctioning Distribution System Controls	________		________
14D	Reservoir Seepage and Leakage	________		________
14E	Evaporation	________		________
14F	Reservoir Overflow	________		________
14G	Discovered Leaks	________		________
14H	Theft	________		________
15	TOTAL Identified Water Losses (Add Lines 14A through 14H.)		________	________
16	Potential Water System Leakage (Subtract Line 15 from Line 13.)		________	________
17	Recoverable Leakage (Multiply Line 16 by 0.75.)		________	________
18	Cost Savings	Dollars per Unit of Volume		
18A	Cost of Water Supply	$________		
18B	Variable O & M Costs	$________		
19	TOTAL Costs Per Unit of Recoverable Leakage (Add Line 18A to Line 18B.)	$________		

LINE	ITEM	Dollars per Year
20	One-Year Benefit from Recoverable Leakage (Multiply Line 17 by Line 19.)	$_______
21	TOTAL BENEFITS from Recoverable Leakage (Multiply Line 20 by 2.)	$_______
22	TOTAL COSTS of Leak Detection Project	$_______
23	Benefit to Cost Ratio (Divide Line 21 by Line 22.)	_______

Prepared by:

_______________________ _______________
Name Date

____
Title

Task 1. Quantify the Water Supply

This part of the water audit identifies, quantifies, and verifies the water supplied to the distribution system.

Step 1. Identify All Water Sources

Identify and list all water sources that supply the distribution system, including interconnections with other systems and intermittent sources or emergency supplies.

Map Selection. Select an existing map that shows the principal mains of the entire delivery system. The best map for the purpose is one that is legible and easy to work with (a scale of 1 inch to 400 feet is suggested). If none is available, the next choices are aerial photos or a regional (city or county) map, with a transparent overlay on which the distribution mains can be drawn. An alternative would be to draw a map that meets your purpose.

Choose a symbol to represent each type of water source: aqueduct turnouts; wells; surface diversions such as lakes, streams, reservoirs; interconnections; and emergency sources.

Plotting Locations of Sources. Identify and plot each water source on a distribution system map.

Identifying Source Measuring Devices. Visit each source location and gather data to construct a table (see Example 2) that summarizes information about the measuring device at each source (such as meters, Parshall flumes, weirs, and stream gauges).

EXAMPLE 2
SYSTEM SUMMARY OF WATER SOURCE MEASURING DEVICES

	Source 1	Source 2	Source 3
Type of Measuring Device	Venturi	Propeller	Venturi
Identification Number (may be serial no.)	0000278-A	8759	OC - 16
Frequency of Reading	Daily	Weekly	Daily
Type of Recording Register	Dial	Dial	Builder Type M
Units Registers Indicate	100,000 gallons	gallons	cubic-feet
Multiplier (if any)	1.0	1.0	100.0
Date of Installation	1950	1968	1955
Size of Conduit	24 inches	8 inches	11.5 inches
Frequency of Testing	Annual	2 years	4 months
Date of Latest Calibration	4/1/84	8/21/84	1/15/85

Step 2. Quantify Water from Each Source

Water Audit Study Period. Select a water audit study period. Choose a period that is long enough to analyze and evaluate total system water use. A 12-month study period starting in January and going through December is recommended. Most water system records are kept by either calendar or fiscal year. Either system normally makes 12 months of data available for review.

It is recommended that a calendar year (January through December) be used in order to reduce the effects of any meter reading lag time. (See Example 8 on page 23.)

Units of Measurement. Choose the measurement units for the audit. Most water utilities record total flow measurements in multiples of acre-feet, cubic-feet, or gallons. The same measurement units should be used throughout the audit.

Note the type of register used for each device and verify the appropriate conversion factor to be used when reading the device.

Totalling Water Sources. Each meter normally has some type of totalling device (register). Registers can be one of two types. Round-reading registers have a series of small dials (pointers) on the register face, registering a volume of water in units, 10s, 100s, 1,000s and 10,000s of cubic-feet or gallons. Direct-reading registers have one large sweep hand for testing and a direct-reading dial that shows total units of volume.

Total the amount of water produced from each source by month and for the entire period as shown in Example 3 (below).

EXAMPLE 3
UNCORRECTED TOTAL WATER SUPPLY IN 1983

Month	Source #1 Turnout #41 acre-feet	Source #2 Well Field acre-feet	Source #3 City Intertie acre-feet	Monthly Totals acre-feet
January	-0-	400	320	720
February	-0-	600	200	800
March	-0-	800	-0-	800
April	400	400	-0-	800
May	815	300	-0-	1,115
June	920	-0-	250	1,170
July	930	-0-	260	1,190
August	1000	-0-	275	1,275
September	900	100	100	1,100
October	400	100	300	800
November	400	-0-	400	800
December	400	-0-	300	700
	-----	-----	-----	-----
TOTALS	6,165	2,700	2,405	11,270

TOTAL Supply to the System 11,270 acre-feet

Calculate the total for all your water sources during the audit period and enter the amount on Line 1 of the Water Audit Worksheet.

Step 3. Verify and Adjust Source Quantities

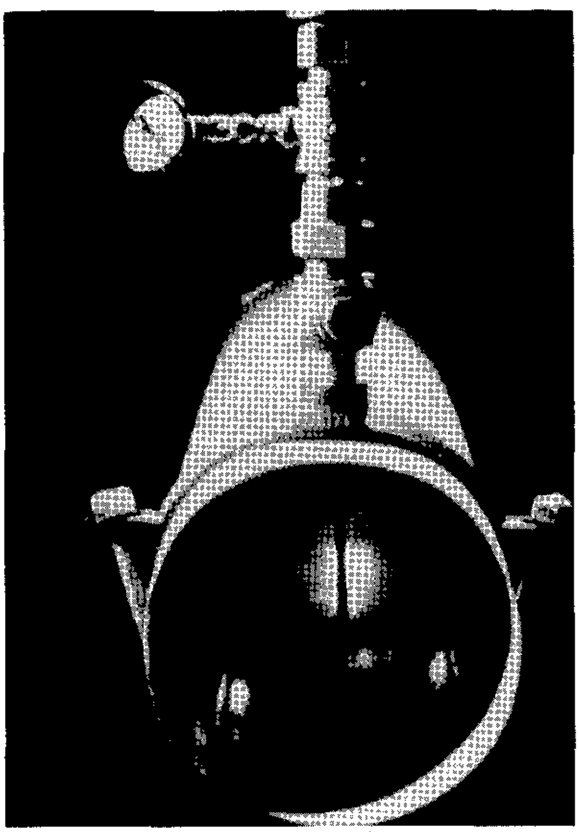
The amount of water supplied to a water system must be accurately quantified. Although most production sources are measured by meters, other devices are also used, such as Parshall flumes or weirs. Measurement errors provide incorrect data. Such errors must be discovered and corrected because incorrect source flow data will invalidate the entire water audit.

→ Arrows in the margin indicate information that is to be entered on the water audit worksheet.

Review available meter test results for accuracy within applicable American Water Works Association (AWWA) standards. If the meter error exceeds the standards for its category, repair and recalibrate it to function within acceptable limits. If no meter test results are available, test the meter.

Possible Causes of Meter Error. Inaccurate source meters can result from causes other than normal wear. Review the distribution system map location of each production measuring device. Then inspect each source meter in the field. Make the following checks and act accordingly.

- o Determine whether the proper types of meters were selected for use.
- o Determine whether meters of the proper size were selected for use. Check this against the manufacturers' recommended ranges.
- o Determine whether meters were installed correctly.
- o Determine whether proper registers were selected and installed correctly.
- o Determine by inspection whether hard-water encrustation is present.
- o Determine whether the meter is level. Meters are usually not designed for slope or vertical operation.
- o Have an employee other than the regular meter reader make a special meter reading of the master meters, or send another employee to accompany the



2. How to use a pitot rod for measuring flow in a pipe.

meter reader to verify the sample readings. The purpose is to determine whether the register is being misread and recorded improperly and the conversion factors are being improperly used.

- The primary device on all venturi meters should be tested with a pinpoint pitometer. A partial blockage to the throat of the meter might be present. Testing the meter with a pitometer will determine if the installation is adequate for non-turbulent flows. The device should be tested at different flow ranges. If the pressure deflection for appropriate flows is adjusted without checking the venturi itself, then the meter can still be recording flows erroneously.

Meter Testing Alternatives. Test all measuring devices that have not been tested within the last 12 months. Choose from among the following options which are in order of effectiveness.

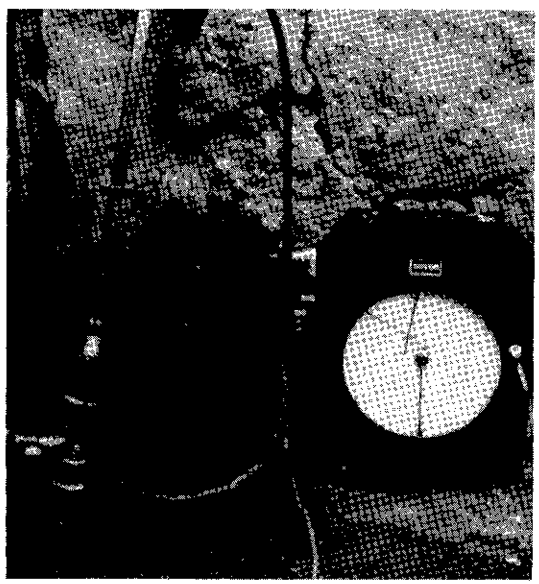
1. Test the meter in place. Retrofitting piping may be required.

2. Compare the meter reading 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 the 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 either in a meter shop or in the field with a variety of portable equipment. Pump efficiency flow testing (sometimes provided for free by electric utilities) can be used to check meters and is provided by some electric utilities. Consultants, meter manufacturers, and special testing laboratories are also available. Some electric utilities use an averaging pitotmeter and the results may be off by as much as 10 percent. A standard single point pitotmeter must be used for accurate results.



3. Recording pitometers may be used to measure flows and calibrate large meters.

Adjusting Source Quantities. Adjust source data for meter inaccuracies. Master meters can either over or under register. When you find a master meter that is inaccurate, adjust the figures to reflect the variance by calculating the corrected metered volume (CMV). To calculate the CMV, divide the uncorrected metered volume (UMV) by the measured accuracy of the meter and subtract the UMV as shown in Example 4.

EXAMPLE 4
ADJUSTMENTS TO SOURCE TOTALS DUE TO SOURCE METER ERROR

Source 1 has a meter accuracy of 95 percent which means that it is under measuring by 5 percent. Source 3 has a meter accuracy of 103 percent which means that it is over measuring by 3 percent. Calculate the CMV by dividing the UMV by the measured accuracy of the meter and subtracting the UMV.

Source I.D.	Uncorrected Metered Volume (UMV)	Percent Meter Accuracy (MA)	Meter Error Calculation Error (ME) $ME = \frac{UMV}{0.01MA} - UMV$	Meter Error (ME)	Corrected Metered Volume (CMV)
1	6,165	95	(6,165)/0.95) - 6,165	324.5	6,489.5
2	2,700	100	(2,700)/1.00) - 2,700	+ 00.0	2,700
3	2,405	103	(2,405)/1.03) - 2,405	- 70.0	2,335.0
TOTAL ADJUSTMENTS to Source Meter Readings Due to Meter Error				+254.5	acre-feet

Enter Source Meter Error on Line 2A of the Water Audit Worksheet. ◄—

Reservoir and Tank Storage Changes. These changes must be considered if the source meters are upstream from the storage facilities. Remember that water flowing out of reservoirs and tanks adds to the supply measured into the system. If the reservoirs have more water at the end of the audit period than at the beginning, then the increased storage was measured by the source meters but not consumed by the customers. 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.

EXAMPLE 5
CHANGES IN RESERVOIR STORAGE

Reservoir	Start Volume in Gallons	End Volume in Gallons	Change in Volume in Gallons
Apple Hill	32,350	36,270	+ 3,920
Cedar Ridge	278,100	240,600	- 37,500
Monument Road	978,400	318,400	-660,000
Davis	187,300	55,300	-132,000

TOTAL = -825,580 gallons
= -2.53 acre-feet

REMINDER: Decreases in storage are added to the supply. Increases in storage are subtracted from the supply.

Enter the Changes in Reservoir and Tank Storage on line 2B of the Water Audit Worksheet. ←

For some water systems, there may be additional contributions or losses to the total supply. For example, there may be an additional source of supply that enters the water system between the master source meter and the finished water system, such as infiltration into an open channel or losses from an unlined or open channel.

These additions or losses should be accounted for as other contributions and losses. Enter Other Contributions or Losses on Line 2C of the Water Audit Worksheet. ←

Add the Source Meter Error, Changes in Reservoir and Tank Storage, and Other Contributions or Losses to the water supply. Enter the result on Line 3 of the Water Audit Worksheet. ←

Add Total Adjustments to Total Water Supply (Line 3) to Uncorrected Total Water Supply (Line 1) to get Adjusted Total Water Supplied to the Distribution System. Enter this on Line 4 of the Water Audit Worksheet. ←

Task 2. Quantify Authorized Metered Water Use

Authorized water is water used for beneficial purposes. It consists of (1) metered deliveries, which are normally sold to customers (industrial, commercial, residential, agricultural, and other); and (2) unmetered deliveries, frequently used for public purposes. All unmetered uses should be metered. When carrying out the following steps, be sure to use the same time period selected for quantifying water from the sources.

Step 1. Identify Metered Uses

You are now ready to identify metered uses of water. Use the same time period as used for quantifying water from the sources.

- o Identify all users of water that are supposed to have meters. Accounts can be identified by meter serial number, connection number, assessor's parcel number, street address, account number, or some other system. Assign each account to a meter reading route. Be sure to include water provided to other agencies.
- o Prepare meter lists by identification number and size of meter for all active accounts. Sort by type of use, including industrial, commercial, residential, agricultural, wholesale transfers, and others. The type of metered use is important because it can help identify accounts that represent larger volumes of sales and greater potential revenue earnings, as shown in Example 6.

Be sure to include all accounts for which metered use data is available, even if the account is not billed. Consider the possibility of accounting procedure errors, improper computer programming, meter misreading or other errors. Unauthorized water use may also be occurring. These improprieties should all be checked.

Please see Task 4, Quantify Water Losses (page 40) for methods to estimate these and other situations where metered use data is unavailable and potential water losses are possible.

EXAMPLE 6
PERCENT WATER CONSUMPTION BY METER SIZE

Meter Size (in)	Number of Meters	Percent of Metered Consumption
5/8	11,480	70.1
3/4	10	0.1
1	338	4.4
1-1/2	124	2.8
2	216	11.7
3	15	6.4
4	7	2.0
6	6	2.5
TOTAL	12,196	100.00

Step 2. Quantify Metered Uses

Add the water uses for all accounts and connections for each size of meter by month (or other billing period) and year as shown in Example 7.

Enter the Uncorrected Total Metered Water Use on Line 5 of the Water Audit ← Worksheet.

EXAMPLE 7
UNCORRECTED TOTAL METERED WATER USE

Month	Residential acre-feet	Industrial acre-feet	Commercial acre-feet	Metered Agriculture acre-feet	Subtotal acre-feet
Jan.	450	110	25	-0-	585
Feb.	500	110	25	-0-	635
Mar.	500	110	25	-0-	635
April	550	120	25	75	770
May	650	130	25	175	980
June	700	150	25	230	1,105
July	800	150	25	175	1,150
Aug.	815	150	25	230	1,220
Sept.	700	140	25	200	1,065
Oct.	500	110	25	-0-	635
Nov.	500	110	25	-0-	635
Dec.	450	110	25	-0-	585
Subtotal	7,115	1,500	300	1,085	10,000
TOTAL Uncorrected Metered Water Use					10,000

Meter Lag Corrections

Corrections must be made to water sales data when the beginning and ending dates for the water audit (the source meter reading dates and customer meter reading dates) do not coincide. The January 1 to December 31 period, when little outside watering occurs, is recommended since it minimizes water use variances caused by summer landscape watering.

An example of the common situation is shown in Example 8 below. In the example, the water audit is conducted for the calendar year, the source meters are read monthly on the first day of each month, and the customers' meters are all read on the tenth day of the month. (The same methods are applicable to bimonthly billing cycles.) The goal is to calculate the amount of water supplied and consumed for exactly the same time period.

EXAMPLE 8
BILLING CYCLES RELATED TO WATER AUDIT PERIODS

Dec. Jan. Feb. Mar. Apr. May Jun. Jul. Aug. Sept. Oct. Nov. Dec. Jan.

|____|

Water Audit Period January 1 to December 31

X X X X X X X X X X X X X

Source meters read on the first of each month

o o o o o o o o o o o o o o

Customer meters read on the tenth day of each month

In the above situation, no correction is made for the water supplied through the source meters since their reading occurs on the same day as the audit 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.

The customer meter readings are read on the tenth of the month and do not coincide with the audit period. Therefore, a correction must be made.

The best way to account for changing numbers of customers and changing water use patterns is to prorate the water use for the first and last billing periods applied to the water audit.

The first billing period has only ten days that actually occur in the audit period. Yet the billing information represents 31 days of water use. If sales for that December 11 through January 10 period are 101.9 acre-feet, the amount applicable to the audit period is:

$$101.9 \text{ acre feet} \times \frac{10 \text{ days}}{31 \text{ days}} = 32.87 \text{ acre-feet}$$

Thus only 32.87 acre-feet of the use read on January 10th applies to the audit period.

Completing the calculations, there are 21 days at the end on the audit period that are not included in the billing data collected on December 10. Use for the last 21 days in December is obtained from the following January billing, 112.5 acre-feet. The amount applicable to the audit period is:

$$112.5 \text{ acre feet} \times \frac{21 \text{ days}}{31 \text{ days}} = 76.20 \text{ acre-feet}$$

Thus 76.20 acre-feet is added to the use read on December 10th.

Customer meters are seldom all read on the same day. They are usually assigned to different meter routes and read on different days. Therefore, a more detailed meter lag correction should be used for each meter reading route, particularly if each customer's meter is read on the same date each month. Example 9 illustrates a situation of three reading dates per month. Again the consumption is prorated for each meter route or book.

The water audit period is the same as above, January 1 to December 31. The three meter routes are read bimonthly: route A on the 1st of the month; route B on the 10th of the month; and route C on the 20th.

EXAMPLE 9
DETAILED METER LAG CORRECTION

The calendar below indicates the beginning and end of the water audit period and the days of use for each meter route.

```
        January 1                                December 31

                          Water Audit Period
Start|_____________________________________________________|End

December    January     February           December    January     February
1  10  20   1   10  20  1   10  20 ......  1   10  20  1   10  20  1   10  20

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         CCCCCCCCCCCCCCCCCCCCCCCC                    CCCCCCCCCCCCCCCCCCCCCCCC
```

Billing records issued during the audit report would not include all of the water used during the audit period. Some water shown as used in the first billing period, issued in February, actually occurred in the preceding December. The last billing period, issued in November and December, would not include water used in December. So, corrections must be made to subtract the water used in December before the audit started. Additional corrections are needed to add water used in December at the end of the audit period.

The December through January billing period is 62 days long.

Route	Read Date	Sales	Adjustment	
A	2/1/84	12 ac-ft	31/62 = -6.0 ac-ft	
B	2/10/84	10 ac-ft	21/62 = -3.4 ac-ft	
C	2/20/84	11 ac-ft	11/62 = -2.0 ac-ft	
	Water Use		------------------------------	-11.4 ac-ft
A	2/1/85	13 ac-ft	31/62 = 6.5 ac-ft	
B	2/10/85	10 ac-ft	21/62 = 3.4 ac-ft	
C	12/20/85	12 ac-ft	11/62 = 2.1 ac-ft	
	Water Use		------------------------------	+12.0 ac-ft
				+0.6 ac-ft

Many water utilities have combined their accounting and billing procedures into a computerized format to make the foregoing procedure easier and quicker.

Enter Adjustments Due to Meter Reading Lag time on Line 6 of the Water Audit Worksheet. ←

Add all metered deliveries and enter the total on Line 7 of the Water Audit ◄— Worksheet.

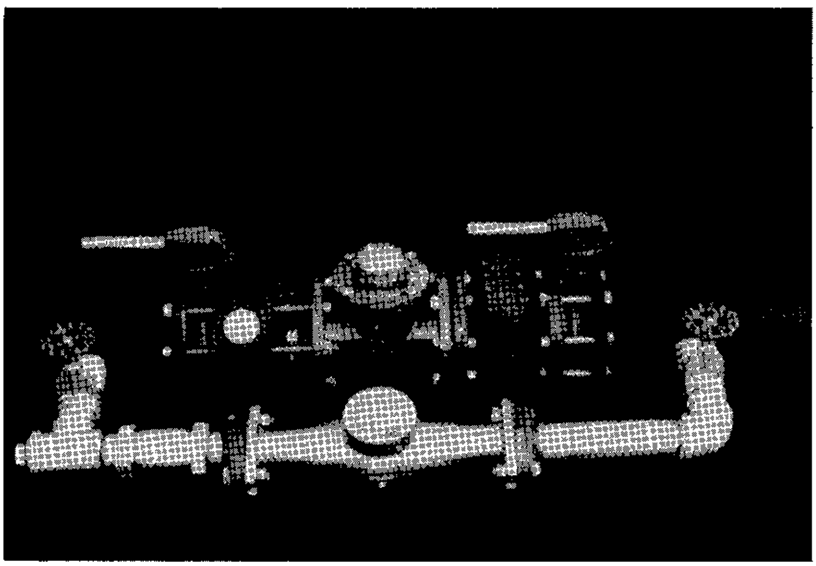
Step 3. Verify and Adjust Metered Use Quantities

Because of their large number, not all sales meters can feasibly be inspected and tested annually. We recommend instead that you annually inspect and test all meters that are more than two inches in diameter and conduct a random sample of meters equal to or less than two inches in diameter.

Review your agency's practices on meter selection, sizing, and installation to see whether present practices permit accurate operation and, if not, which practices should be revised (see Appendixes B, C, D, and E for references).

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 type, sizing, and installation. It is also recommended that all new large meters be inspected and tested before use. Not all new meters are accurate.

Sampling Residential Meters. Choose a random sample of residential meters to inspect and test. We suggest testing at least 50 to 100 meters. Residential meter testing will require test equipment that differs from that used for larger meters. Residential meters may be tested on a test bench or sent to the factory or a consultant for testing. (Refer to American Water Works Association, AWWA, publication No. M6, Water Meters -- Selection, Installation, Testing, and Maintenance, Chapter 6, "Maintenance and Repair of Displacement Meters.")



4. Correct meter installations include a small bypass meter, a debris screen, and check valves on both sides of the meter.

Many agencies are involved in a meter change out program. If you are involved in such a program, be sure to include in the random sample some of the meters being replaced so you can calculate the appropriate meter error for the entire system. It is recommended that you test a representative sample of the new residential meters before use.

Calculating Total Sales Meter Error. Total sales meter error includes meter errors from all meter sizes--residential, commercial, and industrial.

Residential meters are normally tested at low, medium, and high-flow rates. The registration data, normally expressed in percent accuracy, is used to calculate the total meter error at average flow rates. Examples 10 through 14 which follow, demonstrate how to use your existing meter test data and calculate total residential meter error.

Table 2 was produced for 5/8 x 3/4 inch water meters from information in an article by Penchin Tao written for Journal of the American Water Works Association, ("Statistical sampling technique for controlling the accuracy of small water meters," June 1982"). The table shows the percent of time the meter operates at each flow rate; the range of flows for each flow rate; and the average flow for low, medium, and high flows.

TABLE 2
WEIGHTING FACTORS FOR FLOW RATES RELATED TO VOLUME PERCENTAGES

Percent of Time	Range in GPM	Average GPM	Percent Volume
15	Low 0.50 - 1.0	0.75	2.0
70	Medium 1 - 10	5.00	63.8
15	High 10 - 15	12.50	34.2

Percent Volume refers to the proportion of water consumed at the specified flow rate, as compared to the total volume consumed at all rates. Therefore, only 2.0 percent of the total water consumed occurs at the low-flow range of approximately 0.5 to 1 gpm.

Instead of using the percentage of volumes as shown above, you may want to compute your own percentage volume data. By using special dual meter yokes and recording meters, you can determine the actual flow rates for your customers' water meters.

