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ENVIRONMENTAL HEALTH PROJECT

WASH Reprint: Field Report No. 341

Water Loss in Rural Water Systems
in Developing Countries

Alan Wyatt

October 1991

Prepared for the Office of Health
Bureau for Science and Technology
U.S. Agency for International Development
under WASH Task No. 071

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WASH and EHP

With the launching of the United Nations International Drinking Water Supply and Sanitation Decade in 1979, the United States Agency for International Development (USAID) decided to augment and streamline its technical assistance capability in water and sanitation and, in 1980, funded the Water and Sanitation for Health Project (WASH). The funding mechanism was a multiyear, multimillion-dollar contract, secured through competitive bidding. The first WASH contract was awarded to a consortium of organizations headed by Camp Dresser & McKee International Inc. (CDM), an international consulting firm specializing in environmental engineering services. Through two other bid proceedings, CDM continued as the prime contractor through 1994.

Working under the direction of USAID's Bureau for Global Programs, Field Support and Research, Office of Health and Nutrition, the WASH Project provided technical assistance to USAID missions and bureaus, other U.S. agencies (such as the Peace Corps), host governments, and nongovernmental organizations. WASH technical assistance was multidisciplinary, drawing on experts in environmental health, training, finance, epidemiology, anthropology, institutional development, engineering, community organization, environmental management, pollution control, and other specialties.

At the end of December 1994, the WASH Project closed its doors. Work formerly carried out by WASH is now subsumed within the broader Environmental Health Project (EHP), inaugurated in April 1994. The new project provides technical assistance to address a wide range of health problems brought about by environmental pollution and the negative effects of development. These are not restricted to the water-and-sanitation-related diseases of concern to WASH but include tropical diseases, respiratory diseases caused and aggravated by ambient and indoor air pollution, and a range of worsening health problems attributable to industrial and chemical wastes and pesticide residues.

WASH reports and publications continue to be available through the Environmental Health Project. Direct all requests to the Environmental Health Project, 1611 North Kent Street, Suite 300, Arlington, Virginia 22209-2111, U.S.A. Telephone (703) 247-8730. Facsimile (703) 243-9004. Internet EHP@ACCESS.DIGEX.COM.

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WATER LOSS IN RURAL WATER SYSTEMS IN DEVELOPING COUNTRIES

Prepared for the Office of Health
Bureau for Science and Technology
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under WASH Task No. 071

by

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October 1991

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ABOUT THE AUTHOR

Alan Wyatt is a mechanical engineer with extensive experience in the technical and economic aspects of rural water supply in developing countries. He has worked on water supply projects in Haiti, Honduras, Mali, Morocco, and Tunisia. His technical experience includes operations and maintenance, planning and management, and water pump design and selection.

Related WASH Reports

Guidelines for Maintenance Management in Water and Sanitation Utilities in Developing Countries. Technical Report No. 63. June 1989.

Pump Selection: A Field Guide for Developing Countries. Technical Report No. 61. January 1989.

Estimating Operations and Maintenance Costs for Water Supply Systems in Developing Countries. Technical Report No. 48. January 1989.

Assessment of the Operations and Maintenance Component of Water Supply Projects. Technical Report No. 35. June 1986.

CONTENTS

APPENDIXES

BOXES

FIGURES

ACRONYMS

lcpd	liters per capita per day
NGO	Nongovernmental organization
UFW	Unaccounted-for water
WASH	Water and Sanitation for Health Project

EXECUTIVE SUMMARY

This report focuses on water loss in small rural water supply systems in developing countries—systems designed for 500-2,500 people, with water distribution via standposts, yard taps, or, in some cases, direct house connections. The report discusses the benefits of reducing water loss, the factors involved in it, procedures for investigating water loss, and methods of preventing it.

Investigating and correcting water loss is not an easy matter in rural systems. It may be very complicated and quite expensive. The benefits of undertaking a detection and repair program must be clearly identified and judged cost effective. *Investigating* losses has many benefits for planning future work. The greatest potential benefits of *reducing* water loss are improved water quality, conservation of water resources, reduced cost of operation and maintenance, and increased coverage.

The process of investigating water loss has several benefits, whether or not a repair program proves needed or justified. First, investigating water loss lays the groundwork for a program to reduce it, permitting identification of the scope and magnitude of the problem and allowing the design of a rational solution. It may also uncover the need for other maintenance work. Investigating water loss can also help in evaluating projects and system performance. For newly installed systems, the extent of leakage is an indicator of the quality of the construction. In older systems, leakage is an indicator of the degree of system deterioration and of the effectiveness of maintenance programs.

Leaking pipes may be a source of contamination, especially if system pressure falls very low. Also, leakage or wastage around taps, standposts, or connections can lead to stagnant water and related health risks. Reducing water loss can also conserve water, since it should lead to decreased production and withdrawal from the water source. Other benefits may include (1) increased water pressure, leading to more water for consumers; (2) more water for other purposes, such as small-scale irrigation; (3) increased revenues, if the system is metered and if reducing water loss leads to greater consumption; and (4) greater consumer satisfaction due to improved service.

Water losses are either "physical" or "non-physical." Physical losses are actual water resource losses, such as leaks. Non-physical losses, such as illegal water use or meter under-registration, are not actual water resource losses because the water is still put to use. For small rural systems, the most important water losses are in the "physical" category.

There are three main steps in investigating water loss: an initial audit, a field investigation, and a refined audit. These steps tell the investigator how much water is being lost and roughly where leaks are located. The first step is to collect and analyze basic data to get a sense of whether there is serious water loss. The second part of the audit includes field work to verify the information and to collect more precise data on key parameters. Finally, the field results are analyzed by computing water production, demand, and water loss, using the new data. A summary report is then prepared for the operator, the community, and the government office (if any) that oversees the system.