EXAMPLE 10
ADJUSTING RESIDENTIAL METER RECORDS FOR SALES METER ERROR

Residential meter records were adjusted using total residential water sales data from Example 7, Uncorrected Total Metered Water Use, and the following meter test data.

METER TESTING DATA FROM A RANDOM SAMPLE OF 50 METERS

Test Flow Rates	Mean Registration in Percent
Low flows (0.25 gpm)	89
Medium flows (2.0 gpm)	95
High flows (15.0 gpm)	94

EXAMPLE 11
CALCULATION OF RESIDENTIAL WATER METER ERROR

% Volume (%V)	Total Sales Volume (Vt)	Volume at Flow Rate (Vf)	Meter Registration (R)	Meter Error (ME) $ME = \frac{Vf}{(0.01R)} - Vf$	Meter Error (ME) (in ac-ft)
2.0	7,115	142.3	89	[(142.3/0.89) - 142.3]	17.6
63.8	7,115	4,539.4	95	[(4,539.4/0.95) - 4,539.4]	238.9
34.2	7,115	2,433.3	94	[(2,433.3/0.94) - 2,433.3]	155.3
100.0		7,115.0		TOTAL Residential Meter Error =	412.1

To calculate total meter error for large meters, use your mean registration data as shown in Example 12.

EXAMPLE 12
METER TEST DATA FOR LARGE METERS

Meter ID No.	Size	Meter Type	Date of Installation	Manufacturer	Test Date	Mean Registration at Various Flow Rates		
						Low	Medium	High
XYZ001	3 in	Turbine	6/83	Rockwell	10/84	89	85	100
X00ZAA	3 in	Turbine	6/83	Rockwell	10/84	70	88	98
NB123	4 in	Displace	7/80	Sparling	10/84	95	99	102
NB456	6 in	Compound	9/77	Sparling	10/84	98	92.5	102
AA002	6 in	Propellor	5/66	Hersey	10/84	98	98	103
Sum of Mean Registrations						450	462.5	505
Mean Registration for 5 Meters Tested						90	92.5	101

5. Commercial meters may be tested, repaired and calibrated on a meter test bench.

EXAMPLE 13
CALCULATION OF METER ERROR FOR LARGE METERS

Flow recordings were made for 24 hours in July and February 1984 and indicate the percent of volume delivered by large meters at low, medium, and high-flow rates as follows:

Low	10 percent
Medium	65 percent
High	25 percent

From this information the total sales volume for large meters was adjusted as follows:

% Volume (%V)	Total Sales Volume (Vt)	Volume at Flow Rate (Vf)	Meter Registration (R)	Meter Error (ME) $ME = \frac{Vf}{(0.01)R} - Vf$	Meter Error (ME) (in ac-ft)
10	1,500	150	90.0	[(150/0.90) - 150]	16.7
65	1,500	975	92.5	[(975/0.925) - 975]	79.0
25	1,500	375	101.0	[(375/1.01) - 375]	-3.7
TOTAL Meter Error for Large Meters					92.0

EXAMPLE 14
CALCULATION OF TOTAL SALES METER ERROR

Total Sales Meter Error (TSME) = Residential Meter Error + Large Meter Error; therefore, from the totals in Examples 11 and 13, the TSME is:

$$TSME = 412.1 + 92.0$$

$$TSME = 503.74 \text{ acre-feet}$$

Enter adjustments for Total Sales Meter Error on Line 8 of the Water Audit ◀— Worksheet. Add Line 7 to Line 8 and enter the total on Line 9, Corrected ◀— Total Metered Water Deliveries.

Estimating Increased Revenue. One of the major benefits of conducting a water audit is the potential increase in revenues from testing and repairing the larger meters. One can estimate changes in revenue from customers with large meters found to be operating inaccurately.

Again, the calculation for the corrected metered volume, CMV, for each individual meter uses the following formula:

$$CMV = \frac{UMV}{(0.01)MR}$$

Where Uncorrected Metered Volume, UMV, is the volume of water registered on the meter (from the billing records), Mean Registration, MR, is the meter accuracy in percent.

For Example: UMV = 10,000 cubic-feet (from billing records)

MR = 75% (registration accuracy determined by meter tests)

$$CMV = \frac{10,000}{(0.01)(75)}$$

$$= 13,333 \text{ cubic-feet}$$

EXAMPLE 15
POTENTIAL REVENUES FROM RECALIBRATED LARGE METERS

This is an example of revenues that can be recovered by recalibrating and repairing large meters for customers who have large volumes of water use. Frequently these revenues can pay for substantial portions of the water audit as well as the meter test and repair.

(1) Meter ID	(2) Uncorrected Metered Volume (UMV)	(3) Charges Billed 12 months $	(4) Corrected Metered Volume (CMV)	(5) Charges for Corrected Volume 12 months $	(6) Increased Revenues $ Col 5 - Col 3
9793234	3,644	3,847	5,906	6,235	+ 2,388
20548059	5,141	5,751	8,199	9,172	+ 3,421
X123456	6,668	6,911	19,328	20,031	+13,120
16222519	5,738	5,860	26,939	27,512	+21,652

Task 3. Quantify Authorized Unmetered Uses

Step 1. Identify Authorized Unmetered Uses

Many water utilities have some unmetered beneficial uses of water. These are generally called authorized unaccounted-for water. They are most often scattered throughout the service area at public buildings, open-space public areas, and special facilities designed to protect the public. Employees conducting an audit must confirm these uses as unmetered in their service area.

The following authorized uses of water are frequently unmetered.

- Firefighting and Firefighting Training
- Flushing of Mains
- Storm Drain Flushing
- Sewer Flushing
- Street Cleaning
- Schools
- Landscaping in Large Public Areas
- Decorative Water Facilities
- Swimming Pools
- Construction Sites
- Water Quality and Other Testing
- Process Water at Treatment Plants

NOTE: If any of these uses are metered, they should be included with Uncorrected Total Metered Water Use (Line 5).

Step 2. Estimate Authorized Unmetered Uses

Unmetered volumes of water must be carefully estimated to produce an accurate water audit.

This step describes procedures for quantifying water used for unmetered beneficial purposes. In selecting the best procedure for a given situation, you should consider the difficulty of gathering information, the degree of precision necessary, the availability of measuring equipment and skilled personnel, and the possibility of hiring consultants, buying more equipment, or providing training for employees. In cases where evidence shows that a particular water use is very low, a rough estimate could replace a complete, detailed calculation.

We recommend that all uses be metered, even if the customer is not billed for the use.

Batch and Discharge Procedures. Unmetered water use can be estimated by either of two procedures, depending upon how the water is applied.

A. When water is transported in a tank truck or by similar means, 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. This yields the volume of water delivered from the distribution system. Many such containers are used with varying frequency during a year. Careful record-keeping is necessary for completely accurate estimates.

B. 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 during which it flows. This yields the volume of water delivered from the distribution system. The discharge rate may vary. Also, the application period will vary in length and frequency. Again, careful record-keeping is necessary to make accurate estimates.

Firefighting and Firefighting Training. This authorized, unmetered use of water is defined as water drawn from hydrants, fire sprinkler systems, and other water sources dependent upon the piped water distribution system. Uses include fire suppression, fire equipment testing, sprinkler systems flushing, and hazardous materials reduction by public safety crews. It also includes water used to train firefighters, airport personnel, and other public safety employees and volunteers. Firefighting excludes water drawn from ponds, rivers, or other water supplies not connected to the piped water distribution systems.

Estimating this use requires checking fire department records on training, flushing, and fire suppression. Many fire departments use more water during training than in 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" any time a unit responds to a call. A survey of run reports for all fire calls made during the year in the water service area should yield an excellent estimate of the amount of water used by fire departments. Remember to eliminate calls to locations where the water used came from other water supplies (those not connected to your water distribution system).

Estimates of other firefighting water uses, such as sprinkler systems (including their testing), require calculation of the flow of the system and the duration of operation (discharge procedure). Survey all locations (such as schools, stores, apartments, industrial sites, lumberyards, or warehouses) and inspect check meters to acquire such data. The more complete your survey, the better your chances of including water used in testing, leaky sprinkler systems, or incorrectly connected sprinkler systems.

Add the results to determine total water use for Firefighting and Firefighting Training and enter this on Line 11A of the Water Audit Worksheet. ←

Flushing of Mains. This water use is defined as unmetered water vented from the distribution system (frequently to storm drains) to clean the system of contaminants and debris.

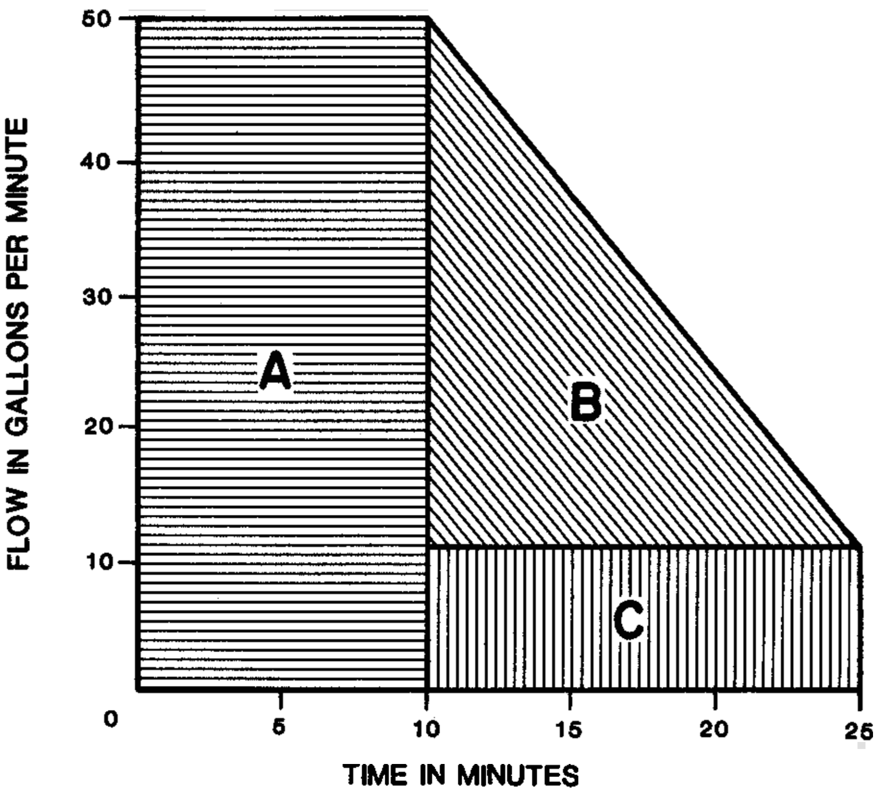
Many utilities have standard flushing procedures and maintain logs of flushing activities, including the location of the main or blowoff and the length of time it flowed. Some agencies even meter the amount of water released. As with all water uses, if metered, the total should already be included in Line 5, Uncorrected Total Metered Water Use.

Estimating water used in the flushing of mains requires a series of discharge estimates. For each location flushed, multiply the flow rate by the duration of the discharge. For instance, 50 gallons per minute (gpm) released for 30 minutes equals 1,500 gallons of water. If the discharge rate is not constant, calculate the volume by figuring the area under a curve. In Example 16, the discharge flowed constantly for 10 minutes at 50 gpm, was uniformly reduced to 10 gpm over the next 15 minutes, and was then shut off.

6. Hydrant flushing programs improve water quality

EXAMPLE 16
CALCULATION OF WATER VOLUME FROM VARIABLE RATE DISCHARGE

Volume A = 50 x 10		= 500 gallons
Volume B = 0.5 x (50 - 10) x (25 - 10)		= 300 gallons
Volume C = 10 x 15		= 150 gallons
	Total Volume	= 950 gallons



Enter the total water volume used for main flushing on Line 11B of the Water Audit Worksheet. ←

Storm Drain Flushing. Water from the distribution system (fire hydrants) used to flush and clean such areas as storm drains, culverts, or catch basins, is defined as storm drain flushing water use.

To estimate the total water used for storm drain flushing, contact the maintenance department for logs of cleaning activity, including truck capacities, number of trucks, truck filling frequency, and portable meter readings. If the water is supplied directly from the piped distribution system, follow the same methods as those used in estimating water used to flush mains (discharge). If the water is transported by truck, use the batch method.

Enter the total water volume used for storm drain flushing on Line 11C of the Water Audit Worksheet.

Sewer Flushing. Water from the distribution system (usually fire hydrants) used to flush and clean sewers and additional water used in sewage treatment plants for treatment processess and maintenance is defined as sewer flushing.

Follow the above Storm Drain Flushing procedure to estimate the total water used for sewer flushing.

Enter the total water volume used for sewer flushing on Line 11D of the Water Audit Worksheet.

Street Cleaning. This water use is defined as water used to clean roadways by direct release from hydrants or sprayed from trucks, sweepers, or other equipment. It includes cleaning park walkways, boat ramps, bus stops, parking areas, and bikeways.

Estimates usually will require use of the batch method. Check with the street department to find out how many times a day the tank trucks and sweeping equipment were filled, the number of trucks used, the truck capacity, and the number of days used during the year. Also identify the equipment type and frequency of use for washing recreational ramps and paths. In Example 17 the total gallons used annually was 1,750,000.

7. Records should be maintained of water used for street cleaning.

EXAMPLE 17
ESTIMATE OF WATER VOLUMES USED BY TANK TRUCKS

July 1, 1983, to June 30, 1984

	Capacity, in Gallons		No. of Refills per Day		No. of Days Used per Year		Volume per Vehicle per Year in Gallons
Vehicle A	200	x	5	x	200	=	200,000
Vehicle B	500	x	10	x	150	=	750,000
Vehicle C	2,000	x	2	x	200	=	800,000
TOTAL Gallons Used Annually							1,750,000

Direct cleaning from hydrants will require discharge estimates.

Enter the total water volume used for street cleaning on Line 11E of the Water Audit Worksheet. ←

Schools. Water use in schools is defined as water used for domestic sanitation, heating and air conditioning, and may also apply to schoolyards and playgrounds that are supplied by school water services.

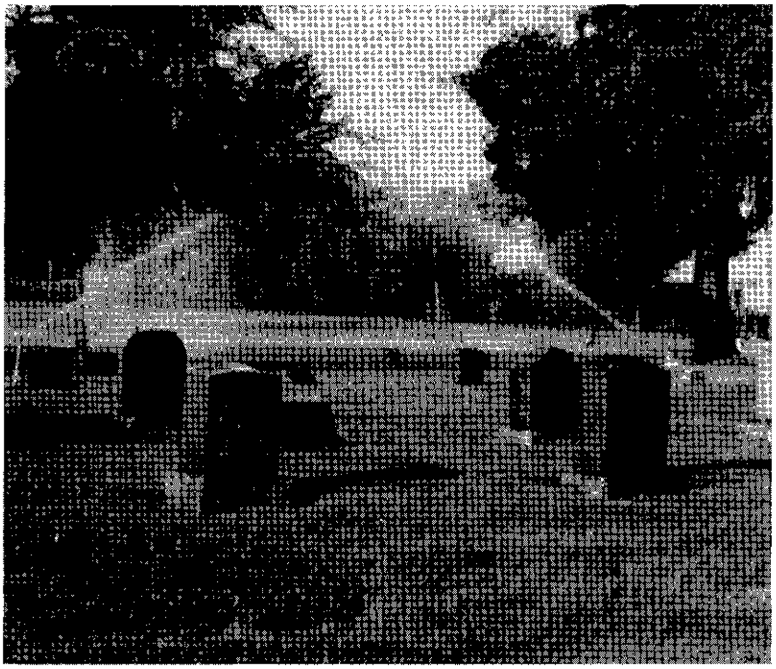
Estimate use by schools by comparing them with metered schools having similar landscaped areas and use characteristics (number of students and faculty, day and evening hours of use, and recreation facilities used).

Enter the total water volume used for unmetered schools on Line 11F of the Water Audit Worksheet. ←

Landscaping in Large Public Areas. This water use is defined as water applied to irrigate vegetation in 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 schedules, size, and vegetative cover.

The amounts of water applied to landscaping can be calculated by several methods: (1) by calculating the actual amounts of irrigation applied, or (2) by using the batch procedure where areas are watered by tank truck (median strips, for instance). Actual amounts of applied water include runoff from misapplied watering. Ask the people who maintain these landscapes for information on frequency and duration of watering. Remember that the watering schedule will usually vary at different times of the season or school year.



8. **Cemeteries may be large water users.**

To estimate the discharge for landscaping, you will need to know (1) the discharge rate at each supply pipe to an irrigated area, and (2) the total amount of time the water is applied at each area. Time controlled irrigation systems make the time determination easier. In making these estimates, remember to use the total time the supply service is discharging, rather than just the subperiod for one lateral.

EXAMPLE 18
ESTIMATE OF LANDSCAPE WATERING

A single 2-inch service provides irrigation water to 4-1/2-acre Sunnyslope Park at the rate of 160 gpm. Each of three laterals provides equal amounts of water and is controlled by a common timer.

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

May and September .... every 3rd day
June .... every 2nd day
July and August .... daily

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

The service supplies 160 gpm or 9,600 gallons per hour (160 x 60). It operates 6 hours each day the park is watered. During those six hours, 9,600 gallons per hour x 6 hours = 57,600 gallons of water applied.

The number of watering days must now be calculated:

Month	No. of Days in Month	Frequency of Watering	Number of Days Watered
May	31	every 3rd day	11
June	30	every 2nd day	15
July	31	all days	31
Aug.	31	all days	31
Sept.	30	every 3rd day	11

Water is applied a total of---99 days

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

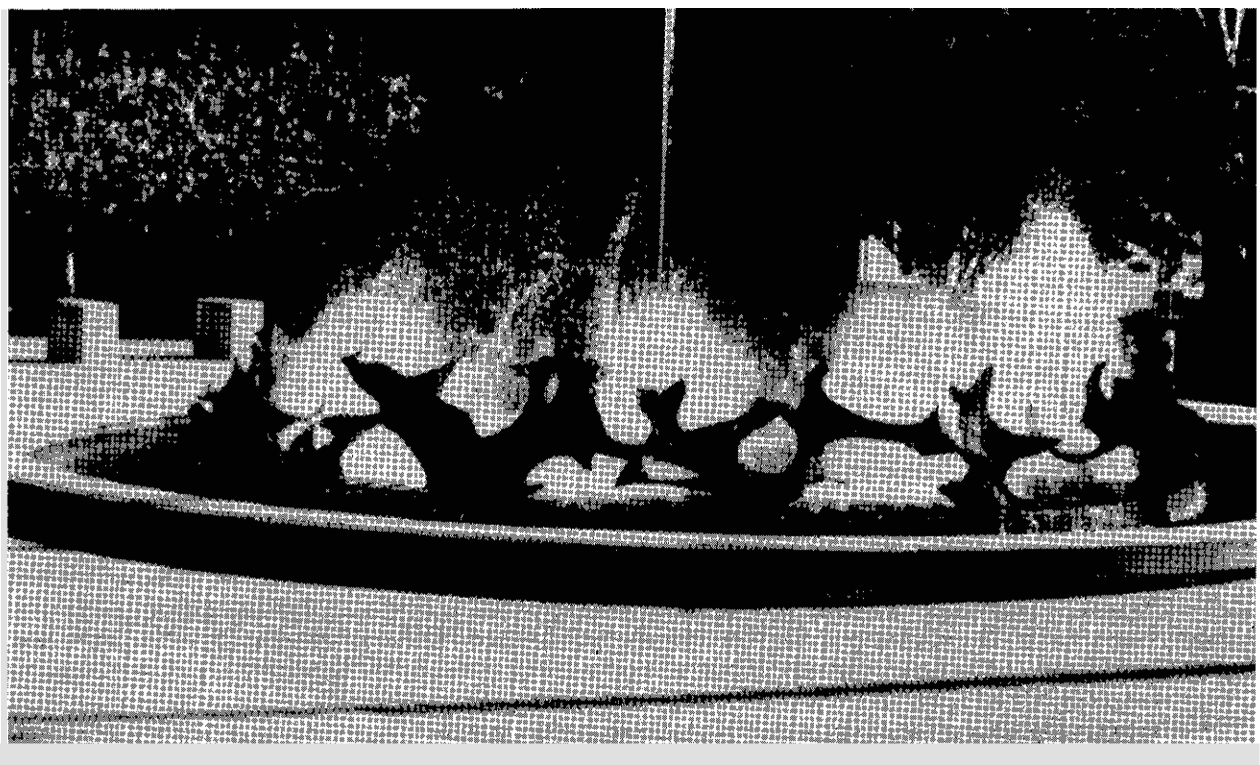
57,600 gallons per day x 99 days = 5,702,400 gallons

or 762,353 cubic-feet

or 17.50 acre-feet

Enter the total water volume used for each category of unmetered landscaping on the lines under Line 11G of your Water Audit Worksheet.

Decorative Water Facilities. This water use is defined as water used for cleaning and maintaining the water quality and quantity in pools, fountains, and other decorative features.



9. Decorative water facilities use large quantities of water.

The principal components of normal water losses from open-air, standing bodies of water are:

- evaporation
- water drained from a pool during maintenance
- water used for cleaning
- leaks

To estimate the evaporative loss components, refer to Appendix I (page 123).

To estimate the water loss from pool drainage, use the following data: the volume of the pool, the likely level to which the pool evaporated before being drained, and the frequency of draining. Use this formula:

$$V \times F = Vw$$

V = volume of pool at time it is drained
F = frequency of pool draining
Vw = volume of water loss due to pool draining

To estimate the water lost in cleaning, first talk to the maintenance people involved. They can identify cleaning and flushing frequencies and pool volumes. They most likely use a hose from some convenient source. If the source is a hose bib from a metered facility, no further calculation is necessary.

For an unmetered water source ask how much time the maintenance work requires after the pool is drained. Ask if the unmetered hose or refill pipe was running during this time. Determine the flow rates for the appropriate outlet, refill pipe, or hose, and calculate the volume used.

To estimate the losses from leaks in decorative water facilities, you can subtract the average amount that should be lost to evaporation from the normal water volume. The difference is water that is leaking from the facility.

After you have estimated the four components of water losses (evaporation, drainage, cleaning, and leaks) add the results to obtain a total for this type of water loss. Add the losses by type of facilities (for example, parks or buildings) within your service area.

Enter the total water volume used for decorative water facilities on Line 11H ← of the Water Audit Worksheet.

Swimming Pools. This water use is defined as water used to maintain volume and water quality, including make-up water, filter cleaning, cleaning of decks and walkways, and operation of associated sanitary and drinking water facilities. Any unmetered water use by concessionaries that depends on the service to the pool should also be included.

Pools will probably be metered, in which case their use will already be counted as a metered use. If they are not, determine unmetered water uses by pools and associated facilities 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.

Enter the total water volume used for all unmetered pool facilities on Line 11I of your Water Audit Worksheet.

Construction Sites. Water use at construction sites is defined as water principally delivered through hydrants to trucks for road dust control, site preparation, landscaping, temporary domestic use, and materials processing (for example, concrete mixing).

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

We recommend that all contractors be required to use a portable meter and report the readings.

Enter the total water volume used for construction sites on Line 11J of your Water Audit Worksheet.

Water Quality and Other Testing. This water use is defined as water used to test distribution system output to meet public health standards and to test meters and new mains.

Estimate water used in water testing by contacting operations staff to determine testing frequency and duration and volumes of water used. Amounts will probably vary with each user.

Enter the total water volume used for water quality and other testing on Line 11K of the Water Audit Worksheet.

Process Water at Treatment Plants. This is defined as water lost (not recycled) after filter washing or sedimentation basin drainage at raw water treatment plants.

Estimate this total water use by again contacting plant operations staff and checking records.

Enter the total water volume used for process water at treatment plants on Line 11L of the Water Audit Worksheet.

You may discover an unmetered use that does not fit any of the previously described categories. If so, describe the use and enter the total water volume used on Line 11M of the Water Audit Worksheet.

Now, add all the authorized unmetered water uses (Lines 11A through 11M) and enter the total on Line 12 of the Water Audit Worksheet.

Task 4. Quantify Water Losses

All water that is not identified as authorized unmetered water is considered to be water lost from the distribution system. This water does not produce revenue and is unavailable for other beneficial uses. To determine Total Water Losses subtract Total Authorized Unmetered Water (Line 12) from Corrected Total Unmetered Water (Line 10) and enter the difference on Line 13 of the Water Audit Worksheet. ◄

Step 1. Identify Potential Water Losses

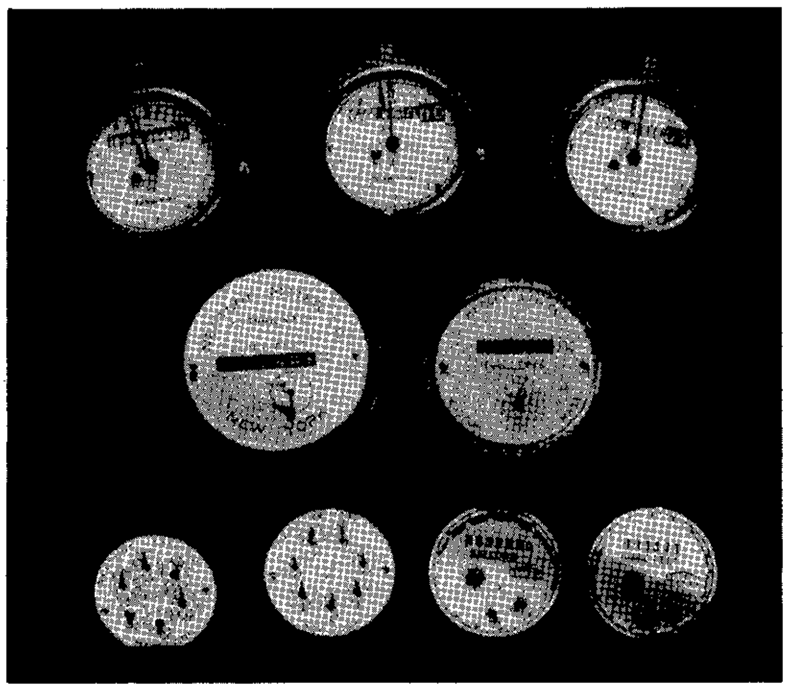
Water lost from the distribution system includes underground leaks and other losses listed below. The total amount lost to leaks can be determined by accounting for all the other losses and subtracting them from the Total Water Losses shown on Line 13.

Water losses other than leakage can generally be attributed to the following causes:

- o accounting procedure errors
- o illegal connections
- o malfunctioning distribution system controls
- o reservoir seepage and leakage
- o evaporation
- o reservoir overflow
- o discovered leaks
- o theft

Step 2. Estimate Losses by Type of Loss

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



10. Meter readers must cope with different meter dials and units of measure.

Accounting Procedure Errors. Water may seem to be lost from the system because of overlapping billing cycles (see discussion of Adjustments Due to Meter Reading Lag Time, (page 21), misread meters, improper calculation methods based on data from meters or other sources, computer programming errors, or other discrepancies. Basically, these types of losses are paper mistakes that can be identified by careful, step-by-step review of the record collecting and computer process. For example, the water meter may be calibrated in cubic-feet and the water bill may be calculated in gallons. Use of an incorrect conversion factor would introduce error in such a case.

The entire billing and accounting procedure from meter reading to total water use and printing of 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. The task of reviewing can be simplified by checking a representative sample from the total number of accounts.

Each meter route book should be checked, to verify a sample number of accounts from each book (or meter route). The steps are:

(a) Determine the number of accounts to be checked from each book or route.

(b) Choose a random sample of accounts to be checked.

(c) Have an employee other than the regular meter reader read the identified accounts, or send another employee to accompany the meter reader to verify the meter reader's readings. Both readings should be taken on the same day if possible. The purpose is to determine whether the register is being read and recorded properly and if the conversion factors are being used properly. Compare the water use volume for both meter readings. Calculate the billing of the identified accounts by hand.

(d) Compare the identified accounts for total water use with billed amounts. Do they agree? If not, what is the reason for the inconsistency?

(e) If meter book readings show a substantial difference from the accounts that were checked, review the normal billing process step-by-step, line-by-line.

Enter the total water volume due to accounting errors on Line 14A of the Water ◄— Audit Worksheet.

Illegal Connections. Identify active connections where unauthorized water use is not included in the accounting and billing process. Unauthorized use of water is usually, but not always, accidental rather than deliberate. Examples include taps to unmetered fire lines in a building (installer may have been unaware that the lines are reserved for fire control); a customer might tap into the main or someone else's service and thus avoid paying for the water; connections erroneously classified as inactive may in fact be in use; meters might not be read or the readings may not be entered into the accounting system. Connections listed as inactive should be confirmed as inactive. A well-programmed computerized billing process may disclose such improper practices.

Determine whether the account is inactive or active. Has the meter been removed or locked in the "off" position? If neither is true, does the meter reader periodically check the inactive accounts to see whether there has been use? Telephone calls or visits to the premises may help.

To identify illegal and unauthorized use, compare all active and inactive accounts with all locations that could receive water. One method is to write the 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 likely 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 and assessor's parcel number. Any parcels without an account number should be investigated. Some water uses may not have an account number and/or may not be metered.

Compare the number of accounts. How many existed at the start of the audit period? Subtract those discontinued during the year. Add new or reactivated accounts. Does the total equal the number of customers who have been billed during the latest complete billing cycle? If not, total the number of accounts and multiply by the average annual customer water use.

Enter the total volume for illegal connections on Line 14B of the Water Audit ← Worksheet.

Malfunctioning Distribution System Controls. Water loss may result from improper application, malfunctioning and improperly set system controls.

The basic steps for determining the volume of loss remain the same: determine the rate of loss, the length of time during which the loss occurred, and the frequency of loss.

Valves are the controlling devices in water distribution systems. They are used for both isolation and control functions. Isolation valves are usually manually operated, and control valves function automatically. Many valves have indicators that show the position of the valve. These can be inspected easily to see whether they are positioned properly. Valves can also be retrofitted with indicators to show their open or closed position.

All control valves will fail sooner or later. As part of the water audit, it is important to inspect each installation that uses automatic system controls and determine whether the valve is working, whether it has been set properly for the particular situation, and whether its size and design are suitable for its intended purpose.

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, each time the pressure reaches the high range, the valve will cause water to spill. Sometimes an unnecessary spill will occur because a pressure regulating valve has been readjusted and the pressure relief valve was not reset.

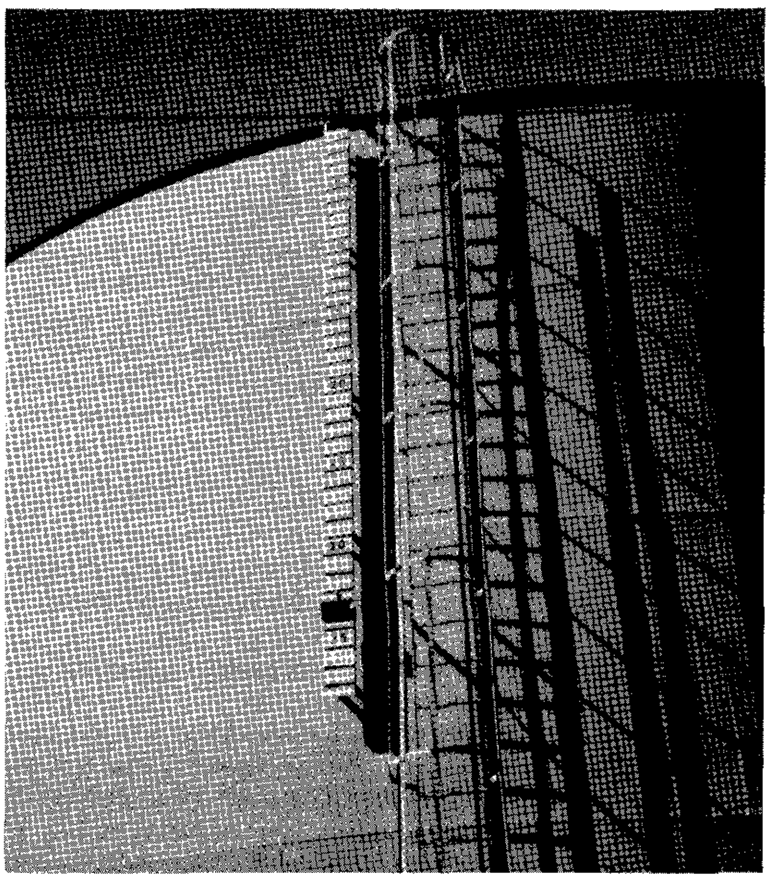
Pressure-Reducing, Pressure-Sustaining, and Pressure-Maintaining Valves - If any of these valves is improperly set, it can cause an altitude control valve, a pressure relief valve, or a surge control valve to spill water.

Surge Relief Valves - If these valves are set too low, they can spill water unnecessarily as a blow-off to the atmosphere, 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 and may allow water to discharge from the distribution system back down the well.

Enter the total loss from malfunctioning distribution system controls on Line 14C on the Water Audit Worksheet.

Reservoir Seepage and Leakage. This is 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 aeveral days. From this information, the rate of seepage can be calculated. Because water may be leaking only at certain elevations of the containment walls, the seepage (or leakage) test should be performed several times at successively lower surface water elevations. Clear wells (polished water storage) are also subject to seepage and should be inspected regularly.



11. Water storage tanks may be subject to overflow and leakage.

Enter the total loss from reservoir seepage and leakage on Line 14D of the Water Audit Worksheet.

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 thus are subject to evaporation. Losses can be calculated by measuring the surface area and applying the proper evaporation data for your area (see Appendix I on page 123).

Enter the total water volume lost to evaporation on Line 14E of the Water Audit Worksheet. ◄

Reservoir Overflow. This occurs most often because the altitude control valve is faulty or missing. Both the periods of overflow and the overflow discharge rate must be determined. (Overflow does not include water discharged to the distribution system.) If the discharge is not directly measured (for example, by a stream gauge below the discharge point), the 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 first from the reservoir inflow.

Enter the total water volume lost to reservoir overflow on Line 14F of the Water Audit Worksheet. ◄

Discovered Leaks. Losses from leaks that are discovered 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 under the section entitled "Measuring and Estimating Losses from Discovered Leaks" on page 75.

Enter the total loss from discovered leaks on Line 14G on the Water Audit Worksheet. ◄

Theft. Most water theft occurs when water is taken illegally from fire hydrants. This usually involves individuals who open the hydrants to fill water trucks or others who commit acts of vandalism. By comparing building department construction permits with water utility temporary use billings, you can determine where large amounts of water are being taken for which proper metering and billing have not been arranged.

Enter the total water volume lost from thefts on Line 14H on the Water Audit Worksheet. ◄

Now, add all the identified water losses (Lines 14A through 14H) and enter the total on Line 15 of the Water Audit Worksheet. ◄

Task 5. Analyze the Water Audit Results and Consider Corrective Measures

Analysis of the water audit results may indicate loss problems in the water distribution system. These could be faulty metering, illegal taps (such as firelines), leaking reservoirs, or leaking mains and services. Determine which corrective efforts would be cost effective to implement. To do so, you need to be able to estimate the value of the leaking water that can be recovered and the cost of recovering it. If the value of the recoverable water exceeds the costs, then your agency should carry out the appropriate leak detection and repair program.

The following paragraphs illustrate the benefit cost procedure for a leak detection survey.

To determine Potential Water System Leakage, subtract Total Identified Water Losses (Line 15) from Total Water Losses (Line 13). Enter the result on Line 16 of the Water Audit Worksheet.

Not all leaks can be detected and repaired. Some are extremely small; however, estimates indicate that 75 percent of all potential water system leakage can be recovered. Therefore, calculate recoverable leakage by multiplying Potential Water System Leakage (Line 16) by 0.75 and enter the result on Line 17, Recoverable Leakage.

Line 18, Cost Savings, is the cost savings that would be achieved if the leakage was prevented. There are two types of cost savings to be realized, purchase cost and variable operations and maintenance (O&M) costs. Both are costs that vary with the amount of water delivered into the distribution system and both exclude fixed costs.

The purchase cost is the "Cost of Water Supply" due to purchases of water for the distribution system from another water supplier. The amount of leakage prevented will reduce the amount purchased from that source. Usually, the most effective cost reduction will result from reducing the amount of water purchased or produced from the most expensive source of supply. Enter the cost per unit your agency pays for its most expensive water supply on Line 18A of the Water Audit Worksheet.

The O&M cost is the "Variable O&M Costs" saved by reducing the amount of water that has to be treated and pressurized in the system. If the agency pumps water from its own wells, it will reduce the amount of energy needed for pumping.

NOTE: Only O&M costs that vary with the amount of water delivered into the distribution system are to be included. Fixed costs that do not vary with the amount of water delivered should not be included. Enter the unit costs of variable operations and maintenance on Line 18B of the Water Audit Worksheet.

Add Costs of Water Supply (Line 18A) to Variable O&M Costs (Line 18B) and enter the total on Line 19, Total Costs Per Unit of Recoverable Leakage.

To determine the One-Year Benefit from Recoverable Leakage, multiply Recoverable Leakage (Line 17) by Total Costs Per Unit of Recoverable Leakage (Line 19). Enter the product on Line 20 of the Water Audit Worksheet.

Since the average lifetime of a leak is estimated at two years, the total benefit from recoverable leakage is the value of the water saved over two years. Therefore, to compute the Total Benefits from Recoverable Leakage, multiply One-Year Benefits from Recoverable Leakage (Line 20) by two and enter the product on Line 21 of the Water Audit Worksheet.

The cost of conducting a Leak Detection survey can be estimated by preparing a

Leak Detection and Repair Plan. Refer to Chapter 4 for suggestions on how to prepare the plan. Enter the Total Costs of Leak Detection Project on Line 22 of the Water Audit Worksheet.

The cost of leak repairs is not entered. DWR conducted an economic analysis entitled An Examination of the Benefits of Leak Detection. The analysis found that a major benefit of a leak detection program is the repair costs avoided (leaks repaired in the future) as a result of the program. Since leaks are continually discovered and repaired in the normal course of the utility's operations, the leaks found in the program would have eventually been repaired at some time in the future. If these leaks are repaired as part of a leak detection program, the utility will avoid the expense of repairing them as they are discovered accidentally. These savings in future repair costs, which are often overlooked when estimates of the savings from leak detection are made, can often be nearly as great as the cost of repairing the 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 leaks is 24 months and the real interest rate is 3 percent, the benefits from avoided future repair costs amount to 94 percent of the cost of repairing the leaks at the time of the 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 zero.

To determine the Benefit to Cost Ratio, divide Total Benefits from Recoverable Leakage (Line 21) by the Total Costs of Leak Detection Project (Line 22). Enter the result on Line 23 of the Water Audit Worksheet.

If the Benefit to Cost Ratio is greater than 1.0, then the benefits of a water audit and leak detection survey are greater than the costs, and a leak detection program should be performed.

REFERENCES

See Appendixes B and C (pages 103 and 107) for guidelines on choosing the appropriate meter for different applications.

See Appendix D (page 111) for guidelines on choosing meters of the proper size.

See Appendix E (page 115) for directions on meter installation. Also check with the equipment manufacturer for guidelines.

See Appendixes F and G (pages 117 and 119) for meter testing procedures.

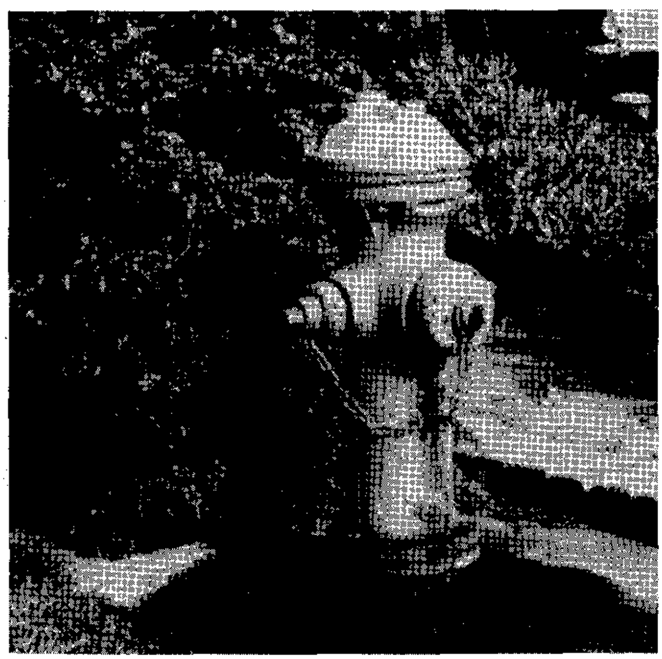
See Appendix H (page 121) regarding long-term meter surveillance.

CHAPTER 3. LEAK DETECTION

Visible and Nonvisible Leaks

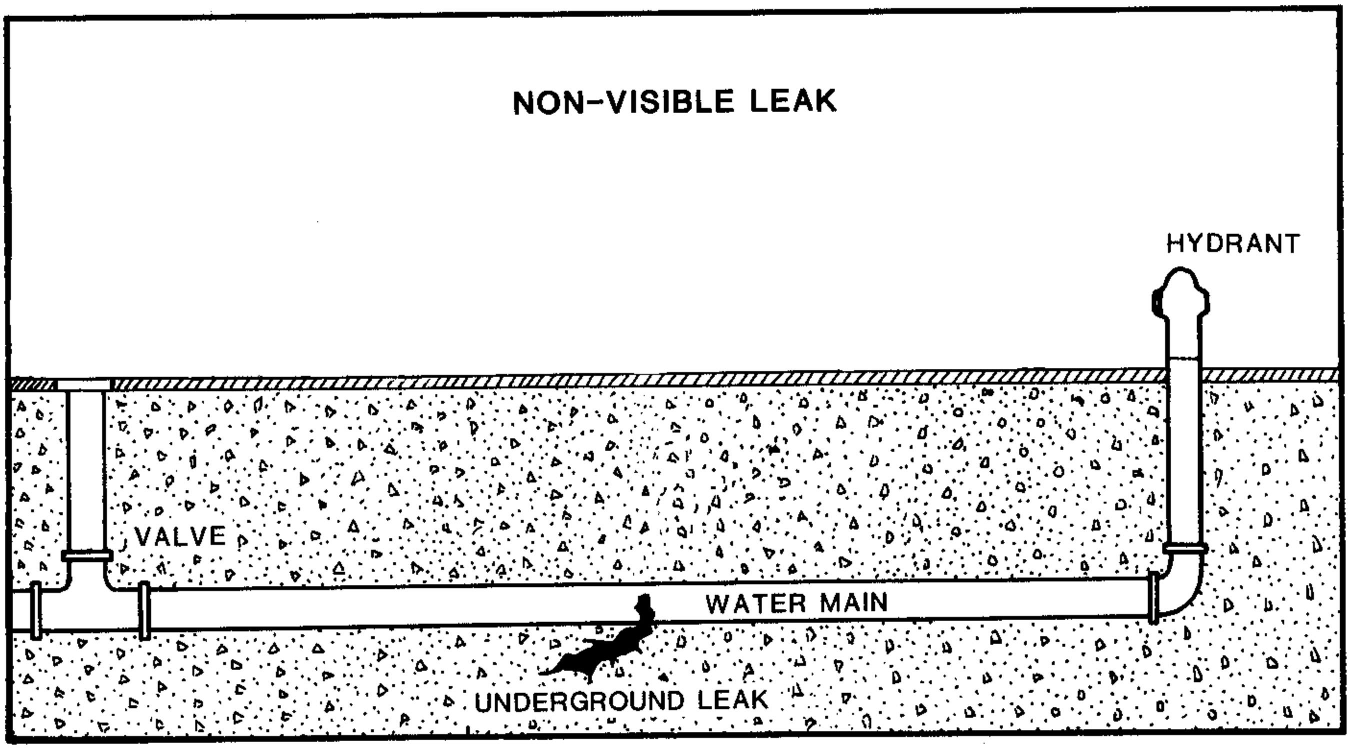
Visible leaks are those leaks that surface and can be seen emerging from the ground or pavement. The source of the leak may be a considerable distance away from the area where it is observed. Many visible leaks are reported by water customers.

Nonvisible Leaks include leaks that percolate into the surrounding ground and leaks that enter other conveyance facilities such as storm drains, sewers, stream channels, or old abandoned pipes. DWR estimates that up to 250,000 acre-feet of leakage occurs in California each year from nonvisible leaks.



12. Visible leaks, similar to this leaky fire hydrant, are easily found.

13. Nonvisible leaks usually occur underground.



2. Nonvisible Leak

Examples of Underground Leaks

Water will take the path of least resistance and may not surface. Most leaks start small and grow larger over time. Most nonvisible underground leaks have an average life of two years. As the age and size of leaks increase, the underground cavity gets larger which increases the potential for damage to overlying property. There are many examples of leaks that never surface. The following paragraphs illustrate a few of them.

City of Beverly Hills

The leak detection team detected sounds of leakage on numerous services and used the ground microphone to pinpoint a main leak. An 8-inch-diameter steel main with a pressure of 80 pounds per square inch (psi) had a leak from a 1/2-inch hole in the top of the main. No evidence of leakage was visible. The leak was calculated to be 53 gpm. The water lost from this leak for the two-year duration was 171 acre-feet. The value of the water lost was calculated to be $43,000.

Placer County Water Agency

The leak survey crew detected leak sounds on a fire hydrant served from a 4-inch cast iron main. Using the ground microphone, the leak location was pinpointed and found inside an 18-inch concrete culvert. The main crossed through the inside of the culvert pipe. The culvert pipe drained storm runoff from a hillside, crossed a road, then terminated in a ravine. Debris carried through the culvert over the years had damaged the 4-inch main and caused an 18-gpm leak which drained into the culvert. Over the two-year period, 58 acre-feet valued at $2,900 was lost through the leak.

City of Petaluma

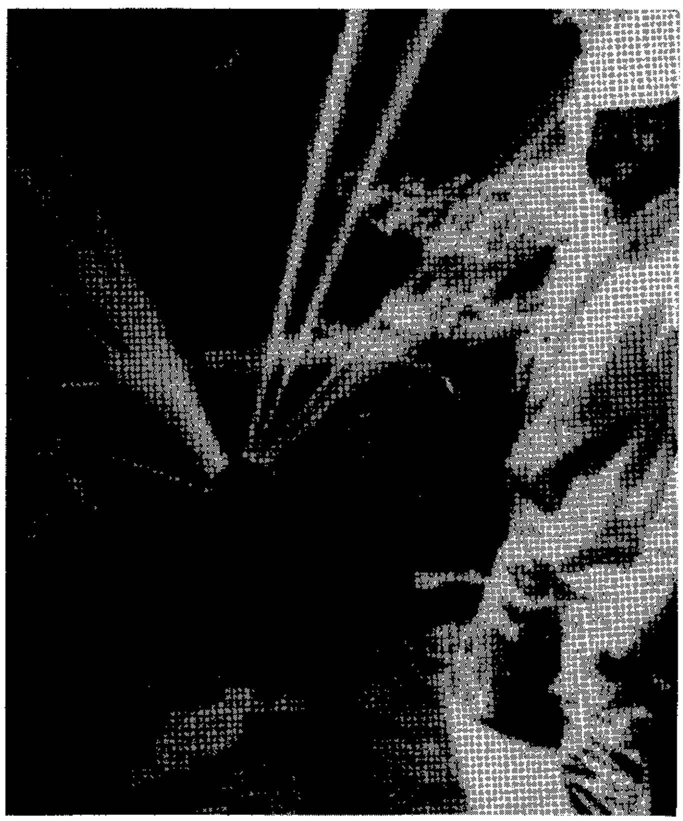
The leak detection crew detected leak noise at several services. Using the ground microphone, the crew pinpointed the leak on an abandoned galvanized service line that had not been shut off. The water lost from the 5-gpm leak for the two-year duration was 16 acre-feet. The value of the water lost was $4,250.

Walnut Valley Water District

The leak detection crew detected a leak sound on a hydrant and service meter. The leak was pinpointed by using a correlator and found in a 1-inch PVC service lateral near the connection to a 10-inch asbestos-cement (AC) main line. Pressure in the line was measured at 120 psi. The leak was a split in the PVC service lateral and was measured using a bucket and stopwatch at 12 gpm. The water lost from the leak for the two-year duration was 39 acre-feet. The value of the water lost was $9,600.