The costs of repairing a leak include the expense of locating the exact spot of hte leak and repairing it. If there is significant leakage, corrective action must be considered. But it should not be automatically assumed that any amount of leakage warrants a repair—the costs and benefits associated with reducing the losses must be compared and a decision made as to whether the corrective work is worth it. For simple gravity-fed systems with an ample water source, the benefits of leak correction may be quite low. The costs of fixing a leak, even a significant one, may far exceed the benefits. In this case, nothing should be done. On the other hand, systems extracting deep groundwater in arid areas with high water demand can benefit greatly from leak repair. Next the cost of making the repair must be estimated. A typical repair may include system shutdown, excavation, component removal, component replacement, pressure testing, back-filling and restoring the ground cover or paving, and return to service. The cost of repairing leaks includes the following components: labor, materials (pipe, fittings, valves, etc.), transport (including driver, fuel, maintenance), allowance for staff traveling overnight, and overhead or other indirect administrative costs.

The best way to keep water loss to a minimum is to prevent it in the first place through good engineering practice and well-supervised construction, followed by a leakage control program that emphasizes punctual maintenance, strong community involvement, and water conservation. Given the difficulties of pinpointing leaks in rural areas, community involvement and conservation are extremely important.

Chapter 1

INTRODUCTION

1.1 Purpose of this Manual

This manual provides rural water supply personnel with practical low-cost techniques for reducing water losses. It examines the financial aspects and offers technical and management guidance in the design of a water loss control program that can be tailored to individual needs.

1.2 Assumed Technical and Institutional Context

Rural water supply systems in developing countries have distinctive characteristics. They are reticulated systems designed for 500-2,500 people, with standposts, yard taps, or direct house connections. Most use groundwater, spring catchments, or, to a lesser extent, surface water as a source of supply. Other typical attributes are:

- Minimal water treatment
- Elevated storage tanks for pumped systems but only minimal storage for spring-fed systems
- Distribution networks ranging from simple "water yard" standposts to many kilometers of buried piping for standposts or connections
- Plastic (PVC or polyethylene) or asbestos-cement piping
- Few valves and generally no metering to simplify maintenance and repair

These design features keep investment costs down and simplify maintenance but they increase the work required to investigate and reduce water losses. The smaller number of pipes, taps, meters, valves, and pipe diameters mean fewer places for leaks to start, also, lower pressures keep losses down. However, the low pressures, non-metallic piping, and lack of valves and meters make the job of loss control more difficult. Rural systems generally are not built to the same standards as urban systems, especially if they are constructed by NGOs or other groups with little or no engineering experience or training. Cost constraints are often tighter and encourage the use of inferior materials.

The institutional context of rural water supply also has important implications for water loss. Rural systems are operated by local caretakers, with some backup from technicians in a regional, district, or national office. The caretakers have only enough training for day-to-day operational tasks and minor maintenance. Major problems and maintenance are supposed to be handled by mobile crews, who usually are overworked, lack parts and tools, have limited budgets, keep no records, and have logistical, bureaucratic, and transportation difficulties. As a result, these rural systems are inadequately maintained, leading to premature deterioration and higher leakage.

Most rural systems are not metered and thus do not have a means of volumetric cost recovery. User fees may be collected at a monthly flat rate, as and when needed, or not at all. Such arrangements, especially where water demands are not fully met, offer no incentive for users to reduce waste. If managers or operators take the trouble to reduce losses, but cost recovery is not linked to consumption, the water saved is quickly consumed by wasteful users. Without evidence of lower costs or increased revenues, there is no reason to reduce losses. Where water demands are met and people conserve, the reduction in leakage will be reflected in cost savings and lower fees.

1.3 Organization of the Manual

The manual has seven chapters and two appendixes following this introduction: the components of water loss; the benefits of investigating and reducing water loss; the steps in investigating water loss; guidelines for evaluating corrective action; pinpointing leaks; establishing a leakage control program; and preventing high water loss thorough sound construction and regular maintenance. Appendix A lists general references and training materials, and Appendix B lists sources of information, products, and services on water loss.

The reader who is not very familiar with the subject should read the whole manual before deciding on a course of action. A high leakage rate might be acceptable if there is an abundant water resource, consumer demands are being met, and the financial and managerial costs of corrective action are high.

Chapter 2

COMPONENTS OF WATER LOSS

2.1 Components of Water Loss

The water that flows through a system ends up in several ways. Some goes to authorized beneficial uses, and some to non-productive losses. Losses are either physical or non-physical. Physical losses occur through pipe leakages and have a financial impact on both the utility or water supplier, in the form of higher production costs or lower revenues, and the community, in the form of larger water system investments. Non-physical losses, through illegal use or inaccurate meter reading, also affect the supplier adversely but may or may not have economic consequences for the community.

Figure 1 illustrates the flow of water in a water supply system. Physical losses are shown with light grey shading, and non-physical losses without shading. The hatching superimposed on the diagram indicates losses with financial implications. For purposes of this manual, water loss includes:

Leakage—Water which drains through: cracks, gaps, holes, or other openings in transmission pipes, fittings, joints, and valves; storage tanks; distribution pipes, fittings, joints, and valves; and standposts, yard taps, house connections, and other water distribution points. Leakage is considered a physical loss with financial implications.

Distribution/Storage System Maintenance—Water is lost in line flushing, storage tank drainage or cleaning, and repairs and maintenance. Figure 1 shows this as a non-physical loss with financial implications. The water is used for a legitimate purpose but the cost is not recovered. Water use in treatment processes (filter backwash, for example) falls into the same category.

Illegal Uses—Water may be consumed illegally through unauthorized hook-ups, connections where meters have been bypassed, turned around, or removed, or at unmetered locations. Night-time theft of large quantities of water from unmetered locations would fall in this category. This is considered a non-physical loss with financial implications.

Unmetered Public Uses—Water may be used for fire fighting, unmetered government or public buildings (clinics, schools, etc), street or sewer cleaning, and construction. As shown below, these are not physical losses but they do have financial implications in lost revenue. Such water is used for a legitimate purpose but the cost is not recovered.

Wastage—Water may be delivered but not used at standposts, taps, connections, livestock troughs, or other distribution points. Note that waste is considered a physical and financial loss in the case of unmetered uses, but only a physical loss for metered uses. Another common source of wastage in rural water systems, particularly pumped systems, is the overflow of elevated storage tanks due to sloppy operating procedures.