City of Santa Clara

The leak crew detected a leak sound on a 6-inch ductile iron pipe. The leak, pinpointed on the main, was a circumferential break caused by settlement. Water from the main was leaking into an adjacent sewer at 98 gpm. Water lost from the leak for the two-year duration was 317 acre-feet. The value of the water lost was $47,000.



14. Circumferential break on a 6-inch cast-iron main. The flow rate was 98 gpm.

Value of Recoverable Leakage

Most agencies are not aware of the existence of nonvisible leaks and the value of detecting and repairing these leaks. Leaks are the first user of water on the water system and do not generate revenue. How much is recovered leakage worth?

Table 3 shows the value of recoverable leakage based upon an average leak lifetime of two years (from "Leak Detection Productivity," by Douglas S. Greeley, Water Emergency and Management Reference Number 1981) and varying leak rates and water costs.

TABLE 3
VALUE OF RECOVERABLE LEAKAGE

Leak Rate gpm	Source of Supply $/acre-foot	Value of Leaking Water $/2 years
1/4	50	40
1/4	100	81
1/4	250	202
1/4	500	404
1	50	162
1	100	324
1	250	808
1	500	1,615
5	50	810
5	100	1,610
5	250	4,038
5	500	8,075
25	50	4,050
25	100	8,100
25	250	20,188
25	500	40,375
100	50	16,150
100	100	32,300
100	250	80,750
100	500	161,500
500	50	80,750
500	100	161,500
500	250	403,750
500	500	807,500

An Overview of Leak Detection Methods

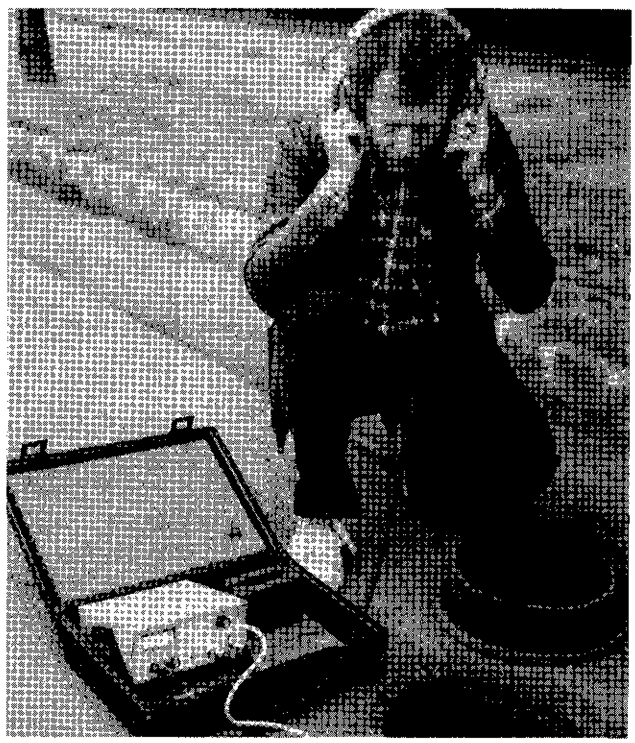
Water Audit

This method is an efficient way for determining the total volume and value of water that is leaking from a water distribution system. The water audit is a subtractive process which includes quantifying total water into the system, water sales, unmetered uses, water losses, and recoverable leakage. The water audit also includes a benefit:cost analysis for recovering potential leakage. The final part of the water audit is the preparation of a Leak Detection and Repair Plan which outlines the equipment, type of crew, method of surveying and pinpointing leaks, and the costs involved. Example 19 in Chapter 4 (page 59) illustrates a Leak Detection and Repair Plan.

Audible Leak Detection

This method uses electronic listening equipment to detect the sounds of leakage. Pressurized water that is forced out through a leak loses energy to the pipe wall and to the surrounding soil area. This energy creates sound waves in the audible range which can be sensed and amplified by electronic transducers or, in some cases, by simple mechanical devices. The sound waves are then evaluated by an individual trained in leak detection who can determine the exact location of the leak. This individual, the operator, conducts an initial listening survey of the entire distribution system and records all suspect sounds. If these sounds are heard again when rechecked later, leaks are pinpointed.

There are three typical leak sounds. The first sound is normally in the



15. Valves are excellent contact points for sounds of leakage.

500 to 800 hertz (Hz) range. It usually originates as an orifice-pipe vibration phenomenon and is transmitted along the pipe wall -- in some instances a considerable distance from the actual point of leakage. The identification of this sound by systematic testing of valves, hydrants, and curb valves will frequently locate potential leaks.

Both the second and third sounds are in the 20 to 250 Hz range. The second sound is caused by the impact of water upon soil in the area of the leak. The third sound resembles the sound of a fountain. It is caused by water circulation, usually in a cavity in the soil near the leak. Unlike the vibration on the pipe wall, the travel distance of these two sounds is limited to the immediate area of the leak, and, for this reason, these two sounds are very important in pinpointing the leak for excavation and repair.

There are a number of factors that influence leak sounds, and these factors must be taken into consideration. They include:

- Pressure - It is usually necessary to have 15 psi or more water pressure for sonic leak detection.

- Pipe Material and Pipe Size - Because metallic pipe is a much better sound conductor than nonmetallic pipe, a closer test interval is required when searching for leaks on nonmetallic pipe. Sonic techniques can be used, however, on pipe and fittings of any material.

- Soil Type - The type of soil greatly influences the amount of sound transmitted to the surface. Empirical observation indicates that sand is normally a good conductor of sound; clay is a poor conductor.

- Surface Type - The type of surface on which the sounding instrument is placed is another factor. Sod tends to insulate and muffle sounds, while asphalt and concrete are good resonators and give a uniform sounding surface.

Zone Flow Measurements

This method can reasonably be undertaken as an extension of the water audit or in some cases directly as a leak detection method. Its purpose is to determine whether a sector or "zone" of a water system is suffering major leakage. To effectively conduct a zone flow measurement a utility must maintain good maps, have valves located at zone control points, and provide a tap in the main for the recording pitotmeter.

Zone measurements are most effective in large residential or rural sections, less so in commercial or industrial areas. The winter months are the best time for zone measurements as they are less affected by outside water use (lawn watering and irrigation). However, nights that are subject to extreme freezing temperature should be avoided, since customers may leave water running to avoid water line freeze-up. Twenty-four-hour recordings are recommended and daytime flows are compared with nighttime flows. Water utility staff should be alert to nighttime reservoir filling or unusual water usage such as night irrigation or a commercial use such as a laundry operation. Allowances are made for minimum usage. Flows greater than these minimum flow rates indicate leakage.

Sections of the water system are isolated and valves are closed to permit water flow from a single line. The usage rate can be estimated to determine whether the flow rate is unacceptably high and warrants additional investigation and correction. Zones can be further subdivided depending upon the existing valving in the area of interest.

Another form of zone measurement is the storage tank method. This type of zone measurement can be used in pressure zones where there are only a few customers and the the entire zone is supplied by storage tanks. Each storage tank is read for volume and all the customer meters in the zone are read. During that time period, the storage tanks are not replenished. After a period of time, such as a week, the procedure is repeated. The potential leakage is the difference between the water supplied to the system from the storage tanks and the sum of the meter readings. With this method, the accuracy of customer meters must have been previously determined.

Normal Course of Operation

This method involves discovering leaks accidentally in the normal course of operations and maintenance. For example, in a valve exercising program leaks may be discovered during the exercising of valves. Meter readers have the opportunity to check for visible meter box leaks when reading the meters.

Leaks You Can Expect to Find

Main Line Leaks

Main line leaks range from a low of 1 gpm to over 1,000 gpm. Leaks due to corrosion usually start out small but can grow to very large leaks.

Splits can occur due to excessive pressure, improper installation settlement, and overloading.

16. Excavating a 53 gpm leak on an old steel main.

17. Service laterals are common in metallic pipes. This leak was measured at 2 gpm.

Joint leaks can occur due to corrosion, improper installation, improper materials, or overloading.

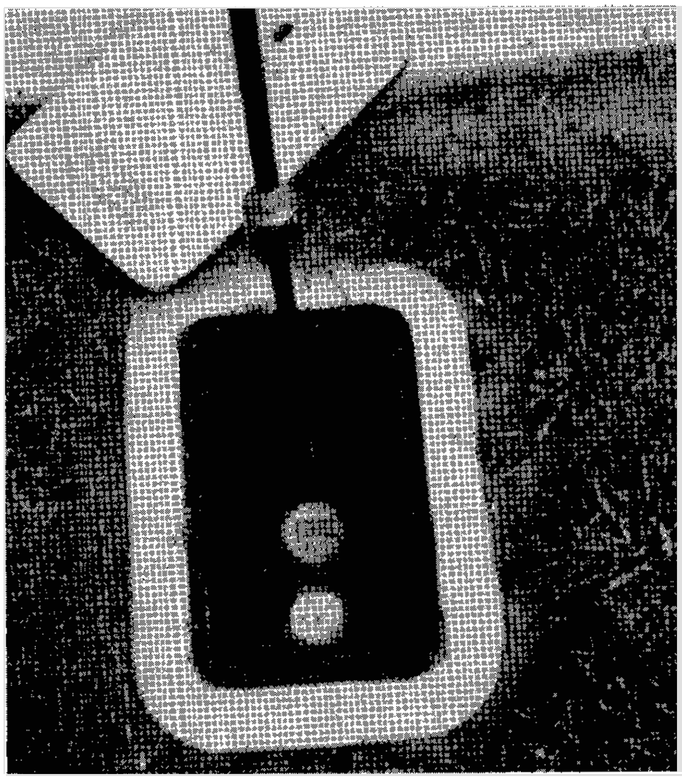
Service Line Leaks

Service line leaks range from a low of 0.5 gpm to over 15 gpm. Service line leaks are caused by the same factors as main line leaks.

Residential Meter Box Leaks

Leaks within the vicinity of the meter box range from a low of a fraction of a gpm to a high of 10 gpm. Common examples include leaks due to:

- o loose spud nuts on either side of the meter
- o loose packing nuts
- o damaged or broken angle stops
- o broken or damaged couplings
- o broken meters
- o damaged or broken meter yokes



18. Leaks from meter boxes are sometimes visible. Here, leak detection equipment determines whether standing water is runoff or leakage.

Residential Customer Leaks

Leaks on the residential customer side of the system range from a low of a fraction of a gpm to a high of 15 gpm. Common examples include:

- o holes or breaks in customer service lines
- o inefficient hose bib or shutoff valves
- o holes or breaks in interior plumbing lines
- o leakage inside plumbing fixtures (toilet fixture leaks are common)

Valve Leaks

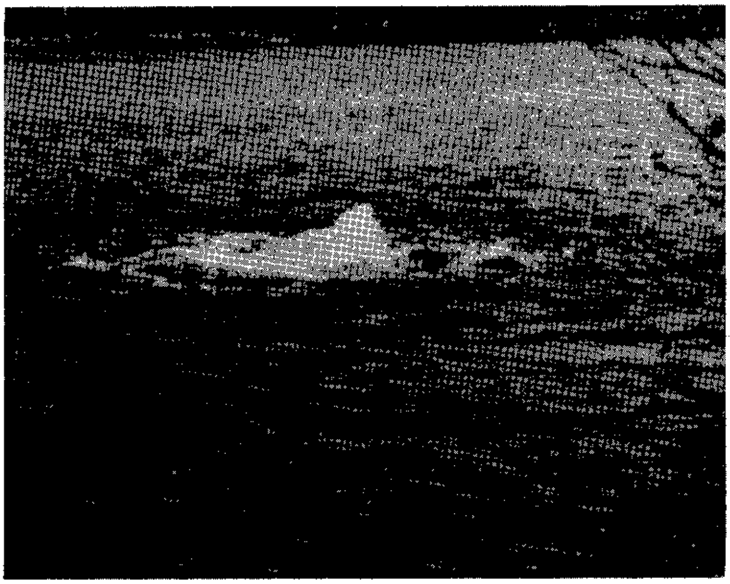
Leaks in distribution system valves range from a low of a fraction of a gpm to a high of 500 gpm. Common examples include leaks due to loose packing and broken valves.

Leaks may start in system controls such as pressure-reducing valves, pressure-sustaining valves, pressure-relief valves, altitude control valves, blowoffs, air-release valves, and others.

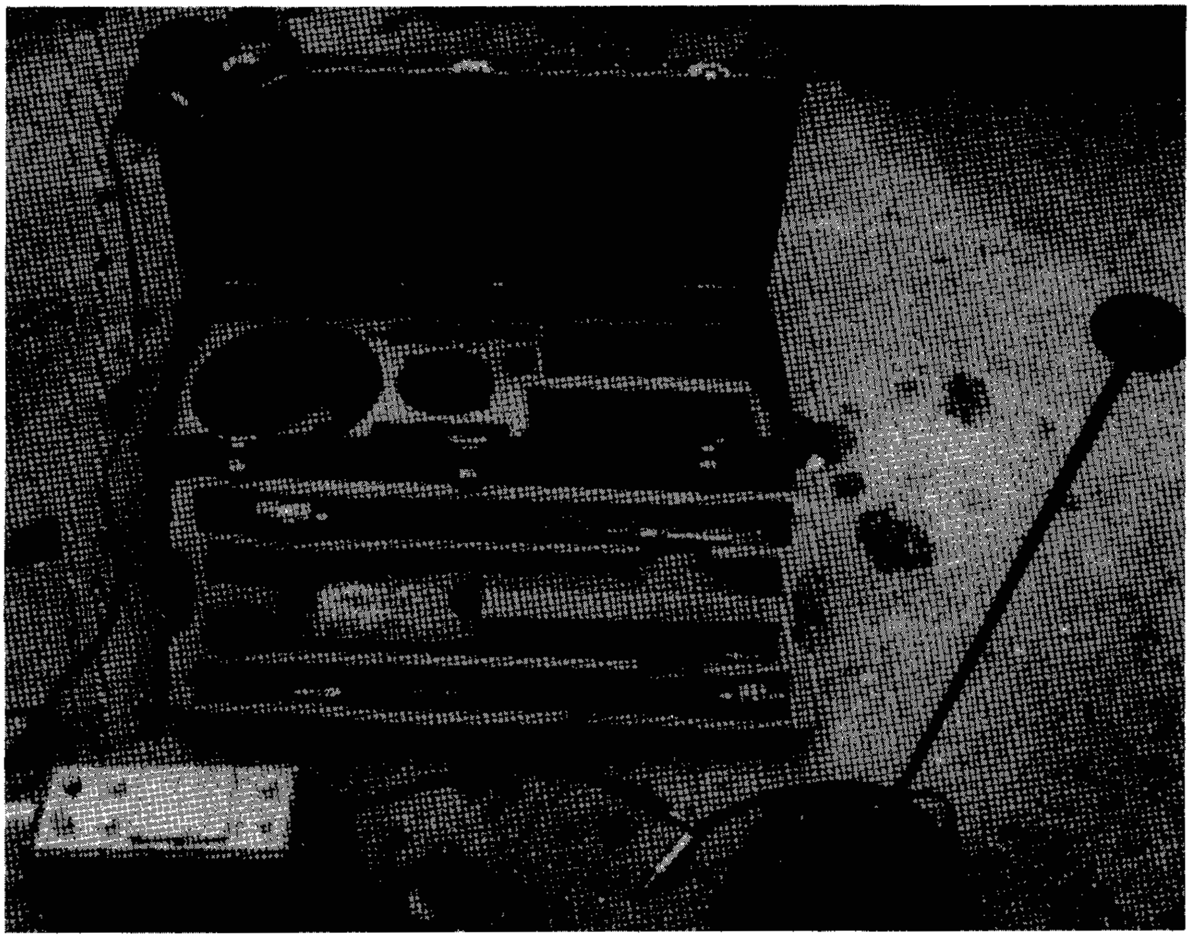
Miscellaneous Leaks

Breaks from excessive pressure, settlement, overloading, improper installation, improper materials, and improper operation may occur.

19. Improper repair of hydrant lateral caused this leak to occur months after initial repairs.



20. Transmission mainline leak under this reservoir was detected by introducing pressurized air into the main.



21. Typical sonic listening equipment.
This is the Heath Son-I-kit.

CHAPTER 4. 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.

Preparing for the Leak Detection Survey

Pre-Survey Review

Prior to conducting a leak detection survey, you should review the specifics of your distribution system. The following information is important to review:

- results of the water audit -- How much water is lost from the system?
- mains and services -- types of pipe, 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 of valves, left or right handed, number of turns to exercise valves, and how often exercised.
- hydrants -- types, sizes, locations, flushing frequencies, and unmetered usage.
- pressure-reducing valves, pressure-sustaining valves, 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?

Leak Detection Equipment

Provide leak detection equipment for crew members including sonic listening equipment with a high frequency listening probe and a low frequency ground microphone for pinpointing leaks. A list of leak detection equipment manufacturers is in Appendix J (page 125).

Provide safety equipment for crew members including:

- safety vests
- traffic cones
- barricades

Provide tools to measure flow rates including a:

- o stopwatch
- o bucket
- o measuring cup
- o pressure gauge
- o measuring tape or a ruler

Provide working tools, such as:

- o meter box lid lifters
- o valve cover lifters
- o valve keys
- o curb stop keys
- o small bailing cans or small manual pumps
- o chalk (keel) or spray paint
- o pipe locators
- o wrenches for tightening meter spud nuts

Selecting Team Members

When selecting team members consider the following qualities:

- o keen sense of hearing
- o ability to discern different sounds
- o familiarity with water meters and the distribution system
- o sense of responsibility
- o ability to estimate leak flows
- o ability to complete leak forms
- o ability to work on their own

Planning the Survey

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

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

Leak Detection & Repair Plan

Prepare a Leak Detection and Repair Plan. A plan is shown on the following pages; a sample plan is included in Appendix A. Blank forms are located in Appendix K (page 127).

EXAMPLE 19
LEAK DETECTION AND REPAIR PLAN
WORKSHEET

Name of Agency: XYZ County Water District Date: 7/18/85

A. Area to be Surveyed

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. Describe each area under B-2. (Items to consider include records of previous leaks, type of pipe, age of pipe, soil conditions, high pressures, ground settlement, and improper installation procedures.)

2. Total miles of main to be surveyed: 146 . If less than the total system is being surveyed, the calculations for the benefit:cost ratio must reflect the reduction. (When calculating the miles of main, include the total length of pipe and exclude service lines.)

3. Average number of miles of main surveyed per day: 2.0 . Explain if more than 3 miles per day are surveyed. (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.) ______

4. Number of working days needed to complete survey: 73 . (Divide Line 2 by Line 3.)

B. Procedures and Equipment

1. Describe the equipment and procedure you will use to detect leaks. Experience has shown that the best results have been obtained by listening for leaks at all system contact points (such as water meters, valves, hydrants, and blowoffs).

   Purchase Heath Son-i-Kit. Attend Manufacturers Seminars and DWR Training. Conduct initial listening survey on all contact points.

EXAMPLE 19 (cont.)
LEAK DETECTION & REPAIR PLAN WORKSHEET

2. Describe why the areas noted on the map (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 - Remainder of system

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

   Not applicable - crew will listen for leaks on all contact points.

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

   Will use low frequency ground microphone to listen over pavement surfaces. Consultants correlator will be used in difficult situations.

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

   The leak detection crew and the repair crew will jointly evcavate all leaks for the first 3 weeks and resolve and dry holes thereafter.

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 and used in the Greeley formula as shown in the Guidebook.

C. Staffing

1. How many agency staff will be used? 2

Staff Costs Including Wages and Benefits:

Person 1	$/hour	17.19	$/day	137.52
Person 2	$/hour	12.50	$/day	100.00
TOTAL	$/hour	29.69	$/day	237.52

2. How many consultant staff will be used? 1

Cost of Consultant Staff:

Person 1	$/hour	31.25	$/day	250.00
Person 2	$/hour	Ø	$/day	Ø
TOTAL	$/hour	31.25	$/day	250.00

D. Leak Detection Survey Costs

Leak Detection Surveys:	$/day	# Days	Cost
1. Agency Crew Costs	237.52	73	$17,340
2. Consultant Crew Costs	250.00	15	$ 3,750
3. Vehicle Costs	2.40	73	$ 175
4. Other			$ Ø
5. TOTAL Survey Costs			$21,265

E. Leak Detection Budget

1. Cost of Leak Detection Equipment	$ 2,550
2. Leak Detection Team Training	$ 400
3. Leak Detection Survey Costs	$21,265
4. TOTAL Leak Detection Costs	$24,215

EXAMPLE 19 (cont.)
LEAK DETECTION & REPAIR PLAN WORKSHEET

F. Leak Survey and Repair Schedule

Indicate realistic, practical dates.

1. When will the leak survey begin? August 1, 1986
2. When will the leak survey be completed? December 15, 1985
3. When will leak repairs begin? August 15, 1985
4. When will leak repairs be completed? January 10, 1986

Prepared by:

C. M. Biggs	7/18/85
Name	Date
Manager	
Title	

Team Training

Train team members prior to conducting a leak detection survey. The following options are available:

- o Attend manufacturers' training seminars.
- o Have manufacturers include on-the-job training when purchasing equipment.
- o Obtain on-the-job training from other agencies with existing programs.
- o Obtain training from a consultant.
- o Obtain training from the DWR District in your area.

22. On-the-job training for leak-detection crews builds confidence.

Equipment Tuneup

Leak detection equipment must be operating properly for a successful survey. Prior to conducting the survey, leak detection staff should familiarize themselves with the equipment. Consult the instruction manual and review the instructions. Check the equipment for the following items:

- Do the batteries need to be charged or replaced? (Bring extra batteries.)
- Are all electrical and physical connections tight?
- Are all controls working properly?
- Check to see if you can hear the basic leak sound by testing the equipment on a hose bib with water running and then with no water running.

Practice with the equipment you will be using to detect leaks. Practice listening and discerning the differences in sounds by determining the following factors:

- the unique background sound of your instrument
- what a quiet sound is (when no leak or water use is present)
- what water use sounds like by opening a hose bib on a customer's service line
- what the sound is when a faucet is dripping
- what the sound is when sprinklers are in use in the area
- what the sound is when the meter is turning

Leak Detection Procedures

Initial Listening Survey

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

23. Listening on all valves and all other contact points in the distribution system is important to an effective survey.

Nonmetallic mains require extra effort in listening surveys. It may be necessary to listen over the main with the ground microphone to detect leak sounds. This is dependent on system pressure, pipe diameter, and equipment sensitivity. To determine whether the system requires listening over nonmetallic mains (Asbestos/Concrete or plastic), use the ground microphone and listen over the main. Have a team member turn on a hose bib at the customer's service. Determine over what distance along the main you hear the sound of water escaping from the hose bib. You may not have to use the ground microphone and listen over the main. If the distance between contact points is greater than the distance that the sound travels along the main, then you should use the ground microphone and listen over the main at appropriate intervals (10 to 25 or 50 feet).

Problems Encountered with the Listening Procedures

Sounds from Customer Use Inside a Dwelling. Examples of such sounds are: showers, toilets, washing machines, pumps, meters, and conversations.

Sounds from Outside a Dwelling. Some of these sounds come from aircraft, wind and rain, street traffic, interference from power lines or transformers, radio broadcasting, or lawn watering.

Sounds from Water Noises. These sounds usually come from adjacent leaks, valves, or turbulence.

Other Problems. Some other problems that may be encountered are faulty equipment (loose electrical connections), improper training, or system pressure less than 15 psi.

EBMUD

CONSERVE WATER

ADDRESS ____________________

CITY ____________

DATE ____________

TIME ____________

East Bay Municipal Utility District is "listening" to its water mains and service connections with electronic leak detection equipment. As part of this survey, customer house plumbing systems are "listened to" at the meter.

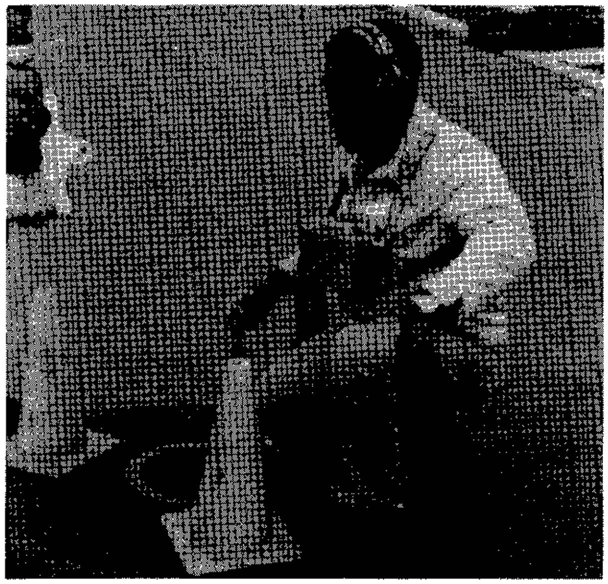
The detectors have picked up the sound of running water on your plumbing system, which could mean that you have leaks in your plumbing. In order to conserve water and to prevent high water bills, please check your house for leaks or running water, using the checklist on the reverse side of this card.

C-93 • 11/75

3. Doorhanger notifying residential customer of possible plumbing leaks.

Relistening to Suspect Sounds

Return to each of the locations noted in the initial listening survey. Using the high frequency contact microphone, relisten for the sounds you heard earlier. If the location is quiet, it is not a leak. If you still hear sounds, is the meter running? If you still hear sounds when there is no water use, a leak probably exists. This leak must be pinpointed.



24. Re-listening to suspect sounds heard on the initial survey confirms the sound of a leak or a water-use sound.

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) if it is a leak sound, determine the leak's exact location.

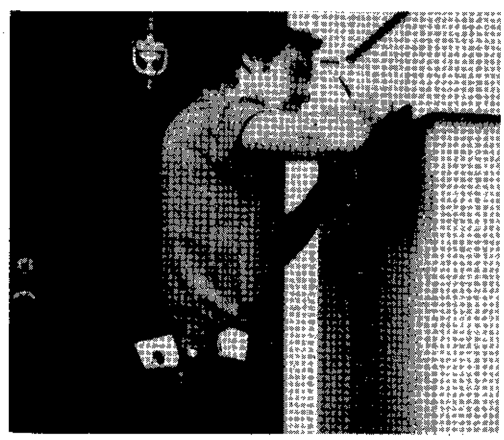
Return to the suspected location and again listen for the sound. Do you hear a leak sound? If you still hear a suspect sound, it might not be a leak. Use all resources available--naked ears, eyes, a sonic amplifier--and walk around the area. The sound may be from something other than a leak, such as a pressure reducing valve or electrical transformer.

Review detailed distribution system maps and locate pressure reducers, forgotten valves, or other system apparatus which might make the suspect sound. Check the immediate vicinity and look for suspicious causes. If you located any suspicious culprits, can they be identified and isolated? For example, a customer pressure-reducing valve can be isolated by shutting off the customer service and bleeding the pressure off the system by opening the customer's hose bib. Be sure to check with the customer before shutting off the service!

25. Listening on both sides of the meter for the loudest sound determines whether a leak is on the utility "side" or the customer's "side."

If the leak noise is heard on a water meter, determine if the sound is louder on the customer side or the agency side of the meter. Look for obvious signs of customer use. Perhaps sprinklers are operating. In this case, the meter may be heard turning even if the meter hand is not moving. Check the meter indicator for movement. The leak may be in the area of the meter box. Listen carefully for leak sounds on both sides of the meter. If you are still uncertain, you can contact the customer and notify him that you will be shutting off his service for a few minutes. Close the angle stop and bleed off system pressure from the customer by opening the hose bib. If the leak sound quits, the leak is within the meter box, on the customer's service line, or in the dwelling. If the noise continues, it indicates the leak is on the agency side of the meter.

If a leak is determined to be on the customer side of the meter, leave a doorhanger (such as the one shown below) notifying the customer that they might have a leak in their service line, interior plumbing, or water using fixtures.



26. A doorhanger notifies a customer that leakage is suspected on his side of the meter.

If the 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 method or using the correlator method.

Ground Microphone Method. The objective of using this method is to find the location of the loudest leak sound over the main or service line (pipe).

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.

27. Effective pinpointing requires the use of pipe locaters to determine the exact location of underground pipes.

Ground microphones are either monophonic or stereophonic, depending upon the manufacturer. The stereo models have the capability to discern differences in intensity between two microphones. However, most models have only one microphone.

28. If the location of pipes is known, a ground microphone will help pinpoint the location of leaks.

When using the ground microphone for pinpointing, remember to set the volume relatively low at the beginning, so loud sounds will not be uncomfortable. Keep the volume adjustment at the same level throughout each pinpointing sequence. If uncomfortably loud sounds are heard, reduce the volume for your safety, then resurvey the points to locate the loudest leakage sounds.

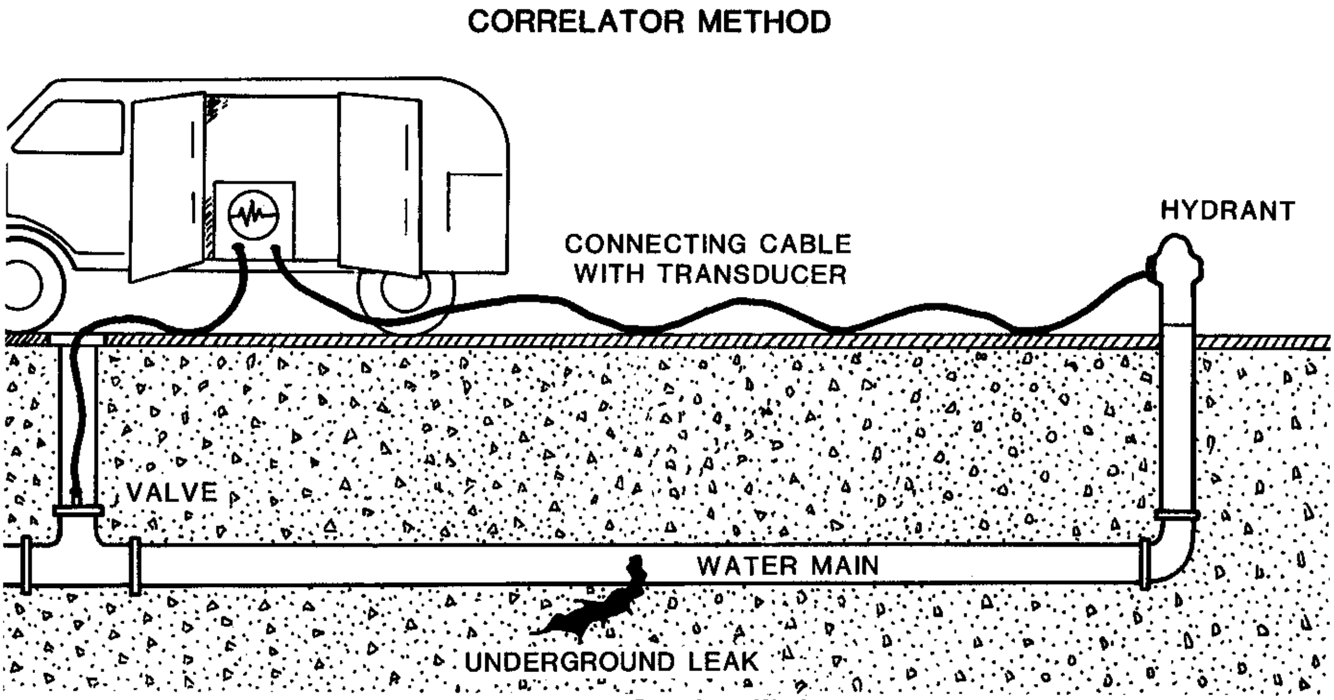
Use the ground microphone and listen for leak sounds every 5 to 10 feet and write notes on the sound intensities. If the equipment has a meter, write the meter readings down. The strongest signal usually indicates the location of the leak. Be careful NOT to change the setting of the volume or other controls during this process. Where possible, avoid comparing sounds from points with different surface and compaction characteristics. If this is unavoidable, make allowance for the fact that the same leak sound will be quieter from a loosely compacted surface than a dense one.

The ground microphone process should be repeated to verify the leak location.

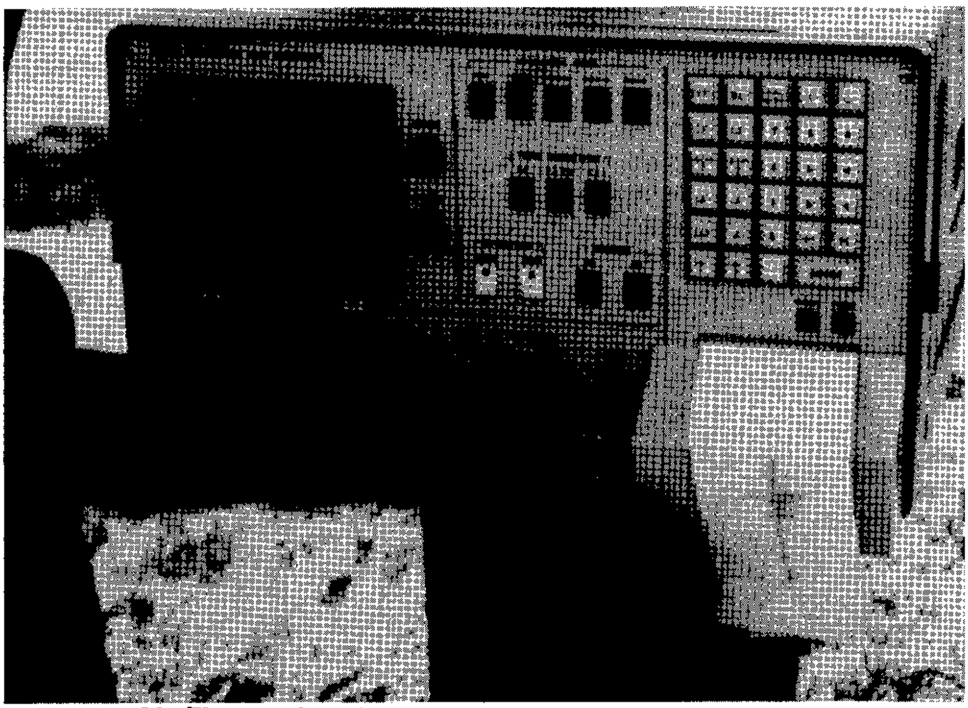
29. Geophones enable listening in stereo.

Correlator Method. A correlator is a "package" of electronic equipment used to pinpoint leaks which usually includes the following items:

- transducers (two or more) which pick up the noise from the pipe and convert it into an electronic signal
- two sets of cables or radio transmitters/receivers to carry the electronic signal from the transducers to the correlator
- amplifiers and a correlator which compare the signals received from two or more signal sources
- a microcomputer
- a speaker (and headphones) to recreate the leak sound for the operator
- a cathode ray tube (CRT) video display
- a paper tape printer, on some models, to provide a permanent written display of the leak wave form and the distance of the leak from the contact points
- a power supply (often a 12-volt automobile battery)

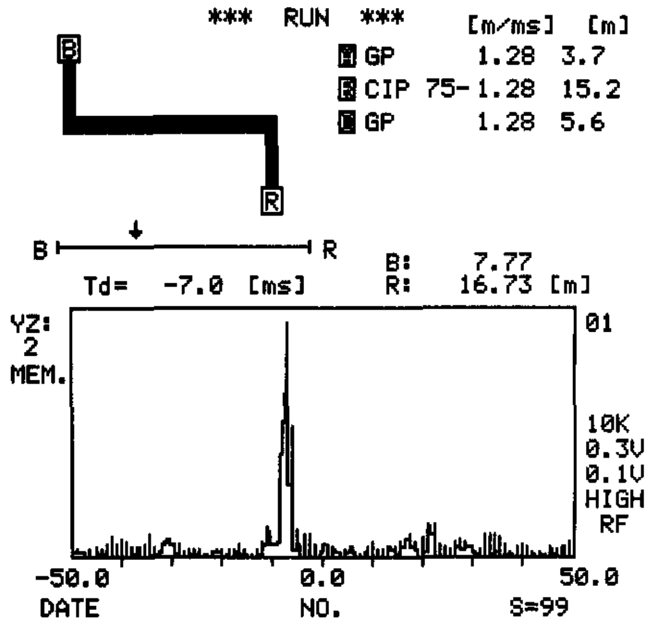


4. **How a Correlator Works**



30. **The correlator helps a pinpoint the location of a leak. Some correlators have a paper tape, along with a CRT, for permanent records of a leak.**

Prospective users of correlators should be advised that correlators are complex electronic equipment that require considerable training for successful use. Correlators are not designed to be carried by hand. They weigh from 25 to 50 pounds and need an electric power supply. The transducers/transmitter units of some models may be used for sonic leak detection when handled carefully.

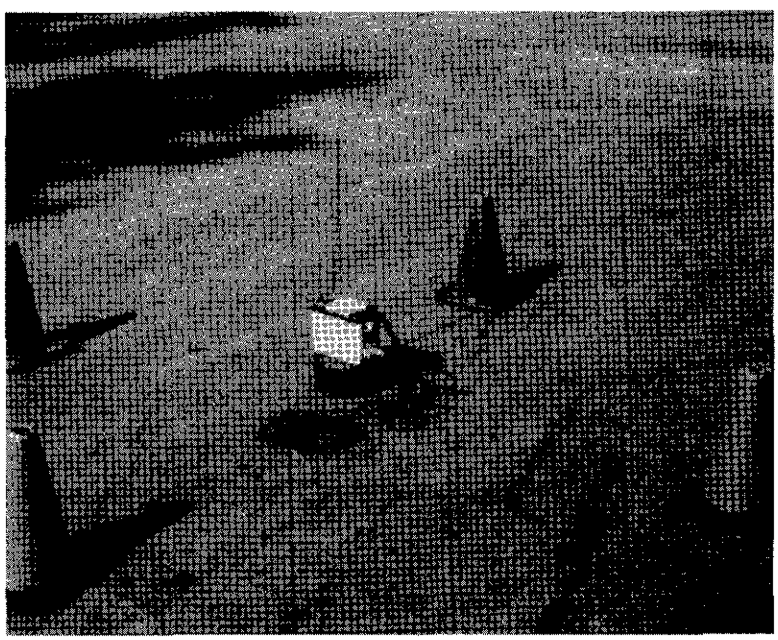


31. Typical paper tape output of leak location. The spike on the chart locates the position of the leak between the blue and red transducers.

After confirming that the same leak sound is still present and can be detected from two separate contact points, the correlator may be used.

The pipe locations and configurations must be determined even more accurately than they were in the sonic equipment method. The distance along the pipe between the contact points must be carefully measured in the field (including the depth from surface to main) and this information is fed into the computer. Pipe size and material type is also input to the computer.

Two electronically amplified transducers are attached to separate contact points on each side of the detected leak. The operator must take great care that the transducers are identified with the correct color-coded contact points. Otherwise, the distance to the leak will be measured from the wrong contact point resulting in a dry hole.



32. A transducer detects the leak sound, which is transmitted by a portable transmitter to the correlator. Pinpointing a leak requires two listening points that span the leak.

The correlator computor senses the leak noise, then calculates the distance from the leak to each transducer. The results are displayed on the CRT video display or printed on paper tape.

The operator then measures the indicated distance from one of the contact points to find the leak location. (A worthwhile check is to remeasure the distances from both contact points to be sure the initial measurements are correct.)

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

Probe Method. An additional procedure to follow when using either of the two previous methods is to drill a small hole through the pavement over the suspected leak location. When drilling holes in the pavement over the main, take care not to damage the pipe. Water may surface through the hole. Insert a metal rod with a "T" handle carefully into the hole and use the high-frequency sonic microphone to listen again for the sound of leakage. Remember to first check for other utilities. Additional holes may be drilled as necessary.

33. In unpaved areas, a probe can be used as an extension to listening directly on the buried pipe.

To assure that you will not be affecting other utilities, before digging, contact Underground Service Alert (USA), a location service, at:

- (800) 422-4133 for the Southern California counties of Imperial, Inyo, Los Angeles, Orange, Riverside, San Bernardino, San Diego, Santa Barbara and Ventura.
- (800) 642-2444 for all other California counties plus the State of Nevada.

Excavating the Leak. When excavating the leak, both 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 assist the repair crew in locating the leak. Leaks may be missed because the leak 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.

34. Uncovering leaks requires careful excavation to avoid other pipes, other utilities, or both.

Leak Detection Tips. The following tips may be of assistance when conducting the leak survey and pinpointing the locations of leaks.

- o Many agencies systematically survey areas outlined on maps. Others follow meter reader routes as they have been well thought out and minimize the distances in covering the system. Greater familiarity with the system layout is needed to effectively cover the meter reading routes.

35. Exercising the hydrant valve helps pinpoint a leak.

- o When using the ground microphone in turf areas the use of a "thumb tack" assists in getting better sounds. A thumb tack is a flat, metal, horizontal plate attached to a strong, metal, verticle spike. The manufacturers of sonic leak detection equipment have information on "thumb tacks".

- o Some agencies concentrate on the listening phase for several days and pinpoint at the end of the week.

- o Except when safety is a consideration, a one-person crew is effective for conducting the listening survey.

- o Leak Detection Survey Daily Log, as shown in Example 20 (Page 74), can be used for the initial leak detection survey. Blank forms are located in Appendix K (page 127).

EXAMPLE 20

LEAK DETECTION SURVEY DAILY LOG

Agency XYZ County Water District

Date 7 (Month) 17 (Day) 85 (Year)

Leak Detection Team Members: Lloyd Williams, Raymond Goodgion, Wesley Kelso

Manufacture and models of Equipment used: F.C.S. Model L - 100

Area Surveyed 7 Map Reference Water Distribution Map

Street and Block Nos: San Antonio, San Gabriel Page & Coordinates
San Juan, San Carlos, San Luis, San Miguel 8600 block.

LEAK NO.	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
51	8959 San Antonio	A	Y	N	Y	
52	N/W Cor. Firestone & San Gabriel	A	Y	N	Y	
54	S/W Cor. Firestone & San Gabriel	A	Y	N	Y	
53	S/W Cor. San Juan & Southern	A	Y	N	Y	
55	8990 San Antonio	A	Y	N	Y	
56	8986 San Carlos	A	Y	N	Y	
57	8921 San Luis	A	Y	N	Y	
58	8659 San Miquel	A	Y	N	Y	

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

Miles of Main Surveyed 4.242 Survey Time 8 hours

Number of Leaks Suspected 8 To be rechecked 8 (Number)

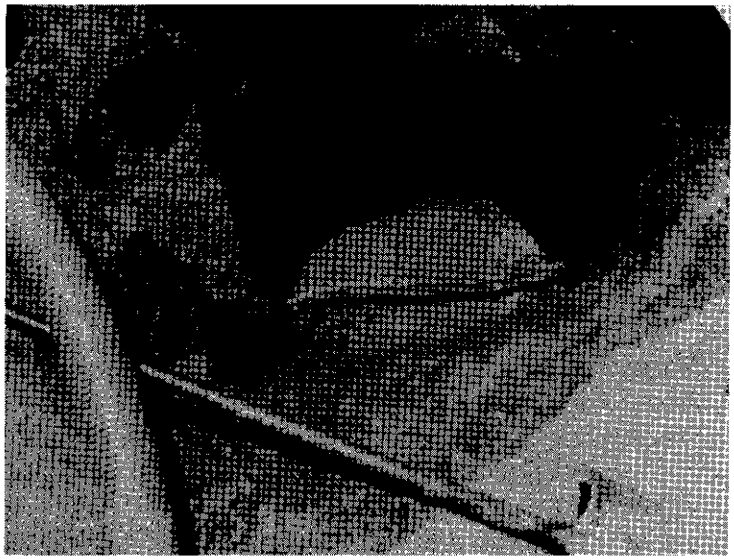
Number of Leaks Pinpointed 0 Pinpointing Time 0 hours

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

Measuring and Estimating Losses from Discovered Leaks

Losses from leaks that are discovered and repaired should be measured to determine the rate of loss and the total volume lost during the life of the leak. Three methods are suggested (from "Leak Detection Productivity," by Douglas S. Greeley in Water Emergency and Management Reference Number 1981):

- o Use a container of known volume and a stop watch.
- o Use a hose and a meter.
- o Calculate losses using modified orifice and friction loss formulas.



36. Service–line leaks can be easily repaired by replacing a part of the service line. Some agencies place the damaged line in line with a test meter and measure the flow rate.

The first method, sometimes known as the bucket and stop watch method, is as simple as its name.

Hold a container against the leak for a predetermined time period. Measure the time with a stop watch. Measure the water captured with a measuring cup or other container of known volume. Then convert time and volume to gallons per minute.

Use time intervals that are easy to deal with.

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

The conversion factor to calculate acre-feet for a two year time period, from gallons per minute (gpm):

$$\frac{(60 \text{ min/hr})(24 \text{ hrs/day})(365 \text{ days/yr})(2 \text{ years})}{325{,}828 \text{ gallons per acre-foot}} = 3.23$$

1.0 gpm for 2 years = 3.23 acre-feet over the two-year average leak lifetime.

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

The second method requires connecting a hose to the leak and directing the flow through a meter.

The third method is the simplest to perform in the field but requires calculations. This method is often helpful for large leaks where the flow is too great to measure and the main must be valved off. It requires that the size and shape of the hole be measured and the line pressure be determined. A pressure gauge or a hand-held blade pitotmeter 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.

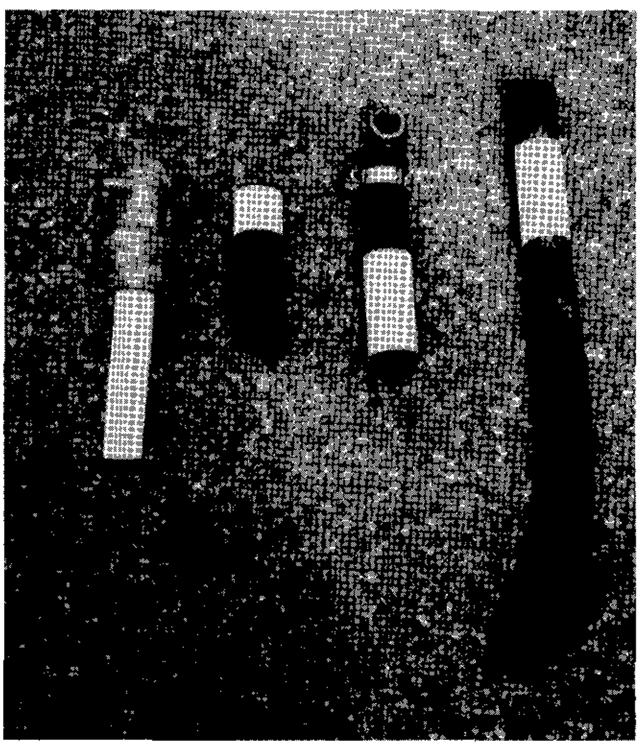
For losses from such items as pipes or broken taps, Greeley assumes an orifice coefficient of 0.80 and calculates flow in gallons per minute from the formula:

$$Q = (43,767/1440) \times A \times \text{square root of } P$$

where Q = flow in gallons per minute
A = the cross sectional area of the leak in square inches and
P = the pressure in pounds per square inch.

For example, if the hole in the pipe were roughly circular, then the area would be: $A = 3.14 \times r^2$. You need only measure the diameter of the hole and ascertain the pressure in the pipe.

For relatively small holes, the following leak rates in gallons per minute (Table 5) were calculated, assuming a circular hole and several pressures.



37. Plastic service line are also subject to deterioration from improper installation, thus resulting in leaks.

Calculating Leak Rates for Small Leaks

The following tables provide leak rates for typical meter box leaks. These tables can be used to convert drips per second and cups per minute to gallons per minute to be entered on the Leak Repair Report.