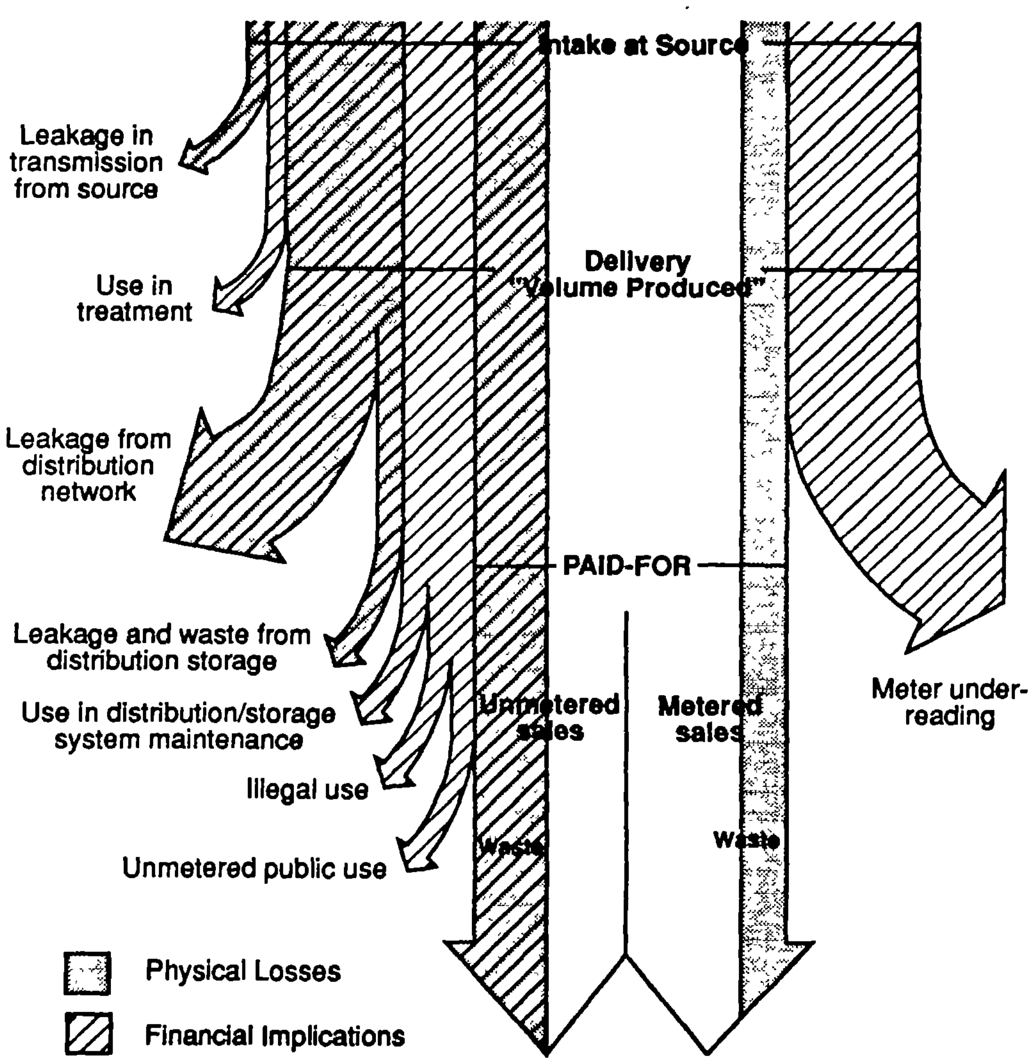


Figure 1 - Flow of Water in a Small Water Supply System

Inaccurate Meter Reading—The meters commonly used in drinking water systems tend to lose their accuracy in time. How soon this happens depends on the type of meter and the water running through it. Generally, after 5 to 10 years a meter will register only 75 percent of the flow, which means a significant financial loss for the utility even though there is no physical loss. Declining accuracy affects master meters, zone meters, and connection meters, though not at the same rate, and explains why utilities have meter testing, calibration, and replacement programs.

The causes and effects of water loss are summarized below.

	Physical Loss	Non-Physical Loss
Financial Implications	- Leakage in transmission, distribution and storage - Waste in unmetered systems	- O&M uses - Unmetered public uses - Illegal use - Meter error
No Financial Implications	- Waste in metered systems	

This manual is concerned mostly with leakages in transmission, distribution, and storage, and wastage at standposts, yard taps, house connections, and storage tanks. Many of the non-physical losses simply do not occur in rural systems, which have no meters and use very little water for O&M purposes. The term unaccounted-for-water (UFW), often applied to urban systems, has not been used here. It refers to the difference between the numbers registered by consumption meters and master meters, and is generally examined for its financial implications. Water loss seems a more appropriate term in the rural context.

2.2 Technical Factors in Water Leakage

There are several technical factors that affect leakage from pipes:

The pipe itself—The pipe material, diameter, and wall thickness are important factors in leakage. In most urban areas, where ductile iron pipe is used, corrosion is the prime concern. But in rural systems, where plastic or asbestos-cement pipes are more common, storing or exposing PVC and other plastic pipes to strong sunlight for extended periods can diminish their strength. Another problem in developing countries is poor quality control in the fabrication of pipes. Pipes with variable wall thicknesses are prone to crack at high pressure.

The environment in which the pipe is placed—The chemistry of the water and the soil can weaken the pipe, especially if it is made of ductile iron or galvanized steel. In addition, stresses from vehicular traffic, soil or ground movement, or loads because of exposure may lead to pipe fracture. If proper depth, bedding, and coverage requirements are not adhered to, breaks will be more frequent. In many parts of Africa, a common problem is the fracture of pipes exposed to the elements and the movements of people at gully crossings.

The quality of construction work—Good design standards do not ensure they will be followed. Poor construction can lead to misalignment, settling, and unexpected stresses, all of which lead to leakages. Careful construction supervision and pressure testing will help keep leakages down.