TABLE 4
LEAK LOSSES FOR CIRCULAR HOLES UNDER DIFFERENT PRESSURES
(losses in gallons per minute)

DIAMETER OF HOLE inches	AREA OF HOLE sq. in.	WATER PRESSURE IN POUNDS PER SQUARE INCH									
		20	40	60	80	100	120	140	160	180	200
0.1	0.007	1.067	1.510	1.850	2.136	2.388	2.616	2.825	3.021	3.204	3.337
0.2	0.031	4.271	6.041	7.399	8.544	9.522	10.464	11.302	12.083	12.816	13.509
0.3	0.070	9.611	13.593	16.648	19.224	21.493	23.544	25.430	27.186	28.835	30.395
0.4	0.125	17.087	24.165	29.597	34.175	38.209	41.856	45.209	48.331	51.263	54.036
0.5	0.196	26.699	37.758	46.245	53.399	59.702	65.400	70.640	75.518	80.098	84.431
0.6	0.282	38.477	54.372	66.593	76.894	85.971	94.176	101.721	108.745	115.341	121.581
0.7	0.384	52.331	74.007	90.640	104.662	117.010	128.184	138.454	148.014	156.993	165.485
0.8	0.502	68.350	96.662	118.387	136.701	152.840	167.424	180.839	193.325	205.052	216.144
0.9	0.636	86.506	122.338	149.833	173.012	193.434	211.896	228.874	244.676	259.519	273.557
1.0	0.785	106.798	151.035	184.979	213.596	238.807	261.600	282.561	302.070	320.394	337.725
1.1	0.950	129.225	182.752	223.825	258.451	288.957	316.536	341.898	365.505	387.676	408.647
1.2	1.131	153.789	217.490	266.370	307.578	343.882	376.704	406.887	434.981	461.367	486.323
1.3	1.327	180.488	255.249	312.615	360.977	403.584	442.104	477.527	510.498	541.465	570.755
1.4	1.539	209.324	296.028	362.559	418.648	468.062	512.737	553.819	592.057	627.972	661.941
1.5	1.767	240.295	339.829	416.203	480.590	537.317	588.601	635.762	679.658	720.886	759.880
1.6	2.011	273.402	386.649	473.547	546.805	611.347	669.697	723.355	773.299	820.208	864.575
1.7	2.270	308.646	436.491	534.590	617.292	690.153	756.025	816.600	872.983	925.938	976.024
1.8	2.545	346.025	489.353	599.333	692.050	773.736	847.585	915.496	978.707	1038.070	1094.220
1.9	2.836	385.540	545.237	667.776	771.081	862.095	944.378	1020.040	1090.470	1156.620	1219.180
2.0	3.142	427.191	604.140	739.918	854.383	955.230	1046.400	1130.240	1208.280	1281.570	1350.890

The above table of losses from roughly circular shaped holes in pipe is computed from the following formula established by Greeley:

Q = (30.394)(A)(square root of P) gallons per minute

where "A" is the cross sectional area of the leak in square inches and "P" is the pressure in pounds per square inch

TABLE 5
LEAK LOSSES FOR JOINTS AND CRACKS UNDER DIFFERENT PRESSURES

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

Q = (22.796)(A)(square root of P)

"A" is the area in square inches and "P" is the pressure in pounds per square inch.

The following table of flow rates was computed in gallons per minute for four different leak dimensions under pressures ranging from 20 to 200 psi.

AREA		WATER PRESSURE IN POUNDS PER SQUARE INCH									
LENGTH	WIDTH	20	40	60	80	100	120	140	160	180	200
1.0	1/32	3.2	4.5	5.5	6.4	7.1	7.8	8.4	9.0	9.6	10.1
1.0	1/16	6.4	9.0	11.0	12.7	14.2	15.6	16.9	18.0	19.1	20.1
1.0	1/8	12.7	18.0	22.1	25.5	28.5	31.2	33.7	36.0	38.2	40.3
1.0	1/4	25.5	36.0	44.1	51.0	57.0	62.4	67.4	72.1	76.5	80.6

TABLE 6
DRIPS PER SECOND CONVERTED TO GALLONS PER MINUTE

Drips per Second	Gallons per Minute
1	0.006
2	0.012
3	0.018
4	0.024
5	0.030

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

TABLE 7
CUPS PER MINUTE CONVERTED TO GALLONS PER MINUTE

8-ounce Cups per Minute	Gallons per Minute
0.25	0.016
0.50	0.031
0.75	0.047
1.00	0.062
1.50	0.094
2.00	0.125
2.50	0.156
3.00	0.188
3.50	0.219
4.00	0.250

Use the Leak Repair Report Form, to record all information regarding leak excavation, flow rates, and leak repair. (See Example 21 on page 79.)

Determining Leak Detection Effectiveness

An important and often neglected part of the leak detection project is the determination of whether the project was a cost-effective water conservation measure. To determine whether the leak detection project was cost effective, the agency must evaluate the completed leak detection project.

The Leak Detection and Repair Project Summary (see Example 22 on page 81) includes information needed for this evaluation.

EXAMPLE 21

LEAK REPAIR REPORT

Agency: XYZ County Water District

Date of Repair: 11 (Month) 5 (Day) 85 (Year)

W.O. No. 10077 Foreman Hal Nielson

Map Reference Water Distribution System

Page and Coordinates Area 13

Leak Identification

Refer to Leak Discovery Report

Discovery Date 11 4 85 Leak No. 197

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

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, 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 or Service Leak, Attach Three Photos:

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

Leak Found ? Yes (Yes/No)

TYPE OF LEAK

Meter Leak	___	Main Line Leak	___	Joint Leak	___
Meter Spud Leak	___	Service Lateral Leak	___	Other Leak	X
Meter Yoke Leak	___	Fire Hydrant Leak	___	Describe	Automatic Flushing Device
Curb Stop Leak	___	Valve Leak	___		

DESCRIPTION OF REPAIR

Damaged part was: X Repaired ___ Replaced

If repaired, what repairs were made?

___ Leak Clamp ___ Repacked valve

___ Welded ___ Recaulked joint

___ Other (describe).

If replaced, what material was used? 3 bags AC patch

Repair time 4 (From To)

Crew Size 2 (persons)

Equipment Used for Repair

___ Backhoe

___ Dumptruck

Repair Costs:

Materials	$ 11.19
Labor	$ 114.72
Equipment	$ 12.00
Other	$ 1.00
Total	$ 138.91

Size of Leak

Measured 3 - 1/2 GPM

Estimated ___ GPM

Method used: Timed 3 - 1/2 gallon bucket with stop watch

EXAMPLE 21 (cont.)

Your annual water loss ratio versus sales has been increasing at a rate of 1% which would indicate that a percentage of these flushing lines were already starting to leak back in 1981.

Description of Damage for Mains and Services

What part was damaged?

___ Pipe barrel
___ Joint
___ Valve
___ Flange nuts, bolts, tie rods
___ Other (describe________________
____

Type of Break

___ Split
___ Hole
___ Circumferential split
___ Broken coupling
___ Service pulled
___ Cracked at corp. stop
___ Gasket blown
___ Crushed pipe
___ Cracked Bell
___ Other (describe)________________
____

In your opinion, what caused the damage?________________
____
____
____

Estimated age of leak in months 48
How Determined *See top of page
Diameter of Main or lateral in inches________________
Depth to top of pipe in inches________________

Pipe Material:

___ Galv. Iron
___ Black Iron
___ Cast Iron
___ Ductile Iron
___ Steel
___ Copper
___ A. C.P.
___ P.V.C.
___ Polybutylene

System Pressure________________
How Determined ________________
____

Examine broken edge of cast or ductile iron pipe:

Origional thickness Inches________

Min. thickness of good grey metal remaining Inches________

Deterioration is on:
___ Outside
___ Inside

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

Number of previous leak repair clamps present________________

Last repair date (if known)________________ Cause of Leak________________
____

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

If yes, explain extent: ________________
____

FOR EXCAVATIONS INDICATE GROUND CONDITIONS

Type of Soil:

_____ Rocky
_____ Sandy
_____ Clay
_____ Hard Pan
_____ Adobe
__X__ Loam
_____ Other ________________

Existing Bedding:

_____ Gravel/Sand
__X__ Native Soil
_____ Pea Gravel
_____ Other ________________

Type of Cover:

_____ Concrete
_____ Asphalt
_____ Soil
_____ Other ________________

EXAMPLE 22
LEAK DETECTION AND REPAIR PROJECT SUMMARY

Agency: XYZ County Water District

Name of Report Preparer: C. M. Biggs

Date: November 30, 1985

Leak Detection Survey

TOTAL Number of Days Leak Surveys were Conducted: 65

First Survey Date: 7/10/85 Last Survey Date: 11/4/85

	Meters	Hydrants	Valves	Test Rods	Other
Number of Listening Points Used:	13,786	1,067	2,505	Ø	17

	Suspected	Pinpointed
Number of Agency Leaks:	175	7

Survey Time: 469 hours Miles of Main Surveyed: 124.7 Pinpointing Time: 2 hours

Average survey rate = $\frac{\text{Miles of main surveyed} \times 8}{\text{Total survey and pinpointing hours}}$ = 2.1 miles per day

TOTAL number of visible leaks reported since survey started, from other sources (not discovered during leak detection surveys). Ø

Leak Repair Summary

Date First Leak Repair Made: 7/11/85 Date Last Leak Repair Made: 11/5/85

Number of Repairs Needing Excavation: 27 Number of Repairs Not Needing Excavation: 148 TOTAL Number of Repaired Leaks: 175

TOTAL Water Losses from Excavated Leaks: 203.5 gpm TOTAL Water Losses from Nonexcavated Leaks: 2.9 gpm TOTAL Water Losses: 206.4 gpm

Excavated Leak Repair Costs		Nonexcavated Leak Repair Costs		TOTAL Repair Costs	
Materials	$ 699.36	Materials	$ 411.68	Materials	$ 1,111.04
Labor	$ 4,377.39	Labor	$ 2,255.72	Labor	$ 6,633.11
Equipment	$ 561.40	Equipment	$ 248.75	Equipment	$ 810.50
Other	$ 35.00	Other	$ 83.50	Other	$ 118.50
Subtotal	$ 5,673.15	Subtotal	$ 2,999.05	TOTAL	$ 8,672.80

EXAMPLE 22 (cont.)
LEAK DETECTION AND REPAIR PROJECT SUMMARY

Agency: XYZ County Water District

Date: November 30, 1985

Leak Detection Project Cost Effectiveness

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

(Vwr) = (Total leakage recovered in gpm)(Conversion Factor)(Water cost, Wc)

Conversion factor = 1 gpm for 2 years = 3.23 acre-feet

Wc = Line 19 of Water Audit Report = water purchase price + operating costs per unit of water

Vwr = (206.4 gpm)(3.23 acre-feet/gpm)(275$/acre-feet) Vwr = $ 183,335

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

Leak Detection Survey Costs

Leak Detection Equipment	$ 2,404.65
Leak Detection Training	$ 400.00
Leak Detection Survey Costs	$25,944.84

TOTAL COST of Leak Detection Survey $28,749.49

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

Benefit:Cost Ratio (B:C) equals: $\frac{\text{Value of Water Recovered}}{\text{Total Cost Leak Detection Survey}}$

B:C = 6.4

For planning future leak detection efforts, you can calculate average survey costs per mile.

Step 4. Determine average survey costs per mile of main surveyed (C/M).

C/M = $\frac{\text{Total Cost of Leak Detection Survey}}{\text{Total Number of Miles Surveyed}}$ $\frac{\$\ 28,749.00}{M\ \ 124.70}$

C/M = $ 230.6

APPENDIX A
SAMPLE COMPLETED AUDIT REPORT & LEAK DETECTION AND REPAIR PLAN

This sample completed Water Audit report was used by the California Department of Water Resources as an example for participants to follow in its statewide Leak Detection Grant Program. Participating water utilities and districts conducted water audits for a one-year period with emphasis on master and sales meter accuracy plus unmetered water uses. No low-flow zone measurements were required, although in several instances, they might have been useful.

WATER AUDIT REPORT

Prepared by XYZ County Water District

This report includes the following items:

- a water audit worksheet
- uncorrected total water supply
- adjustments to total water supply due to source meter error
- uncorrected total metered water use
- meter test results
- adjustments due to system service meter error
- a description of accounting procedures reviewed
- a description of actions taken to determine unmetered uses
- a description of actions taken to determine water losses
- a summary of recommendations for system improvements proposed as a result of the water audit
- a leak detection and repair plan

All discussions and tables refer to the line numbers of the Water Audit Worksheet.

Submitted by:

C. M. Biggs
Name

Manager
Title

7/18/85
Date

WATER AUDIT WORKSHEET

For the Water District: ______________________

LINE	ITEM	WATER VOLUME Subtotal	WATER VOLUME Total Cumulative	UNITS*
1	Uncorrected Total Water Supply to the Distribution System (Total of Master Meters)		11,270	Acre-feet
2	Adjustments to Total Water Supply			
2A	Source Meter Error (+ or -)	+ 254.5		Acre-feet
2B	Change in Reservoir and Tank Storage (+ or -)	+ 2.5		Acre-feet
2C	Other Contributions or Losses (+ or -)	Ø		Acre-feet
3	TOTAL Adjustments to Total Water Supply (+ or -) (Add Lines 2A, 2B, and 2C.)		+ 257.0	Acre-feet
4	ADJUSTED TOTAL Water Supplied to the Distribution System (Add Line 1 and Line 3.)		11,527.0	Acre-feet
5	Uncorrected Total Metered Water Use	10,000		Acre-feet
6	Adjustments Due to Meter Reading Lag Time (+ or -)	+ 0.6		Acre-feet
7	Subtotal: Metered Deliveries (Add Lines 5 and 6.)		10,000.6	Acre-feet
8	TOTAL Sales Meter Error and System Service Meter Errors (+ or-)		504.1	Acre-feet
9	CORRECTED TOTAL Metered Water Deliveries (Add Lines 7 & 8.)		10,504.7	Acre-feet
10	CORRECTED TOTAL Unmetered Water (Subtract Line 9 from Line 4.)		1,022.3	Acre-feet

* The units of water measurement must be consistent throughout the worksheet. Their selection (e.g., acre-feet, millions of gallons, hundred cubic feet) is left to the user.

LINE	ITEM	WATER VOLUME Subtotal	Total Cumulative	UNITS*
11	Authorized Unmetered Water Uses			
11A	Firefighting & Firefighting Training	30.		Acre-feet
11B	Main Flushing	5.		Acre-feet
11C	Storm Drain Flushing	1.5		Acre-feet
11D	Sewer Cleaning	2.		Acre-feet
11E	Street Cleaning	5.4		Acre-feet
11F	Schools	Ø		Acre-feet
11G	Landscaping in Large Public Areas			
	Parks	140.		Acre-feet
	Golf Courses	370.		Acre-feet
	Cemeteries	12.		Acre-feet
	Playgrounds	19.		Acre-feet
	Highway Median Strips	2.		Acre-feet
	Other Landscaping	1.		Acre-feet
11H	Decorative Water Facilities	Ø metered		Acre-feet
11I	Swimming Pools	Ø metered		Acre-feet
11J	Construction Sites	Ø metered		Acre-feet
11K	Water Quality and Other Testing (pressure testing pipe, water quality, etc.)	Ø metered		Acre-feet
11L	Process Water at Treatment Plants	0.2		Acre-feet
11M	Other Unmetered Uses	Ø		Acre-feet
12	TOTAL Authorized Unmetered Water (Add Lines 11A through 11M.)		588.1	Acre-feet

LINE	ITEM	WATER VOLUME Subtotal	Total Cumulative	UNITS*
13	TOTAL Water Losses (Subtract Line 12 from Line 10.)		434.2	Acre-feet
14	Identified Water Losses			
14A	Accounting Procedure Errors	35.7		Acre-feet
14B	Illegal Connections	1.		Acre-feet
14C	Malfunctioning Distribution System Controls	Ø		Acre-feet
14D	Reservoir Seepage and Leakage	+ 0.2		Acre-feet
14E	Evaporation	30.		Acre-feet
14F	Reservoir Overflow	Ø		Acre-feet
14G	Discovered Leaks	67.		Acre-feet
14H	Theft	Ø		Acre-feet
15	TOTAL Identified Water Losses (Add Lines 14A through 14H.)		133.9	Acre-feet
16	Potential Water System Leakage (Subtract Line 15 from Line 13.)		300.3	Acre-feet
17	Recoverable Leakage (Multiply Line 16 by 0.75.)		225.2	Acre-feet
18	Cost Savings	Dollars per Unit of Volume		
18A	Cost of Water Supply	$ 225/Acre-foot		
18B	Variable O & M Costs	$ 50/Acre-foot		
19	TOTAL Costs Per Unit of Recoverable Leakage (Add Line 18A to Line 18B.)	$ 275/Acre-foot		

LINE	ITEM	Dollars per Year
20	One-Year Benefit from Recoverable Leakage (Multiply Line 17 by Line 19.)	$ 61,930
21	TOTAL BENEFITS from Recovered Leakage (Multiply Line 20 by 2.)	$ 123,860
22	TOTAL COSTS of Leak Detection Project	$ 24,215
23	Benefit to Cost Ratio (Divide Line 21 by Line 22.)	5.12

Prepared by:

C. M. Biggs
Name

Manager
Title

7/18/85
Date

SYSTEM SUMMARY OF WATER SOURCE MEASURING DEVICES

	Source 1	Source 2	Source 3
Type of Measuring Device	Venturi	Propeller	Venturi
Identification Number (may be serial no.)	0000278-A	8759	OC - 16
Frequency of Reading	Daily	Weekly	Daily
Type of Recording Register	Dial	Dial	Builder Type M
Units Registers Indicate	100,000 gallons	gallons	cubic feet
Multiplier (if any)	1.0	1.0	100.0
Date of Installation	1950	1968	1955
Size of Conduit	24 inches	8 inches	11.5 inches
Frequency of Testing	Annual	2 years	4 months
Date of Latest Calibration	4/1/84	8/21/84	1/15/85

UNCORRECTED TOTAL WATER SUPPLY IN 1983

Month	Source #1 Turnout #41 acre-feet	Source #2 Well Field acre-feet	Source #3 City Intertie acre-feet	Monthly Totals acre-feet
January	-0-	400	320	720
February	-0-	600	200	800
March	-0-	800	-0-	800
April	400	400	-0-	800
May	815	300	-0-	1,115
June	920	-0-	250	1,170
July	930	-0-	260	1,190
August	1000	-0-	275	1,275
September	900	100	100	1,100
October	400	100	300	800
November	400	-0-	400	800
December	400	-0-	300	700
TOTALS	6,165	2,700	2,405	11,270

TOTAL Supply to the System 11,270 acre-feet (Entered on Line 1)

ADJUSTMENTS TO SOURCE TOTALS DUE TO SOURCE METER ERROR

Source I.D.	Uncorrected Metered Volume (UMV)	Percent Meter Accuracy (MA)	Meter Error Calculation Error (ME) $ME = \frac{UMV}{0.01MA} - UMV$	Meter Error (ME)	Corrected Metered Volume (CMV)
1	6,165	95	(6,165)/0.95) - 6,165	324.5	6,489.5
2	2,700	100	(2,700)/1.00) - 2,700	+ 00.0	2,700
3	2,405	103	(2,405)/1.03) - 2,405	- 70.0	2,335.0

TOTAL ADJUSTMENTS to Source Meter Readings Due to Meter Error +254.5 acre-feet
(Entered on Line 2A)

CHANGES IN RESERVOIR STORAGE

Reservoir	Start Volume in Gallons	End Volume in Gallons	Change in Volume in Gallons
Apple Hill	32,350	36,270	+ 3,920
Cedar Ridge	278,100	240,600	- 37,500
Monument Road	978,400	318,400	-660,000
Davis	187,300	55,300	-132,000

TOTAL = -825,580 gallons
-2.53 acre-feet
(Entered on Line 2B)

UNCORRECTED TOTAL METERED WATER USE

Month	Residential (in acre-feet)	Industrial (in acre-feet)	Commercial (in acre-feet)	Metered Agriculture (in acre-feet)	Subtotal (in acre-feet)
Jan	450	110	25	-0-	585
Feb	500	110	25	-0-	635
Mar	500	110	25	-0-	635
April	550	120	25	75	770
May	650	130	25	175	980
June	700	150	25	230	1,105
July	800	150	25	175	1,150
Aug	815	150	25	230	1,220
Sept	700	140	25	200	1,065
Oct	500	110	25	-0-	635
Nov	500	110	25	-0-	635
Dec	450	110	25	-0-	585
Subtotal	7,115	1,500	300	1,085	10,000

TOTAL Uncorrected Metered Water Use 10,000
(Entered on Line 5)

DETAILED METER LAG CORRECTION

The December through January billing period is 62 days long.

Route	Read Date	Sales	Adjustment
A	2/1/84	12 ac-ft	31/62 = -6.0 ac-ft
B	2/10/84	10 ac-ft	21/62 = -3.4 ac-ft
C	2/20/84	11 ac-ft	11/62 = -2.0 ac-ft

Water Use ------------------------------ -11.4 ac-ft

Route	Read Date	Sales	Adjustment
A	2/1/85	13 ac-ft	31/62 = 6.5 ac-ft
B	2/10/85	10 ac-ft	21/62 = 3.4 ac-ft
C	12/20/85	12 ac-ft	11/62 = 2.1 ac-ft

Water Use ------------------------------ +12.0 ac-ft

+0.6 ac-ft
(Entered on Line 6)

CALCULATION OF RESIDENTIAL WATER METER ERROR

% Volume (%V)	Total Sales Volume (Vt)	Volume at Flow Rate (Vf)	Meter Registration (R)	Meter Error (ME) $ME = \frac{Vf}{(0.01R)} - Vf$	Meter Error (ME) (in ac-ft)
2.0	7,115	142.3	89	[(142/0.89) - 142]	17.9
63.8	7,115	4,539.4	95	[(4,539/0.95) - 4,539]	238.9
34.2	7,115	2,433.3	94	[(2,433/0.94) - 2,433]	155.3
100.0		7,115.0		TOTAL Residential Meter Error =	412.1

METER TEST DATA FOR LARGE METERS

Meter ID No.	Size	Meter Type	Date of Installa-ation	Manufac-turer	Test Date	Mean Registration at Various Flow Rates: Low	Medium	High
XYZ001	3 in	Turbine	6/83	Rockwell	10/84	89	85	100
XOOZAA	3 in	Turbine	6/83	Rockwell	10/84	70	88	98
NB123	4 in	Displace	7/80	Sparling	10/84	95	99	102
NB456	6 in	Compound	9/77	Sparling	10/84	98	92.5	102
AA002	6 in	Propellor	5/66	Hersey	10/84	98	98	103
Sum of Mean Registrations						450	462.5	505
Mean Registration for 5 Meters Tested						90	92.5	101

CALCULATION OF METER ERROR FOR LARGE METERS

Flow recordings were made for 24 hours in July and February 1984 and indicate the percent of volume delivered by large meters at low, medium, and high flow rates as follows:

Low	10%
Medium	65%
High	25%

From this information the total sales volume for large meters was adjusted as follows:

% Volume (%V)	Total Sales Volume (Vt)	Volume at Flow Rate (Vf)	Meter Registration (R)	Meter Error (ME) $ME = \frac{Vf}{(0.01)R} - Vf$	Meter Error (ME) (in ac-ft)
10	1,500	150	90.0	[(150/0.90) - 150]	16.7
65	1,500	975	92.5	[(975/0.925) - 975]	79.0
25	1,500	375	101.0	[(375/1.01) - 375]	-3.7
TOTAL Meter Error for Large Meters ----------------------------------					92.0

CALCULATION OF TOTAL SALES METER ERROR

Total Sales Meter Error (TSME) = Residential Meter Error + Large Meter Error; therefore:

TSME = 412.1 + 92.0

TSME = 504.1 acre-feet
(Entered on Line 8)

Line 11A **Firefighting & Firefighting Training:**

The four fire companies in the service area do not make firefighting reports. The fire commander reviewed their logs. They report 10 structural fires and a 5-day wild fire (water airlifted from open reservoir) plus 8 days (48 hours) of training where water was used.

Water Use Estimates are:

Firefighting	20 acre-feet
Training	10 acre-feet
TOTAL	30 acre-feet

Line 11B **Main Flushing:**

Mains were flushed through relief valves and hydrants on 18 occasions (54 hours total) accounting for approximately 5 acre-feet.

Line 11C **Storm Drain Flushing:**

The County Department of Waste Water Treatment estimates approximately 1.5 acre-feet of water used to relieve congested storm drains.