The service conditions—Higher system pressure increases the likelihood of leakage. Poor design can lead to water hammer, which can make conditions worse.

The amount of maintenance performed—A neglected pipe network will deteriorate much faster than one which is well maintained. Leaking pipes can create cavities in the ground, weakening the support below and increasing the chances of extensive pipe rupture. Valves that are never used or inspected are more likely to leak, as are old pipes that are rarely replaced.

2.3 Magnitude of Water Leakage

The physical leakage from a distribution network can vary greatly, depending on the factors described and the amount of leak detection and repair work done. The magnitude of leakage can be expressed in several ways.

Leakage rate over time—A 2 mm-diameter pinhole in a pipe leaks at about 1 to 5 l/m, which translates into about 1.4-7.2 m^3/day, or 520-2,100 m^3/yr. Leakage from a larger hole would be many times greater. Cracks or joint leaks have a different geometry and varying leakage rates.

Leaks per kilometer of pipe length—Studies of cities around the world show a broad range from 0.5 to 0.02 leaks/km/yr (or 50 km to 2 km per leak). This estimate covers the bigger leaks that are discovered and repaired, but there may be many more smaller leaks that are undetected.

Net water leakage per kilometer of pipe length—Physical leakage is often summarized as a loss per kilometer of pipe length. Figures from a

British survey of pipes 150-1,050 mm in diameter and from 2 to 100 years old gave a range from very low to over 56,000 m^3/km/yr. In that survey, 73 percent of urban trunk mains had leakage rates of less than 4,400 m^3/km/yr (500 l/hr/km), and only 7 percent had a leakage above 17,500 m^3/km/year (2000 l/hr/km). Another source indicates that "unavoidable leakage" should be on the order of 4.6 m^3/km/yr per mm of pipe diameter. For a typical rural system ranging from 50-150 mm, this would be 230-690 m^3/km/year. A system with about 1,000 m^3/km/year (2.7 m^3/km/day) would be doing pretty well, but one at 10,000 m^3/km/year (27 m^3/km/day) would not. The exact point of concern depends on local costs and benefits, which are reviewed in Chapter 5.

Percentage of water volume produced—One of the most common measures is total losses (or just leakage) as a percentage of volume "produced" (i.e., water put into distribution). There is little information on this in rural areas in developing countries. One set of night-time tests in Botswana estimated physical losses at under 10 percent. Another study of five systems in Peru showed a range of 20 to 60 percent. In urban areas in developing countries total loss rates of 40 to 50 percent are common.

Chapter 3

BENEFITS OF INVESTIGATING AND REDUCING WATER LOSS

3.1 Benefits of Investigating Water Loss

Investigating water loss will assist the following activities:

Planning Water Loss Reduction—Without a thorough investigation of the cause of water loss, water loss reduction will be a hit-or-miss effort.

Project Evaluations—For newly installed water systems, the extent of leakage is an indicator of the quality of construction. A new system should not leak more than 5 to 10 percent. For older systems, the magnitude of leakage is an indicator of the extent of system deterioration. This will help in evaluating the effectiveness of maintenance programs and in assessing the need for rehabilitation or system expansions.

Water Use Studies—Actual consumption can be calculated by subtracting water losses from total production. This figure is important for evaluating the current level of service, planning expansions, and designing future systems.

Other Maintenance Tasks—Water loss investigation may uncover the need for other maintenance work. For example, a site visit for leakage assessment may find that a diesel engine needs an overhaul, or a storage tank needs repainting.

3.2 Benefits of Reducing Water Loss

Some benefits can be measured in financial terms, others in economic terms. In certain instances, however, quantification of the benefits is next to impossible. A key factor in determining financial benefits is the extent to which consumer demand is satisfied. If needs are well met, the main benefits will be in reducing water production and, consequently, O&M costs. On the other hand, if all needs are not being met, the water savings can be allocated to these needs, with a resultant increase in revenue.

Among the benefits of reducing water loss are:

Increased System Pressure—As leaks decrease, system pressure will increase and more water will be delivered to consumers. Also, connections on higher ground will receive a more regular supply. Ironically, increased pressure can also cause new leaks or greater flow from small ones, which underlines the need for regular inspection and maintenance.

Improved Water Quality—Leaking pipes may be a source of contamination, especially if system pressures drops. With fewer leaks and higher pressure, contamination of the distribution system will decrease. Also, leakage around taps, standposts, or connections produces stagnant water and related health risks.

Conservation of Water Resources—If consumer demands are being met adequately, water loss reduction will permit decreased production, and the lowering of withdrawals from the water source. This will be beneficial for restoring aquifer capacity and augmenting stream flow.

Reduced O&M Cost—Decreased production made possible by water loss reduction will be reflected in lower O&M outlays for chemicals, electricity, and fuel. The operating period for pumps, engines, and treatment equipment will be shortened, and the need for costly maintenance or repairs will be delayed. O&M costs will not be reduced if the water saved is used for other purposes, although this may bring increased revenue.

Increased Coverage—If less water is lost, more people can be given service, through extensions to unserved sections of a town or village, or to an adjacent community. Adding new customers is the principal means of increasing revenue in unmetered systems. Expanded coverage can also obviate the cost of investment in a system at the new location.

New Water Uses—As less water is lost, more can be made available for such purposes as small-scale irrigation and small commercial or institutional use. For example, a school which had no water supply could now be served. Overall, communities will see higher benefits from their water system.

Higher Revenue Potential—Supplying additional demands will boost revenue. If the system is metered and the billing and collection functions work well, the increase in revenue will be noticed immediately. If, however, the system is on a flat-rate tariff as is common in rural areas, revenue increases will not be noticed unless new connections are made or new subscribers signed on.

Higher Consumer Satisfaction—Increased water availability and lower O&M costs enhance user satisfaction with the level of service provided. Attention to leaks indicates a well-run system and pleases the people who are paying for water. Reduced O&M costs keep water rates down, which in turn encourages consumers to participate in leakage control.