Line 11D **Sewer Cleaning:**

The County Department of Waste Water Treatment estimates approximately 60 days work using jet vactor and releases from fire hydrants for an estimated 2.0 acre-feet of water.

Line 11E **Street Cleaning:**

County and community highway department reports are combined in the following table.

ESTIMATE OF WATER VOLUMES USED BY TANK TRUCKS FOR STREET AND SIDEWALK TRAINING

January 1, 1983 to December 31, 1983

	Capacity, in Gallons		No. of Refills per day		No. of Days Used per year		Volume per Vehicle per Year in Gallons
Vehicle A	200	x	5	x	200	=	200,000
Vehicle B	500	x	10	x	150	=	750,000
Vehicle C	2,000	x	2	x	200	=	800,000

TOTAL GALLONS Used Annually 1,750,000
or 5.4 acre-feet

Line 11G Landscaping in large public areas is not metered. Three estimating methods were used:

For playgrounds and cemeteries comparisons were made with Myfair City playgrounds and cemeteries which are metered. A per-acre watering rate of 7 and 6 feet respectively per acre were used.

	Cummulative Area in Service District (in acres)	Water Rate	TOTAL Water Use
Parks	20.0	7.0 ft/acre	140
Playgrounds	2.7	7.0 ft/acre	19
Cemeteries	2.0	6.0 ft/acre	12

Golf Courses - The 62 acre municipal golf course was estimated by measuring the rate of flow and determining the length of watering periods.

Typical water application: 10 hours per day
250 days per year
804 gallons per minute

yields 120,600,000 gallons per year or 370 acre-feet

Highway median strips are watered by large tanker trucks, operated similar to vehicle "B" in the street cleaning operation.

yields 500 gallons x 10 refills per day x 130 day/year=650,000 gal
=2 acre-feet

Another 1/4 acre memorial park is watered but specific quantities are not recorded. Water use is estimated at 1 acre-foot and included as "Other" landscaping.

Line 11K Water Quality Testing

Water amounts used for testing are less than 500 gallons per year (0 acre-feet).

Line 11L Process Water

Treatment plant operators do not maintain specific records. The operators estimate 0.2 acre-feet released to waste after filter backwash.

Line 14 Identified Water Losses

Line 14A Accounting Procedure Errors

Four meter readers were accompanied on their rounds for one-half day each. This procedure sampled approximately 800 connections. This effort plus revision of the billing department's computer procedures resulted in the discovery that 0.5 percent of residential meters were inoperable or misread.

Estimated loss:

0.005 x 10,200 connections x .7 acre-feet/year = 35.7 acre-feet

Line 14B Illegal Connections

During the meter reading rounds, one small shop was discovered using water where there was no meter.

Estimated loss: 1 acre-foot

Line 14C Malfunctioning System Controls

Using an updated system schematic all system controls were methodically checked. They all operated correctly.

Line 14D Reservoir Seepage

Each of the system's closed reservoirs were individually valved off from the system for 24 hours. One tank showed change in evaluation.

Estimated annual loss = 175 gallons x 365 days = 63,875 gal
= 0.2 acre-feet

Line 14E **Estimated loss:**

Crystal Lake is an open reservoir of 5 acres surface area. Estimated evaporation in excess of rainfall is 6 feet per year.

Estimated loss = 6 feet x 5 acres = 30 acre-feet

Line 14G **Discovered Leaks**

Work records report four excavations for leak repair. Two were emergency repairs with large leaks believed to be short-lived (30 days undetected) 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 appropriate hole size in the pipe using Greeley's formula as shown in Table 5 of this guidebook. All mains involved operated at 50 psi.

Hole Size Diameter	Total Loss in Gallons per Day	Date of Repair	Number of Days Leak Existed	TOTAL LOSS in Gallons
1"	243,000	5/15/83	30	7,290,000
1"	243,000	6/18/83	30	7,290,000
0.25"	15,200	6/25/83	180	2,736,000
0.25"	15,200	10/28/83	300	4,560,000
			TOTAL LOSS	21,876,000
				= 67 acre-feet

Line 14H **Thefts**

No thefts were identified.

Line 18A **Cost of Water Supply**

Purchase price of water from CC Aqueduct = $225/acre-feet

Line 18B **Variable Operations & Maintenance Costs**

Power Purchases = $45/acre-foot*
Water Treatment = $5/acre-foot*

*From 1983 Report to the State Controller

Summary of recommendations for system improvements resulting from water audit.

- o Conduct Leak Detection Program
- o Customer meters will be tested when received from the manufacturer
- o The revised accounting billing programs will check accounts for stopped meters.
- o Recommendations are being made that the publicly owned parks, playgrounds, cemeteries, and golf courses be metered.
- o The leak repair crew will be told to measure leak discharge when leaks are uncovered.
- o Water audits are to be performed annually.

LEAK DETECTION AND REPAIR PLAN WORKSHEET

Agency Name: XYZ County Water District **Date:** 7/18/85

A. Area to be Surveyed

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. Describe each area under B-2. (Items to consider include records of previous leaks, type of pipe, age of pipe, soil conditions, high pressures, ground settlement, and improper installation procedures.)

2. Total miles of main to be surveyed: 146. If less than the total system is being surveyed, the calculations for the benefit:cost ratio must reflect the reduction. (When calculating the miles of main, include the total length of pipe and exclude service lines.)

3. Average number of miles of main surveyed per day: 2.0. Explain if more than 3 miles 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.)

4. Number of working days needed to complete survey: 73. (Divide Line 2 by Line 3.)

B. Procedures and Equipment

1. Describe the equipment and procedure you will use to detect leaks. Experience has shown that the best results have been obtained by listening for leaks at <u>all system contact points</u> (such as water meters, valves, hydrants, and blowoffs).

   Purchase Heath Son-i-Kit. Attend Manufacturers Seminars and DWR Training. Conduct initial listening survey on all contact points.

LEAK DETECTION AND REPAIR PLAN WORKSHEET

2. Describe why the areas noted on the map (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 - Remainder of system

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

   Not applicable - crew will listen for leaks on all contact points.

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

   Will use low frequency ground microphone to listen over pavement surfaces. Consultants correlator will be used in difficult situations.

5. Describe how the leak detection team and the leak 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 3 weeks and resolve and dry holes thereafter.

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 and used in the Greeley formula as shown in the Guidebook.

LEAK DETECTION AND REPAIR PLAN WORKSHEET
Page 3 of 4

C. Staffing

1. How many agency staff will be used? 2

Staff Cost Including Wages and Benefits:

Person 1	$/hour	17.19	$/day	137.52
Person 2	$/hour	12.50	$/day	100.00
TOTAL	$/hour	29.69	$/day	237.52

2. How many consultant staff will be used? 1

Cost of Consultant Staff:

Person 1	$/hour	31.25	$/day	250
Person 2	$/hour	Ø	$/day	Ø
TOTAL	$/hour	31.25	$/day	250

D. Leak Detection Survey Costs

Leak Detection Surveys:	$/day	# DAYS	Cost
1. Agency Crew Costs	237.52	73	$ 17,340
2. Consultant Crew Costs	250.00	15	$ 3,750
3. Vehicle Costs	2.40	73	$ 175
4. Other			$ Ø
5. TOTAL Survey Costs			$ 21,265

E. Leak Detection Budget

1. Cost of Leak Detection Equipment	$ 2,550
2. Leak Detection Team Training	$ 400
3. Leak Detection Survey Costs	$ 21,265
4. TOTAL Leak Detection Costs	$ 24,215

LEAK DETECTION AND REPAIR PLAN WORKSHEET
Page 4 of 4

F. Leak Survey and Repair Schedule

Indicate realistic, practical dates.

1. When will the leak survey begin? August 1, 1985
2. When will the leak survey be completed? December 15, 1985
3. When will leak repairs begin? August 15, 1985
4. When will leak repairs be completed? January 10, 1986

Prepared by:

C. M. Biggs
Name

Manager
Title

7/18/85
Date

APPENDIX B
TYPES OF METERS

Velocity Meters

Propeller

The measuring element is a rotor or propeller facing upstream that is rotated by the moving water striking its angular blades. The propeller may be small in diameter in relation to the internal diameter of the pipe, especially in the larger sizes. The propeller has a slight lag in starting or stopping; therefore, this meter is intended primarily for main-line service where flow rates do not change abruptly.

Turbine

The meter consists of a very light waterwheel operated by the current and carries on its axis a worm for actuating gearing and a totalizer. The rate of flow is computed from the rotations during a given period. A more recent design, the magnetic flowmeter, requires electrical connections and is not a completely self-contained unit.

Ultrasonic

Acoustic flowmeters operate on the principle that the propagation velocity of acoustic signals in liquids is changed when a component of the liquid's velocity parallels the direction of acoustic propagation. In practice, up to four acoustic paths are set up at an angle to the flow. Each path consists of two identical transducers facing each other at a precisely known distance. Typical path angles vary from 30 to 65 degrees, depending on available space and accuracy requirements. The average liquid's velocity on each path is determined by measurement of the acoustic travel time in each direction. The liquid velocity measured at each path is integrated across the flowing area to determine the total volume flow rate. Such meter systems have very critical installation requirements and, while excellently amenable to computer input, are rather costly. Both ultrasonic and doppler flow measurement techniques require turbid rather than clear fluid to work effectively.

Electromagnetic

The electromagnetic flowmeter uses the same basic principle as the electrical generator. When a conductor moves across a magnetic field, a voltage is induced in the conductor, and the magnitude of the voltage is directly proportional to the speed of the moving conductor. If the conductor is a section of conductive liquid flowing in a nonconductive pipe through a magnetic field, and electrodes are mounted in the pipe wall, the voltage induced across the electrodes should be proportional to the flow rate.

Differential Pressure

Flow Tubes/Venturi. As fluid passes through the reduced area of the venturi throat, its velocity increases, resulting in a pressure differential between the inlet and throat regions. That passage immediately following the throat gradually increases in flow area; consequently, the fluid's velocity decreases, causing pressure recovery. The differential pressure across the venturi's throat can be recorded directly or translated into actual flow units by employing various types of differential pressure meters and capacity curves.

Venturi tubes are employed whenever the head loss is to be minimized or where fluids handled contain sufficient amounts of materials in suspension to render other devices such as orifice plates or flow nozzles ineffective. Widest application has traditionally been in low-pressure gas lines and large water mains.

Measurements accurate to within plus or minus 0.5 percent can be made for nearly all pipe sizes. For larger diameter pipes piezometer rings and tap arrangements may be critical.

Venturi tubes will maintain their accuracy over relatively long periods. In most applications the venturi is a self-cleaning device because its internal configuration allows smooth flow and minimizes erosion and clogging. Venturi tubes are mostly maintenance-free. They have no moving parts or mechanical features or glass that can break or become fatigued or strained. Testing the accuracy of the venturi is difficult since alternative measuring devices of similar accuracy and size are often unavailable or difficult to install. When calibrating the venturi, it is imperative to check the venturi itself and not just the manometer apparatus. Be sure that the gauges are calibrated to agree with the actual confirmed flow. Do not adjust the manometer apparatus to agree with a hypothetical standard which is probably not occurring.

Orifice Plate. The orifice sensing unit consists of a round plate in which is bored, usually concentrically, a hole of predetermined size. The plate is inserted across a straight run of pipe. Pressure taps are provided, either at specified distances upstream and downstream from the orifice plate or within orifice flanges, by which the orifice plate is inserted in the line.

The determination of the relation between flow rates and differential pressures has been reduced to formulas by which an orifice coefficient can be readily computed for any size of orifice in any size of pipe.

Pitotmeter. The pitot tube measures fluid velocities by its sensitivity to pressure differences associated with the pitot tube when it is inserted in the pipeline. Velocity measurements are made along a transect inside the pipe. Then the velocity measurements are multiplied by the proportional cross sectional area to determine the fluid flow. The sum of all the proportional flows is the total flow within the pipe.

Positive Displacement Meters

Disc Measuring Chamber

The nutating disc meter consists of a movable disc mounted on a concentric sphere. The disc is contained in a working chamber with spherical side walls and top and bottom surfaces that extend conically inward. It is restricted from rotating about its own axis by a radial partition that extends across the entire height of the working chamber. The disc is slotted to fit over this partition. The water enters the side of the meter and strikes the disc, forcing it to rock (nutate) in a circular path without rotating about its own axis. A pin extending out from the inner sphere, perpendicular to the disc, traces a circular path as it is driven by the nutating motion. This pin drives the undergear that controls the meter's register.

Compound Meters

This meter measures over a wide range of flow, including very low flows. It is called "compound" because it has a large turbine meter on the main line and a small meter on a bypass line, with a valve to direct water to one or the other meter automatically. Sometimes both meters are in the same housing. Compound meters may have either single or double registers.

Proportional or Fire Line Meters

The proportional meter measures a small but relatively constant percentage of the water flowing through the line. A multiplying factor is built into the meter register so that it records the total quantity that has passed through the main line. This is accomplished by providing an expanded section of the line with a ring at the downstream end having an internal diameter equal to the nominal pipe diameter. The restriction ring creates a drop in line pressure just below it (compared with full line pressure upstream). This differential in pressure forces a portion of the water through the small displacement-type bypass meter.

Open Channel Meters

Weirs

A weir is an obstruction built across an open channel over which the water must flow. The water usually flows through an opening or notch on the weir plate. Sharp-crested weirs have three basic configurations: rectangular, V-notch, and Cipolletti.

Flumes

Flumes are specially designed, open channel flow sections with a restriction that increases fluid velocity. They can be designed for installation in a circular pipe section.

Flumes have several advantages over weirs. The flow velocity through flumes is high; therefore, they tend to be self-cleaning systems that minimize deposition of sediment or solids. Flumes can operate with much smaller head losses than experienced with weirs, a decided advantage for irrigation.

A Parshall flume is employed where it is important to maintain a low head loss or where the liquid contains a large amount of suspended solids.

APPENDIX C
RECOMMENDED USES OF METERS BY CLASSIFICATION

All meter installations should be reviewed to determine whether the proper meter has been chosen for each installation. Table B-1 lists uses of meters by classification. Table B-2 compares meter standards for Class I and Class II meters. (Both tables are taken from an article by Ed Seruga, "Sizing and Selecting Modern Water Meters," in Water Engineering and Management, January 1982.) Refer to the AWWA publication, Water Meters--Selection, Installation, Testing, and Maintenance (AWWA Number M6) for additional information.

TABLE C-1
RECOMMENDED USES OF METERS BY CLASSIFICATION

Type	Size	Applications
Positive Displacement	5/8"	Residences, small apartments, small businesses. Demand flow rates: 1/8 to 29 gpm. Maximum continuous demand to 10 gpm.
	3/4"	Large residences, small to medium apartments. Demand flow rates: 1/4 to 30 gpm. Maximum continuous demand to 15 gpm.
	1"	Medium apartments, beauty parlors, barber shops, small motels, filling stations, small businesses, industrial processes. Demand flow rates: 3/8 to 50 gpm. Maximum continuous demand to 25 gpm.
	1-1/2"	Medium motels, hotels, large apartments, small industry, small processing plants. Demand flow rates: 5/8 to 100 gpm. Maximum continuous demand to 50 gpm.
	2"	Larger hotels, motels, apartment complexes, industrial plants, processing plants. Demand flow rates: 1-1/4 to 160 gpm. Maximum continuous demand to 80 gpm.
Class II—Turbine	2"	Medium to large hotels, motels, large apartment complexes, industrial plants, processing plants, irrigation. Demand flow rates: 3 to 200 gpm. Maximum continuous demand tO 160 gpm.
	3"	Large hotels, motels, industrial plants, processing plants, irrigation. Demand flow rates: 4.3 to 450 gpm. Maximum continuous demand to 350 gpm.

TABLE C-1 (cont.)

	4"	Large industrial and processing plants, irrigation, refineries, petro-chemicals, pump discharge. Demand flow rates: 25 to 2,500 gpm. Maximum continuous demand - 1,000 gpm.
	6"	Large industrial manufacturing and processing plants, irrigation, pump discharge. Demand flow rates: 25 to 2,500 gpm. Maximum continuous demand - 2,000 gpm.
Class I— Turbine*	8"	Industrial, manufacturing, processing, pump discharge. Demand flow rates: 140 to 1,800 gpm. Maximum continuous demand - 900 gpm.
	10"	Industrial, manufacturing, processing, pump discharge. Demand flow rates: 225 to 2,900 gpm. Maximum continuous demand to 1,450 gpm.
	12"	Industrial, manufacturing, processing, pump discharge. Demand flow rates: 400 to 4,300 gpm. Maximum continuous demand to 2,150 gpm.
Compound, New High— Velocity Styles		Medium motels, hotels special customers having high and low demand; schools, public buildings, large apartment and condominium complexes, hospitals.
	2"	Demand flow rates: 1/4 to 160 gpm. Maximum continuous demand to 160 gpm.
	3"	Demand flow rates: 1/2 to 350 gpm. Maximum continuous demand to 350 gpm.
	4"	Demand flow rates: 3/4 to 1,000 gpm. Maximum continuous demand to 1,000 gpm.
Compound Older Styles	6"	Demand flow rates: 1-1/2 to 1,000 gpm. Maximum continuous demand to 500 gpm.
	8"	Demand flow rates: 1 to 1,600 gpm. Maximum continuous demand to 800 gpm.
	10"	Demand flow rates: 4 to 2,300 gpm. Maximum continuous demand to 1,150 gpm.

* Class I Turbines below 8 inches are not included because of the higher performance of Class II models.

TABLE C-2
AMERICAN WATER WORKS ASSOCIATION TURBINE METER STANDARDS FOR CUSTOMER SERVICE

Meter Size (in)	Safe Maximum Operating Capacity (gpm)	Maximum Rate for Continuous Duty (gpm)	Maximum Loss of Head at Safe Maximum Operating Capacity (psi)	Normal Test Flow Limits (gpm)
Class 1—Vertical-Shaft & Low-Velocity Horizontal Type				
1-1/2	100	50	15	12 - 80
2	160	80	15	16 - 120
3	350	175	15	24 - 250
4	600	300	15	40 - 400
6	1,250	625	15	80 - 1000
8	1,800	900	15	140 - 1600
10	2,900	1,450	15	225 - 2500
12	4,300	2,150	15	400 - 4000
Class II—In-Line (High Velocity Type)				
2	160	100	7	4 - 160
3	350	240	7	8 - 350
4	630	420	7	15 - 630
6	1,400	920	7	30 - 1400
8	2,400	1,600	7	50 - 2400
10	3,800	2,500	7	75 - 3800
12	5,000	3,300	7	120 - 5000

APPENDIX D
METER SIZING PARAMETERS

When the type of meter has been selected, the meter should be properly sized for operation. This means that it must measure the water accurately through the full range of the customer's use. Water meters are designed to deliver a maximum flow for short periods and a lower flow for long periods without sustaining damage or above normal wear.

Meters mean revenue, and revenue can be lost because a meter does not register accurately. Loss of registration can result from wear, improper installation, and improper size or type of meter.

If a meter is operating outside its intended range, it cannot register all the flow, even though it may be accurate. With a compound meter with appreciable flow at the change-over point, the loss in revenue can be substantial.

A 24-hour or 7-day recorder attached to a water meter will provide maximum, average, and minimum rates of flow, which are essential in determining whether the meter is the proper size and type for the installation. Without comparing this information with the meter's capacity, the selection of a proper size and type of a water meter becomes a matter of guesswork based on experience. For large meter installations, a wrong guess based on experience that is not representative of a particular situation can be costly and cause a considerable loss of revenue.

Large water meters register flow inaccurately for several reasons. Among them are these:

<u>The wrong size or type of water meter was selected</u>. In some cases, the meter was selected to match the size of the service. From the standpoint of income, it would be better to assume that the meter should be smaller than the service; however, this is no time for assumptions. Of course, flow should not be restricted, but with the amount of revenue at stake, meter sizing should be based on the type of factual information provided by a recorder chart.

<u>A change in customers occurred at a specific location</u>. The usage profile of the new customer often differs considerably from that of the original customer.

<u>A change in customer usage due to water conservation or changes in production and/or products dealt with</u>.

A meter should be of adequate size but not oversized. Sizing should be based on the maximum and minimum demand and average usage rate of the customer.

The AWWA has established standards on flow capacities and maximum pressure losses for cold-water meters. New meters have also been designed that caused lower pressure losses. The estimator can follow the AWWA standards or the head-loss flow curves provided by the manufacturer for newer models, as appropriate.

Tables D-1,* D-2,* and D-3* provide data from which approximate pressure loss can be determined. These tables are based on pressure-flow data taken from curves of several types of 1975-model meters and averaged to produce tables of values that the estimator can use when rating curves are not available. These tables are not applicable to some of the earlier meters, and the estimator should use them only as approximations for late-model meters.

There are several important considerations in sizing a meter installation. The flow requirement, not the pressure loss through the meter, should determine the size of the meter to be installed. Oversizing a meter to lower the pressure loss can mean low flows will fail to register. It will also increase the cost of maintenance. Furthermore, if there is good reason to believe the customer plans to increase the demand for water, the estimator should provide for larger metering facilities later, adding a meter box and connections that will meet future needs.

TABLE D-1
DISPLACEMENT-TYPE METERS MEETING AWWA SPECIFICATIONS
FLOW-PRESSURE LOSS AVERAGES OR 1937-MODEL METERS

Size (in)	Maximum Capacity AWWA Flow Criteria (gpm)	(psi)	Recommended Design Criteria-80 percent of Maximum Capacity (gpm)	(psi)	Recommended for Continuous Flow-30 Percent of Maximum Capacity (gpm)	(psi)	Brands of Meters Avgs.
5/8 x 3/4	20	10.4	16	6.1	6.0	1.0	6
3/4	30	10.6	24	6.9	9.0	1.05	6
1	50	9.3	40	6.3	16.5	1.0	6
1-1/2	100	11.3	80	8.6	30.0	0.9	6
2	160	10.4	128	6.5	38.0	0.5	6
3	300	13.1	240	8.3	90.0	1.1	3

* American Water Works Association, <u>Sizing Water Service Lines and Meters</u>, AWWA Number M22.

TABLE D–2
COMPOUND–TYPE METERS MEETING AWWA SPECIFICATIONS
FLOW–PRESSURE LOSS AVERAGES OF 1973–MODEL METERS

Size (in)	Maximum Capacity AWWA Flow Criteria		Recommended Design Criteria-80 Percent of Maximum Capacity		Recommended for Continuous Flow-30 Percent of Maximum Capacity		Brands of Meters Avgs.
	(gpm)	(psi)	(gpm)	(psi)	(gpm)	(psi)	
2	160	9.2	128	6.1	80	2.6	3
3	320	13.4	250	8.9	160	4.2	5
4	500	9.6	400	6.3	250	3.5	5
6	1000	9.4	800	5.8	500	2.5	4
8	1600	12.0	1280	7.8	800	4.0	3

TABLE D–3
TURBINE–TYPE METERS MEETING AWWA SPECIFICATIONS
FLOW–PRESSURE LOSS AVERAGES OF 1973–MODEL METERS

Size (in)	Maximum Capacity AWWA Flow Criteria		Recommended Design Criteria-80 Percent of Maximum Capacity		Recommended for Continuous Flow-50 Percent of Maximum Capacity		Brands of Meters Avgs.
	(gpm)	(psi)	(gpm)	(psi)	(gpm)	(psi)	
2	160	4.5	128	2.8	80	1.0	5
3	350	4.6	280	3.0	175	1.2	4
4	600	3.5	480	2.1	300	0.8	4
6	1250	3.5	1000	2.0	625	0.7	4

APPENDIX E
METER INSTALLATION CONSIDERATIONS

Correct meter installation is highly important. Because a meter is a mechanical device, it begins to wear and lose accuracy from the day it is installed. In time it will stop functioning. Provisions should be made during installation to field test meters in line for accuracy.

When installing large meters, include the following:

1. Isolation valves in both the inlet side and the outlet side of the meter.

2. Test plugs downstream of the meter between the meter and the downstream isolating valve.

3. A meter bypass with isolating valve or a bypass meter to provide water to the customer while the meter is being serviced. The bypass connection should be placed upstream of the inlet isolating valve and downstream of the outlet isolating valve so that it forms a "U" around the main meter.