Reduced Investment—If water losses are reduced, long-term expansions to handle growth in demand can be delayed or avoided altogether. In the short term, water saved in one community can be piped to another one nearby, saving investment funds.

Chapter 4

STEPS IN INVESTIGATING WATER LOSS

The investigation of water loss has three steps: an initial audit, field visits, and an analysis of results. These steps indicate the extent of the loss and roughly where it is occurring, and enable the investigator to evaluate the need for corrective action.

4.1 STEP 1—Initial Audit

The first step is to collect basic data to get an approximate idea of how serious the problem is. This could cover a single system or a number of systems in a region and is usually done in the office by an engineer. The tasks in this step are:

1) Collect system design studies, drawings, diagrams, and maps.

All available system design documents, drawings, diagrams, or maps, especially of the distribution system, should be assembled. If such records are lost, the contractor who did the construction work or the government agency or firm that designed the system should be traced. If only initial design sketches can be found, it is important to remember that the "as-built" configuration may be different. As leak detection and repair work proceeds, diagrams should be updated. If no drawings can be found, new ones should be made.

2) Find design water demand.

The designers of a system usually make some estimate of the demand, based on population, daily per capita consumption, seasonal variations, and projected population growth. System design documents should be examined for the design daily (or monthly) water consumption for different times of the year (dry season/wet season).

3) Estimate current water demand.

The design demand provides the basis for an estimate of current demand. If the system was built a number of years ago, the current demand can be estimated from the current population, or a projection of population, and per capita demand. One approach is to project current population and multiply it by the original estimate of per capita (or per household) consumption. This is a simple approach, but users may in fact be using more (or possibly less) water than the design estimate. Recent surveys of other systems may provide a useful comparison.

4) Collect and analyze any records on current water production.

Some sources of information on current water production are:

- Master production meter readings (although these are not always available)
- Initial design flow measurements at springs or other gravity sources
- Pumping records (hours per day of pump operation derived from operator logs, if available) and an estimate of the pumping rate

5) Compare production and demand to estimate losses.

The difference between annual production and annual demand will provide a preliminary estimate of losses as follows:

- Total water production: in m^3/yr, or m^3/day, or lpcd
- Total water consumption: in m^3/yr, or m^3/day, or lpcd
- Total losses: in m^3/yr, or m^3/day, or lpcd
- Percentage of loss: loss as a percentage of production
- Loss per kilometer per year: in m^3/km/yr

6) Look for trends in repair records, if any.

A review of system maintenance records may provide useful clues before field work is started. Frequent pipe breaks may indicate corrosive soils, pressure problems, other factors contributing to leakage. Immediate repairs will indicate that people are aware of the importance of losses.

4.2 STEP 2—Field Visits

The second step is to verify the information gathered in Step 1 and to refine it. Field visits should be made by a team of two persons, with the collaboration of the local operator/caretaker, water user association, village chiefs, etc. The team should spend one or two days at the site and come equipped with basic hand tools.

BOX 1—STEP 1 Example Calculations

1) *Collect system design studies, drawings, diagrams and maps*—Suppose a hypothetical system consisting of a deep well, turbine pump, diesel engine, elevated 25m^3 water storage tank, 4 km of 75mm polyethylene pipe, and 5 standposts serving a village. When the system was built, in 1985, the village population was estimated at 2000 people. The well and tank are both near the center of the settlement, with 1 line running north 2 km and another running south 2 km. There is a standpost at the tank, and at 1 km intervals along each of the 2 lines. The dynamic water level in the well was estimated to be 100m, and with the height of the tank and other losses the head was estimated at 110 m. The design pumping rate is 20m^3/hr.

2) *Find design water demand*—The original designers assumed a per capita consumption of 50 lpcd. Designers estimated that summer demand might reach 75 l, while in the winter, during the rains, the consumption would fall to around 25 lpcd. Thus the design water demand is 100m^3.

3) *Estimate current water demand*—Current policy is to use a 3 percent population growth rate in rural areas, so current water demand is:

1989: $2000 \times 1.03^4 \times 50$ lpcd = 2251 people x 50 lpcd = 113 m^3/day or 41,245 m^3/yr.

1990: $2000 \times 1.03^5 \times 50$ lpcd = 2318 people x 50 lpcd = 116 m^3/day or 42,340 m^3/yr.

4) *Collect and analyze any records on current water production*—There is no metering at the system. The only records are hours pumped per day, from operators logs. In 1989, the total hours pumped was 2700 hours, or an average of 7.4 hrs/day. Based on the design figure of 20 m^3/hr and 2700 hours we get a 1989 production figure of 54,000 m^3/yr or an average of 148 m^3/day.

5) *Compare water production and demand—estimate losses*

- Total water production in 1989: 54,000 m^3/yr, or 148 m^3/day, or 66 lpcd
- Total water consumption in 1989: 41,245 m^3/yr, or 113 m^3/day, or 50 lpcd
- Total amount of losses in 1989: 12,755 m^3/year, or 35 m^3/day, or 16 lpcd
- Percentage of loss: 35/148 = 24 percent
- Loss per kilometer per year: 3,200 m^3/km/yr—modest

1) *Interview operator/caretaker.*

- Collect any records of fuel, repairs, etc.; discuss production and consumption

- Discuss any recent significant changes in system operating performance (operating hours per day, fuel consumption rate, water pressure, flow rate, color, etc.)

2) *Interview local leaders / water users.*

- Find out if there have been recent change in water pressure, flow, or color, or increased incidence of water-related diseases—which may indicate significant leakage.

- Find out if there have been any recent counts of people or families using the system, and assess the degree of demand satisfaction.

3) *Inspect standpost taps, livestock troughs, fountains, kiosks.*

- Locate any leakage or wastage and estimate flow (bucket and watch).

- Correct minor problems immediately. Plan follow-up maintenance for jobs requiring more than 1/2 hour or additional parts or tools.

4) *Inspect transmission lines, storage, distribution network.*

- Locate lines

- Look for wet spots (ask people nearby)

- Look for uncharacteristic vegetation near the lines

- Look for depressions in the soil

- Check all valve boxes for moisture or wetness

- Use long steel probes to find wet subsoil

- Check any air release valves carefully

- Focus on gullies, road crossings, and other points where pipes are subjected to loads

- Look for any signs of illegal taps or connections

5) *Look for leaks—two quick checks.*

There are two methods, which depend on the presence of at least some valving, to quickly check for leaks in transmission or distribution lines: listening on valves along the line, and pressure tests. Both require that all outlets should be closed, which may mean doing a check late at night. In a small rural system with a few standposts, it should be possible to obtain the cooperation of users to shut off all outlets for a couple of hours.

The procedure to be followed with the first method is:

- Close all valves controlling flow in and out of the selected zone or length of line.

- Listen on each valve. One end of a flashlight, a long wrench, or a valve key can be placed on the valve and the other end against the ear. If water is heard seeping past, the valve should be repaired and then closed. The sonoscope or aquaphone described in Chapter 6 will work better, but even a simple device is enough.

- Open the valve that controls water flow *into* the zone and listen carefully. If water rushes into the zone, there is a leak in the zone. Some people refer to this as "cracking" the valves.

The second method uses a simple pressure gauge mounted somewhere in the zone. A gauge mounted on a nipple that can be inserted in place of a stopcock at a standpost will work. After the gauge is installed:

- Close all valves controlling flow in or out of the zone.

- Listen on each valve. If water is heard seeping past, the valve should be repaired and then closed.

- Watch the gauge. If the pressure falls more than a few m of head per minute (5-10 psi), there is probably a leak. A leak will produce a swift steady drop in pressure, whereas if someone were drawing water the pressure would fluctuate.

Both methods are simple enough for a pump operator, who could be trained to use them regularly.

6) Measure water loss on transmission, storage, and distribution.

If there is an elevated storage tank in the system, a simple method can be used to measure the amount of leakage. The process is as follows:

- Close valves to all zones of the distribution system.
- Listen on each valve. If the sound of water is heard seeping past, the valve should be repaired and then closed.
- Wait one hour and remeasure the storage tank water level. If there is a drop, there is a leak in the tank itself. Calculate the rate of loss and note it for later use.
- Arrange with users to close all outlets for one or two hours, or conduct the test late at night when legitimate use is likely to be zero.
- Measure the level in the storage tank.
- Open the valve to the zone under study and wait one or two hours.
- Remeasure the storage tank level and compute the total loss. Subtract any storage tank loss to get the distribution loss in the zone.

If the system is metered at the water source and has a storage tank, a similar process can be applied to measuring losses in a transmission line from the source to the tank. The flow of water should be stopped or diverted, the storage tank level measured, outlets from the tank closed, and the tank filled for a known period. Then the tank level should be rechecked, and the volume arriving at the tank compared with the volume transmitted. This will show the loss.

The more valves there are, the more the zones that can be created, and the easier it will be to pinpoint the leakages. If there is no storage tank, as might be the case in some spring/gravity feed systems, the only way to measure losses is to install a meter and measure the flow when all authorized outlets are shut off.

7) Measure water production rate.

It is worthwhile to measure the water production rate even if records exist. If there is no meter, as is common, the amount of water produced can be estimated by watching the rise in water level in a storage tank. The outlet valve of the tank must be closed, the water level in the tank measured or marked, the pump run for about an hour, the level rechecked, and the volume pumped computed. If there is a long pipe from the pump to the tank, leakage in the line could go undetected. In this case the only choice is to install a meter (temporarily at least) to measure the pump output and then the leakage in the line.

BOX 2—STEP 2 Follow-up Site Field Visit Results

A field investigation was conducted at the site to collect additional data.

1) *Interview caretaker-operator*—There were no additional records at the operators shed. Discussions with the operator indicate that there have been no sudden changes in system performance that he was aware of.

2) *Interview local leaders/water users*—Users also have not observed any sudden changes in the quantity or quality of the water. Discussions with community leaders revealed no detailed data on the number of people served, but did indicate that people located some distance away are walking to collect water from the far north standpost. The community had decided that they need not contribute to the water association. The leaders wanted to know if another standpost could be built nearer to these people, and have them contribute more.

3) *Inspect standpost taps, livestock troughs, fountains, kiosks*—An inspection revealed a leak in one standpost on the north branch, and one on the livestock trough on the south branch. Both were estimated at about 1 l/m (using a bucket and watch). The caretaker said these had been leaking for only a short period. The caretaker proceeded to make the repairs.

4) *Inspect transmission line, storage, distribution network*—The team walked the north and south branches and found no obvious spots for leakage, other than the two small leaks noted above.

5) *Looking for leaks—listening on transmission/distribution lines*—There are only two valves in the system, both at the outlet of the storage tank. One controls flow to the north and the other the south. All standposts were shut down, valves closed and checked, and then "cracked". Some noise was heard in the north branch, but the south branch sounded ok.

6) *Looking for leaks—pressure tests on transmission/distribution lines*—Pressure tests were done by putting a pressure gauge in place of the valve on the northern-most standpost (and then southern-most). Observations showed a steady pressure in the south branch—indicating a tight zone, but a slow but steady pressure drop in the north.

7) *Measure water loss on transmission, storage, and distribution*—The water loss in the north branch was measured at 2 m^3/hr, and essentially zero in the south branch.

8) *Measure water production*—The water production rate was measured at 19 m^3/hr, close to the design value of 20 m^3/hr.

4.3 STEP 3—Analysis of Results

1) *Recompute water production and demand with new data.*

The water production and water demand should be recomputed, from the results of the field visit. If these data conflict with data in the initial audit or with other data collected in the field visit, good judgment should be used to reconcile such differences. If there are clear differences that cannot be explained easily, additional field work is necessary.

2) Recompute losses.

Recompute losses in the same way as in Step 1 (see Section 4.1, task 5).

3) Convey results to operator and regional manager.

A summary report (similar to the example given here) should be submitted to the operator and the community, and to the regional government office that oversees water systems. If the operator and the community are unable to read engineering reports, the findings can be communicated at a meeting.