   If a meter is installed with a bypass meter, the bypass meter should remain open and a check valve must be installed downstream to force the water at low flow through the bypass meter. If the meter is not installed in this manner, the low flows will pass unregistered through the large meter because water follows the path of least resistance. The check valve should be either internally spring-loaded or externally controlled so that a differential pressure of about 5 to 10 pounds is required to open the check valve.

   If meters are installed in parallel, one meter should act as a primary meter and the other as a secondary meter. To do this, place a check valve downstream of the secondary meter to ensure a pressure loss of at least 5 to 10 pounds through the primary meter before the secondary meter begins operating. This provision is necessary to make certain both meters register low flows.

4. To ensure proper meter functioning (by reducing turbulence), install the meters according to the manufacturer's specifications governing the number of straight pipe diameters upstream and downstream of the meter. Another method is to install straightening vanes.

When installing turbine meters, use a strainer on the inlet side of the turbine. The strainer has two functions: to keep foreign matter from damaging the turbine, and to ensure that the water approaching the turbine is fairly equal in velocity across the diameter of the pipe and is not spiraling.

APPENDIX F
METER TESTING IN GENERAL

A water meter, like any other mechanical device, is subject to wear and deterioration, and, over a period of time, it loses its peak efficiency. How long water meters retain their overall accuracy depends on many factors, such as the quality of the water being measured, rates of flow, total quantity, chemical buildup, and abrasive materials carried by the water. The only way to determine whether a specific meter is operating efficiently is to test it.

Meters are tested for several reasons, including (1) determining the total amount of meter error within the distribution system; (2) ensuring that the cost of water service is equitably distributed among all customers; (3) determining the amount of revenue lost to the water utility; and (4) determining whether a meter is capable of registering low flows. Unfortunately, displacement meters, the type most commonly used, may seriously underregister for long periods without completely ceasing to operate.

Elements of a Meter Test

The three basic elements needed to test overall meter efficiency are:

1. For the operating range of the meter, designate the number of different flow rates to be tested.

2. At each designated flow rate, determine the volume of water to be passed through the meter for each test.

3. Specify accuracy limits that meters must meet at differing rates to be acceptable for use.

Test Rates

Three rates of flow--minimum, intermediate, and maximum--are necessary to properly test displacement, compound, and propeller meters. For compound and fire-service meters, the changeover point must be established to determine overall operational efficiency and accuracy of registration. It is also important to establish at what point a meter begins to register low flow. Low flows below that point do not produce revenue.

The meter testing program should begin with the low flow rates. If in the course of testing, the meter speed changes, be sure there was no use by the customer. High flows must be avoided prior to low and medium flow testing since the high flow could flush out sand and other materials. Such flushing would totally negate later low flow tests.

The intermediate rate of flow should be at or near the high point of registration (about 10 percent of rated capacity) to ensure that the meter will not over register at any rate of flow.

Tests for full-flow accuracy are not necessary at the "safe maximum capacity" rate shown in the appropriate AWWA standard because meters are seldom operated at rated capacity. The maximum point of registration depends on meter design but is usually about 10 percent of rated meter capacity. At rates above that, the accuracy curve is fairly flat, and accuracy differs little over a wide range of flows. Maximum-rate test flows of about three-fourths of rated capacity are practical. They are especially advantageous in multiple testing of small meters.

Accuracy Limits

Accuracy limits are established to ensure that water meters record as accurately as possible and as commercially feasible. Meters tend to register variably by 2 to 3 percent over the entire range of flows. (This does not occur when the flow is so low that it fails to register.) For example, a 5/8-inch meter in good condition will register within the following limits: at 95 percent or higher with a 1/4-gpm flow; at a maximum of 101.5 percent with a 2-gpm flow (usually 10 percent of rated meter capacity); and then at not less than 98.5 percent with a 20-gpm flow.

It is not normally considered economically feasible to repair older meters to bring them up to the accuracy levels achievable by new meters at the minimum rate. For this reason, separate accuracy limits are shown in the following tables for new and repaired meters on the minimum flow test. The limits set for repaired meters are considered to represent those that require good meter shop procedures. Repaired meters should register at least 90 percent on this test. A higher percentage is recommended for desirable shop quality standards.

Meter Test Alternatives

Meters can be tested in-place (field testing) or in the meter shop (bench testing).

Field Testing

As the cost of meter removal and replacement increases, field testing becomes a more attractive method. Large meters can be tested with a pitotmeter. The portable meter test unit is adequate for smaller meters. The portable test equipment compares a previously calibrated meter with the meter being tested. In field testing, both meters must be full of water and under positive pressure and the control valve to regulate flow must always be on the discharge side of the calibrated meter.

Bench Testing

A meter shop typically uses equipment that varies from a simple Rotameter (rate-of-flow indicator) to a volumetric test bench that can test several meters at one time. Rising costs of meter removal and replacement are also causing many utilities to phase out their meter shops and either replace their meters without testing, or send them out to be tested.

For a detailed description of meter testing, refer to the American Water Works Association (AWWA) publication, Water Meters--Selection, Installation, Testing, and Maintenance, AWWA Number M6.

APPENDIX G
METER TESTING WITH A PITOT ROD

The purpose of the pitot rod is to measure the flow of liquid in a closed conduit under pressure. The pitot rod measures the velocity of fluid in the conduit and the diameter of the conduit. From these measurements, the flow can be calculated. The pitot rod can be accurate to within about 2 percent. This accuracy cannot be obtained with an "averaging pitot rod" but only with a pitot rod that calculates the velocity profile.

The pitot rod can be used on any closed conduit which has been retrofitted with a one-inch corporation cock. The test can be performed by an experienced operator in about two hours with good conditions.

The pitot rod can be used to test the accuracy of large water meters, measure the flow of a pipe, perform loss of head tests, determine Hazen's flow coefficients, perform zone measurements, conduct fire flow tests, determine direction of flow, determine 24-hour flows, and indicate flow reversals.

For directions on using a pitot rod, refer to the manual Practical Hydraulics and Water Flow Monitoring Workshop*, developed by Carl F. Buettner Workshops.

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* Revised July 1982, Polcon Inc., St. Louis, Missouri

APPENDIX H
LONG-TERM METER SURVEILLANCE

(Well-Suited For Large Meters and Large Revenue Producing Customers)

After a meter has been tested and calibrated, surveillance or review of consumption records should be initiated to ensure the meter will operate as long and as accurately as possible at the least possible cost.

A useful technique is to review billing records at regular periods for each meter. Computerization helps immensely, otherwise sampling techniques may be necessary. It is not necessary to review records every billing period; a quarterly or semi-annual review will be sufficient. Compare the records for at least a 12-month period to guard against seasonal changes in the customer's water use pattern. Contact the customer and if the customer's actual usage is not changing and the consumption records are declining, then the meter may be losing accuracy and should be scheduled for inspection and testing.

Flow rates will vary from customer to customer, even where meters of the same size are in use. Rates of use also vary with the season of the year. It is useful to record each customer's typical maximum and minimum monthly usage. This information can be used to anticipate demand.

APPENDIX I
CALCULATING EVAPORATIVE WATER LOSS

Evaporative water losses from large bodies of water include water lost directly to the atmosphere from open-air, standing bodies of water. Evaporative losses are particularly significant during hot weather at large unmetered pools and reservoirs. It is often difficult to estimate losses from small pools and fountains.

Ponds and reservoirs in California annually lose an average of 50 to 80 inches of water by evaporation. During the summer, daily evaporation losses may be 0.33 inches per day from each acre of pond or reservoir surface (about 9,000 gallons per day per acre). Exposure to winds and high air temperatures are principal contributing factors. The wind disrupts the saturated boundary layer over the water surface, and the air increases its capacity to hold moisture as its temperature rises.

Calculations of evaporative losses are possible, but they are also complex, and they require detailed local environmental data not otherwise normally available. To estimate evaporative losses, use the evaporation pan data for locations in California shown here in Table I-1, an excerpt from Evaporation from Water Surfaces in California, Bulletin 73-79, California Department of Water Resources. The bulletin provides monthly total evaporation data at 478 locations throughout California.

TABLE I-1
MEAN ANNUAL EVAPORATION AT PRINCIPAL CALIFORNIA LAKES
(inches)

Location	Inches
Berryessa	78
Cachuma	69
Castaic	81
Clair Engle	57
Clear	60
Eagle	48
Elsinor	75
Folsom	67
Henshaw	71
Hetch Hetchy	46
Isabella	87
Matthews	74
Millerton	86
Nacimiento	71
Oroville	67
Perris	87
Pine Flat	68
Pyramid	87
San Antonio	76
San Luis	109
Shasta	68
Silverwood	87
Success	82
Tahoe	38

The evaporation data in Table I-1 and Bulletin 73-79 represent what is sometimes called gross evaporation, which is the actual depth of water lost to the atmosphere. Although evaporation rates for evaporation pans have been shown to be larger than those for lakes, the data referenced here does not take this into account. No adjustments of these data are expected to be made by users of this Guidebook.

APPENDIX J
LEAK DETECTION EQUIPMENT
(A Partial List dated December 1991)

This list may not contain all manufacturers of leak detection equipment or accurate prices. DWR makes no recommendations on the capability of any equipment. The information provided may not be current and other equipment may be available.

Type	Company	Model	Price	Telephone/State
Sonic	Heath	Aqua-Scope	$1,655	916/371-2520 (CA)
		Son-i-kit	$3,900	916/371-2520 (CA)
Sonic	Fisher	XLT-20	$1,345	209/826-3292 (CA)
Sonic	Metrotech	HL-2000	$3,175	415/940-4900 (CA)
		HL 90	$1,348	
		200L	$ 802	
Sonic	Fluid Conservation Systems	S 20	$2,900	800/531-5465 (TX) 512/794-0222 (TX)
Sonic	Goldak	777-A	$ 985	818/240-2666 (CA)
Sonic	Subtronic			
	Fuji Tecom	WL-200	$2,178	510/686-3747 (CA)
	Fuji Tecom	HG-10	$2,275	510/686-3747 (CA)
	Fuji Tecom	FD-7	$ 765	510/686-3747 (CA)
Acoustic	Pollard	Geophone	$ 275	516/746-0842 (NY)
Correlator	FCS	9090 1000	$44,000 $25,000	800/531-5465 (TX) 512/794-0222 (TX)
Correlator	Ruble		$20,000	800/347-8253 (MN)

The American Water Works Association "Buyer's Guide" may list additional equipment. 303/794-7711 (CO)

APPENDIX K
WATER AUDIT AND LEAK DETECTION FORMS

NOTE

The forms in Appendix K may be "snapped out" for your convenience and ease of calculation.

WATER AUDIT WORKSHEET

For Water District: ______________________________

Line	Item	Water Volume: Subtotal	Water Volume: Total Cumulative	Units*
1	Uncorrected Total Water Supply to the Distribution System (Total of Master Meters)		______	______
2	Adjustments to Total Water Supply			
2A	Source Meter Error (+ or -)	______		______
2B	Change in Reservoir and Tank Storage (+ or -)	______		______
2C	Other Contributions or Losses (+ or -)	______		______
3	TOTAL Adjustments to Total Water Supply (+ or -) (Add Lines 2A, 2B, and 2C.)		______	______
4	ADJUSTED TOTAL Water Supplied to the Distribution System (Add Line 1 and Line 3.)		______	______
5	Uncorrected Total Metered Water Use	______		______
6	Adjustments Due to Meter Reading Lag Time (+ or -)	______		______
7	Subtotal: Metered Deliveries (Add Lines 5 and 6.)		______	______
8	TOTAL Sales Meter Error and System Service Meter Errors (+ or -)		______	______
9	CORRECTED TOTAL Metered Water Deliveries (Add Lines 7 & 8.)		______	______
10	CORRECTED TOTAL Unmetered Water (Substract line 9 from Line 4.)		______	______

* The units of water measurement must be consistent throughout the worksheet. Their selection (e.g., acre-feet, millions of gallons, hundred cubic-feet) is left to the user.

WATER AUDIT WORKSHEET

Line	Item	Water Volume Subtotal	Water Volume Total Cumulative	Units*
11	Authorized Unmetered Water Uses			
11A	Firefighting & 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	______		______
11I	Swimming Pools	______		______
11J	Construction Sites	______		______
11K	Water Quality and Other Testing (pressure testing pipe, water quality, etc.)	______		______
11L	Process Water at Treatment Plants	______		______
11M	Other Unmetered Uses	______		______
12	TOTAL Authorized Unmetered Water (Add Lines 11A through 11M.)		______	______

Line	Item	Water Volume Subtotal	Water Volume Total Cumulative	Units*
13	TOTAL Water Losses (Substract Line 12 from Line 10.)		________	________
14	Identified Water Losses			
14A	Accounting Procedure Errors	________		________
14B	Illegal Connections	________		________
14C	Malfunctioning Distribution System Controls	________		________
14D	Reservoir Seepage and Leakage	________		________
14E	Evaporation	________		________
14F	Reservoir Overflow	________		________
14G	Discovered Leaks	________		________
14H	Theft	________		________
15	TOTAL Identified Water Losses (Add Lines 14A through 14H.)		________	________
16	Potential Water System Leakage (Subtract Line 15 from Line 13.)		________	________
17	Recoverable Leakage (Multiply Line 16 by 0.75.)		________	________
18	Cost Savings	Dollars per Unit of Volume		
18A	Cost of Water Supply	$________		
18B	Variable O & M Costs	$________		
19	TOTAL Costs Per Unit of Recoverable Leakage (Add Line 18A to Line 18B.)	$________		

WATER AUDIT WORKSHEET

Line	Item	Dollars per year
20	One-Year Benefit from Recoverable Leakage (Multiply Line 17 by Line 19.)	$________
21	TOTAL BENEFITS from Recoverable Leakage (Multiply Line 20 by 2.)	$________
22	TOTAL COSTS of Leak Detection Project	$________
23	Benefit to Cost Ratio (Divide Line 21 by Line 22.)	________

Prepared by:

____ ________________

Name **Date**

____

Title

LEAK DETECTION AND REPAIR PLAN WORKSHEET

Agency Name: ________________________________ **Date:** ____________

A. Area to be Surveyed

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. Describe each area under B-2. (Items to consider include records of previous leaks, type of pipe, age of pipe, soil conditions, high pressures, ground settlement, and improper installation procedures.)

2. Total miles of main to be surveyed:_________. If less than the total system is being surveyed, the calculations for the benefit:cost ratio must reflect the reduction. (When calculating the miles of main, include the total length of pipe and exclude service lines.)

3. Average number of miles of main surveyed per day: ____________. Explain if more than 3 miles per day are surveyed. (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.) __________

   ____

   ____

4. Number of working days needed to complete survey: ____________. (Divide Line 2 by Line 3.)

B. Procedures and Equipment

1. Describe the equipment and procedure you will use to detect leaks. Experience has shown that the best results have been obtained by listening for leaks at <u>all system contact points</u> (such as water meters, valves, hydrants, and blowoffs).

   ____

   ____

   ____

   ____

2. Describe why the areas noted on the map (A-1) have the greatest potential for recovering leakage.

____

____

____

____

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

____

____

____

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

____

____

____

____

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

____

____

____

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

____

____

C. Staffing

1. How many agency staff will be used? ______

Staff Costs Including Wages and Benefits:

Person 1	$/hour	________	$/day	________
Person 2	$/hour	________	$/day	________
TOTAL	$/hour	________	$/day	________

2. How many consultant staff will be used? ______

Cost of Consultant Staff:

Person 1	$/hour	________	$/day	________
Person 2	$/hour	________	$/day	________
TOTAL	$/hour	________	$/day	________

D. Leak Detection Survey

Leak Detection Surveys:	$/day	# Days	Cost
1. Agency Crew Costs	______	______	$________
2. Consultant Crew Costs	______	______	$________
3. Vehicle Costs	______	______	$________
4. Other	______	______	$________
5. TOTAL Survey Costs			$________

E. Leak Detection Budget

1. Cost of Leak Detection Equipment	$________
2. Leak Detection Team Training	$________
3. Leak Detection Survey Costs	$________
4. TOTAL Leak Detection Costs	$________

F. Leak Survey and Repair Schedule

Indicate realistic, practical dates.

1. When will the leak survey begin? ______________________
2. When will the leak survey be completed? ______________________
3. When will leak repairs begin? ______________________
4. When will leak repairs be completed? ______________________

Prepared by:

______________________ ______________________

Name **Date**

____

Title

LEAK DETECTION SURVEY DAILY LOG

Agency____________________

Date ______ ______ ______
Month Day Year

Leak Detection Team Members: __________ __________ __________

Manufacture and models of Equipment used: ____________________

Area Surveyed __________ Map Reference __________

Street and Block Nos: __________ Page & Coordinates __________

LEAK NO.	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

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

Miles of Main Surveyed ______ Survey Time ______ hours

Number of Leaks Suspected ______ To be rechecked ______
Number

Number of Leaks Pinpointed ______ Pinpointing Time ______ hours

Remarks: ____________________

LEAK REPAIR REPORT

Agency ____________________

Date of Repair: ________ (Month) ________ (Day) ________ (Year)

W.O. No. ________ Foreman ____________________

Map Reference ____________________

Page and Coordinates ____________________

____

Leak Identification

Refer to Leak Discovery Report

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, 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 or Service Leak, Attach Three Photos:

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

Leak Found ? ________ (Yes/No)

TYPE OF LEAK

Meter Leak	____	Main Line Leak	____	Joint Leak	____
Meter Spud Leak	____	Service Lateral Leak	____	Other Leak	____
Meter Yoke Leak	____	Fire Hydrant Leak	____	Describe ________	
Curb Stop Leak	____	Valve Leak	____	________	

DESCRIPTION OF REPAIR

Damaged part was: ____ Repaired ____ Replaced

If repaired, what repairs were made?

____ Leak Clamp ____ Repacked valve

____ Welded ____ Recaulked joint

____ Other (describe). ____________________

____

If replaced, what material was used? ____________________

Repair time ____________ (From To)

Crew Size ____________ (persons)

Equipment Used for Repair

____ Backhoe

____ Dumptruck

Repair Costs:

Materials	$ ________
Labor	$ ________
Equipment	$ ________
Other	$ ________
Total	$ ________

Size of Leak

Measured ____________ GPM

Estimated ____________ GPM

Method used: ____________________

____

Description of Damage for Mains and Services

What part was damaged?

___ Pipe barrel
___ Joint
___ Valve
___ Flange nuts, bolts, tie rods
___ Other (describe________________

In your opinion, what caused the damage?________________

Estimated age of leak in months________________
How Determined ________________
Diameter of Main or lateral in inches________________
Depth to top of pipe in inches________________

Type of Break

___ Split
___ Hole
___ Circumferential split
___ Broken coupling
___ Service pulled
___ Cracked at corp. stop
___ Gasket blown
___ Crushed pipe
___ Cracked Bell
___ Other (describe)________________

Pipe Material:

___ Galv. Iron
___ Black Iron
___ Cast Iron
___ Ductile Iron
___ Steel
___ Copper
___ A. C.P.
___ P.V.C.
___ Polybutylene

System Pressure________________
How Determined ________________

Examine broken edge of cast or ductile iron pipe:

Origional thickness Inches________

Min. thickness of good grey metal remaining Inches________

Deterioration is on:
___ Outside
___ Inside

Is there evidence of previous leak or repairs in same gêneral area? ___ Yes ___ No

Number of previous leak repair clamps present________________

Last repair date (if known)________________

Cause of Leak________________

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

If yes, explain extent: ________________

FOR EXCAVATIONS INDICATE GROUND CONDITIONS

Type of Soil:

___ Rocky ___ Sandy
___ Clay ___ Hard Pan
___ Adobe ___ Loam
___ Other ________________

Existing Bedding:

___ Gravel/Sand
___ Native Soil
___ Pea Gravel
___ Other ________________

Type of Cover:

___ Concrete
___ Asphalt
___ Soil
___ Other ________________

LEAK DETECTION AND REPAIR PROJECT SUMMARY

Agency ______________________________

Name of Report Preparer ______________________________

Date ____________________

Leak Detection Survey

TOTAL Number of Days Leak Surveys were Conducted: _____

First Survey Date: ____________ Last Survey Date: ____________

Number of Listening Points Used:	Meters	Hydrants	Valves	Test Rods	Other
	_____	_____	_____	_____	_____

Number of Agency Leaks:	Suspected	Pinpointed
	_____	_____

Survey Time: _____ hours Miles of Main Surveyed: _____ Pinpointing Time: _____ hours

$$\text{Average survey rate} = \frac{\text{Miles of main surveyed} \times 8}{\text{Total survey and pinpointing hours}} = \_\_\_\_\_ \text{ miles per day}$$

TOTAL number of visible leaks reported since survey started, from other sources (not discovered during leak detection surveys). _____

Leak Repair Summary

Date First Leak Repair Made: ____________ Date Last Leak Repair Made: ____________

Number of Repairs Needing Excavation: _____ Number of Repairs Not Needing Excavation: _____ TOTAL Number of Repaired Leaks: _____

TOTAL Water Losses from Excavated Leaks: _____ gpm TOTAL Water Losses from Nonexcavated Leaks: _____ gpm TOTAL Water Losses: _____ gpm

Excavated Leak Repair Costs		Nonexcavated Leak Repair Costs		TOTAL Repair Costs	
Materials	$ _____	Materials	$ _____	Materials	$ _____
Labor	$ _____	Labor	$ _____	Labor	$ _____
Equipment	$ _____	Equipment	$ _____	Equipment	$ _____
Other	$ _____	Other	$ _____	Other	$ _____
Subtotal	$ _____	Subtotal	$ _____	TOTAL	$ _____

LEAK DETECTION AND REPAIR PROJECT SUMMARY

Agency ____

Date ________________________

Leak Detection Project Cost Effectiveness

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

(Vwr) = (Total leakage recovered in gpm)(Conversion Factor)(Water cost, Wc)

Conversion factor = 1 gpm for 2 years = 3.23 acre-feet

Wc = Line 19 of Water Audit Report = water purchase price + operating costs per unit of water

Vwr = (_____ gpm)(3.23 acre-feet/gpm)(___$/acre-feet) Vwr = $ __________

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

Leak Detection Survey Costs

- Leak Detection Equipment .... $ _________
- Leak Detection Training .... $ _________
- Leak Detection Survey Costs ...... $ _________

TOTAL COST of Leak Detection Survey $ _________

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

Benefit:Cost Ratio (B:C) equals:

$$\frac{\text{Value of Water Recovered}}{\text{Total Cost Leak Detection Survey}}$$

B:C = _____

For planning future leak detection efforts, you can calculate average survey costs per mile.

Step 4. Determine average survey costs per mile of main surveyed (C/M).

$$C/M = \frac{\text{Total Cost of Leak Detection Survey}}{\text{Total Number of Miles Surveyed}} \quad \frac{\$ \text{ \_\_\_\_\_\_\_\_\_\_}}{M \text{ \_\_\_\_\_\_\_\_\_\_}}$$

C/M = $ ________

POTENTIAL REVENUES FROM RECALIBRATED LARGE METERS

Agency Name: ______________________________ **Date:** ________________

One may estimate revenue gains likely from customers with large meters found to be operating inaccurately (slowly or fast, but not broken). The metered use records for the customer for the entire audit period should be available to best estimate the benefits.

To calculate the corrected metered volume (CMV) use the following formula:

$$CMV = \frac{UMV}{(0.01RE)}$$

UMV (Uncorrected Metered Volume) is the volume of water registered on the meter (from the billing records), RE (Registration Error) is the meter accuracy in percent, and 0.01 is a conversion factor to change percentage to a decimal.

For Example: UMV = 10,000 cubic feet (from billing records). RE is 75% (Registration accuracy determined by meter tests).

$$CMV = \frac{10,000}{(75)(0.01)}$$

CMV = 13,333 cubic feet

(1) METER ID	(2) UNCORRECTED METERED VOLUME (UMV)	(3) CHARGES BILLED 12 months $	(4) CORRECTED METERED VOLUME (CMV)	(5) CHARGES FOR CORRECTED VOLUME 12 months	(6) INCREASED REVENUES $ (Col 5)-(Col 3)

92 83009

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