BOX 3—STEP 3 Analyze Results

1) Recompute water production, losses and demand with new data.

The measurements of water production rate has generally confirmed previous data. The minor difference between the design figure of 20 m/hr and the field result of 19m^3/hr is rather small given the variations in water tables, and the accuracy of the rather crude methods used. Thus water production remains basically unchanged. Thus production can be kept at our original estimate of 148 m^3/day. However our loss measurements indicate 1 m^3/hr, or 24 m^3/day, not the estimate of 35 m^3/day from STEP 1. If loss is less than expected, consumption must be more—either because the actual population is more than anticipated, or the per capita consumption is higher.

2) Recompute production, consumption, and losses.

Given a production of 148 m^3/day and losses of 24 m^3/day, consumption can be estimated at 124 m^3/day, as summarized below:

- Total water production in 1989: 54,000 m^3/yr, or 148 m^3/day, or 66 lpcd
- Total water consumption in 1989: 45,260 m^3/yr, or 124 m^3/day, or 55 lpcd
- Total losses in 1989: 8,740 m^3/yr, or 24 m^3/day, or 11 lpcd
- Percentage of loss: 24/148 = 16 percent
- Loss per kilometer per year: 2,200 m^3/km/yr—modest

3) Convey results to operator and regional manager.

A summary report was prepared with these results and delivered to the O&M manager of the regional water supply agency, and a copy sent to the operator to review and discuss with the community.

Chapter 5

EVALUATING CORRECTIVE ACTION

Corrective action should be considered only after a careful comparison of costs and benefits. For simple gravity-fed systems with an ample water source, the costs of fixing even a significant leak may far exceed the benefits, and no action should be taken. On the other hand, systems extracting deep groundwater in arid areas with high water demand will benefit greatly from repairing a leak. Numerous studies in urban areas have shown that if water losses are more than 15-25 percent, the costs of leakage control will pay for themselves. But blindly applying this rule could be a mistake, especially in a rural context.

This chapter outlines an approach for a more careful investigation that can be applied to evaluating a single repair at one site, several repairs at one site, or repairs to systems in a whole region. If several installations are involved, the one most in need of repair should be attended to first. In theory, work should begin on the most beneficial sites and continue until the cost of repair is about equal to the benefits to be gained. Corrective action should then stop.

5.1 Assessing the Costs of Repairs

The cost of repairing a leak includes the cost of locating the leak and then repairing it.

Locating a leak can be anywhere from quite easy to quite difficult. If investigations have shown there is a leak in a section several kilometers long and there are no tell-tale signs on the surface, the task will take time. (More on the process of locating leaks is given in Chapter 6.) With experience, field personnel will be more proficient in pinpointing leaks and cost estimates will gain from this experience.

The repair may include:

- System shutdown
- Excavation
- Component removal
- Component replacement
- Pressure testing

- Back-filling and restoration of the ground cover or paving
- Return to service

The components of the cost of repair are:

- Labor
- Materials (pipe, fittings, valves, etc.)
- Transport (including driver, fuel, maintenance)
- Subsistence allowance for staff traveling overnight
- Overhead or other indirect administrative costs

There are no rules of thumb that apply here. The estimator will have to collect information, interview repair personnel, and derive reasonable estimates for the case at hand.

5.2 Assessing the Financial Benefits of Repairs

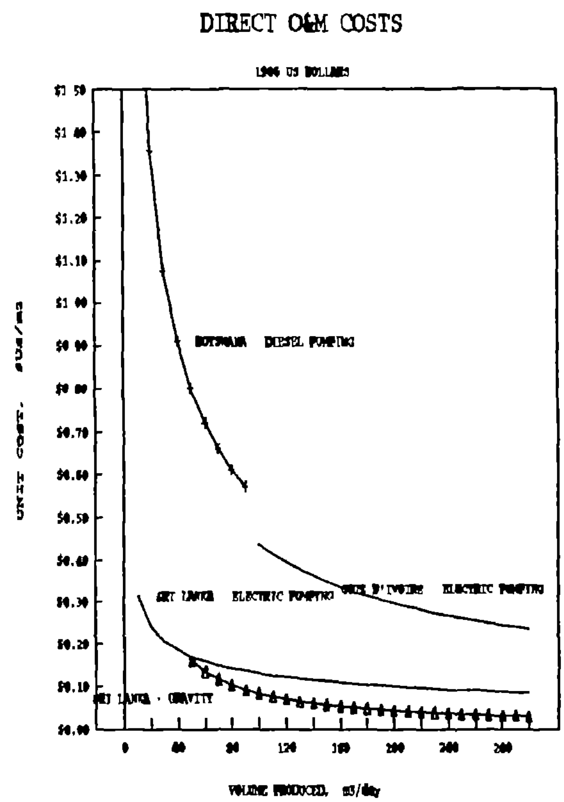
As mentioned in Chapter 3, the financial benefits could be either a reduction in O&M cost or an increase in revenue. Where demands are well satisfied, a reduction in water loss will mean a reduction in water production and a reduction in O&M cost. Alternatively, if the water retrieved is used to provide additional families with service, it will bring in increased revenue.

5.2.1 O&M Cost Reduction

The benefits will be the annual volume of water saved multiplied by the unit cost of water. The graph at right compares O&M costs for small rural water systems in Botswana, Côte d'Ivoire, and Sri Lanka. Costs vary for different locales, different pumping systems, and different system scales. For example, O&M cost savings for a diesel pumping system like the one in Botswana, which before repairs produced 50 m^3/day and after repairs reduced production to 35 m^3/day, would be:

Savings	=	Original Volume x Original Cost - New Volume x New Cost
	=	(50 m^3/day x \$0.48)–(35 m^3/day x \$0.59)
	=	\$24.00–\$20.65 = \$3.35/day
	=	\$1,220 / year

The same reduction in volume for an electric pumping system in Sri Lanka produced an annual savings of only $600, and for a gravity system only $70.



These data illustrate the effect of economies of scale. The unit cost is higher at 35 m^3/day than at 50 m^3/day, mainly because of fixed costs (mostly operator salary). The operator must be paid the same salary whether leakage, and hence production, is reduced or not. Reduced production affects only variable costs (principally diesel fuel), and since in most small systems these are much lower than fixed costs, the overall cost reduction is proportionately smaller. Gravity-fed systems have few variable costs and would probably experience little cost reduction with leakage control. In general, larger systems with higher variable costs (fuel, electricity, chemicals, etc.) stand to gain the greatest financial benefits.

The kind of O&M cost data used in this example may be hard to find. But savings can be estimated from savings in variable costs for items such as engine fuel, electric power, chemicals, and transportation.

Since a certain amount of leakage is unavoidable it is unrealistic to try to reduce leakage to zero. The cost of finding and repairing leaks could outweigh the savings, but it is hard to predict the breakeven point. Perhaps an irreducible loss of 500-1,000 m^3/km/yr (Section 2.3) would be an acceptable base.

5.2.2 Revenue Increases

Where the demand for water has not been fully satisfied, the water saved from plugging leaks can be supplied to new users and can bring in added revenue. The financial benefits would be the increased sales multiplied by the water fee. However, if the tariff is a flat monthly rate, the extra water provided to existing users will not bring a revenue gain. Also, if collections are poorly organized, selling more water will bring no gains.

5.3 Comparing Benefits and Costs

The costs of repairing a leak are quantifiable, the benefits less easy to pin down. Repairs could hold for years, or a new leak could develop six months later in the same area. Most studies assume that the benefits from a repair will last just one year.

5.4 Practical Considerations

In many cases there are factors beyond costs and benefits that influence the decision on whether or not to repair. If the people who pay the operating costs are not the people who would pay for replacing a stretch of leaking pipe, conflicts could arise. There are also instances where operating funds are adequate but capital funds are simply not available for sizable repairs. Political pressure may also favor spending money to keep pump equipment running rather than to fix an underground pipe which no one sees.

BOX 4 Sample Calculations for the Example from Chapter 3

Cost of Leakage Repair

There is some uncertainty as to how many leaks there are in the north branch, so a range of cost estimates has been prepared.

Leak pinpointing			
	Labor: 2 persons x 2-4 days @$10.00/day		$ 40-$ 80
	Transport: Pickup 100-200 km x $0.30/km		$ 30-$ 60
Leak Repair			
	Labor: 2 persons x 2-4 days @$10.00/day		$ 40-$ 80
	Materials:		$ 50-$100
	Transport: Pickup 100-200 km x $0.30/km		$ 30-$ 60
		Subtotal	$190-$380
Administrative Costs	20 percent		$ 38-$ 76
		TOTAL	$228-$456

Benefits of Leakage Repair

It was found that the system had a total loss of 24 m^3/day, based on a leakage rate of 2200 m^3/km/yr. We could expect to reduce that to about 1000 m^3/km/yr, representing a savings of 1200 m^3/km/yr. The network total length is 4 km leading to an expected savings of 4800 m^3/yr or 13 m^3/day.

O&M Cost Reduction Approach

Approximate data puts the unit cost at $0.20 to $0.30. Thus the benefits are estimated at:

Benefits = 4800 m^3/yr x $0.20 to 4800 m^3/yr x $0.30 = $960 - $1440

Revenue Increase Approach

The water savings could be applied to serving additional families, who could be signed up as association members and pay the current monthly tariff of $2.00. If we assume 55 lpcd, and 6 persons per family, the savings of 13 m^3/day indicates that 40 additional families, can be served. This would yield an annual increase in revenue of $960.

Comparison of Benefits and Costs

If the additional people nearby are not served, the benefits would be the result of the O&M cost reduction calculation. Under these conditions, the benefits are 2 to 3 times the expected costs, and the corrective work should continue. In fact the community could finance the repair itself. It would be interesting to add in the cost of the water loss investigation itself. If that were around $250, the total cost would still be under the benefits. However if the community can secure funds for the extension to serve more nearby people, they will receive the revenue increase benefits. Still the benefits exceed the costs, even with our crude estimate of the cost of the water loss investigation added in. After the work is done, the actual costs incurred, and savings gained should be measured to evaluate results and improve cost estimation procedures.

Chapter 6

PINPOINTING LEAKS

Locating leaks may be the hardest task of all. Many features of the typical rural system make sonic approaches considerably more difficult than in urban areas.

6.1 Leakage Sounds

Water leaking from pipes produces sounds of different frequencies. The vibration of the pipe well at an orifice-type leak has a frequency range of 300-1000 hz. This sound can be heard at any point of contact with the pipe such as a valve box or corporation stop. The sounds of water leaking onto the surrounding soil and water circulating in the soil cavity near the leak have frequencies in the 100-250 hz range. They travel through the soil and can be detected by listening devices at the surface. Such sounds are localized and are very helpful in pinpointing leaks.

Several factors affect the sounds of leaking water. Metallic pipes transmit higher frequency sounds much farther. Sandy soils conduct lower frequency sounds better than clay soils do. Smooth paved surfaces make listening easier, while sod or vegetative covers deaden sound. Metal plates can be used in conjunction with surface listening devices to counteract this effect. Low pressure in the system tends to decrease the intensity of the leak sounds. The rule of thumb is that at least 10-15 meters of head (15-20 psi) is needed for sonic leak detection. The conditions in many rural water systems in developing countries are not conducive to sonic leak detection. Non-metallic piping, low pressures, unpaved ground surfaces, and few valves or other listening points make the use of this technique difficult.

6.2 Sonic Leak Detection Devices

There are two types of sonic leak detection devices—those for direct listening and those for indirect or surface listening.

Simple Probes. The simplest for direct listening are screwdrivers, pipe wrenches, flashlights, valve keys, or any other long metallic objects. One end of the probe is placed on the valve stem or other listening point and the other is pressed against the ear.

Aquaphones (shown below) are a slightly improved version of the simple probe. They consist of a metal rod and an earpiece and cost $10-$15.

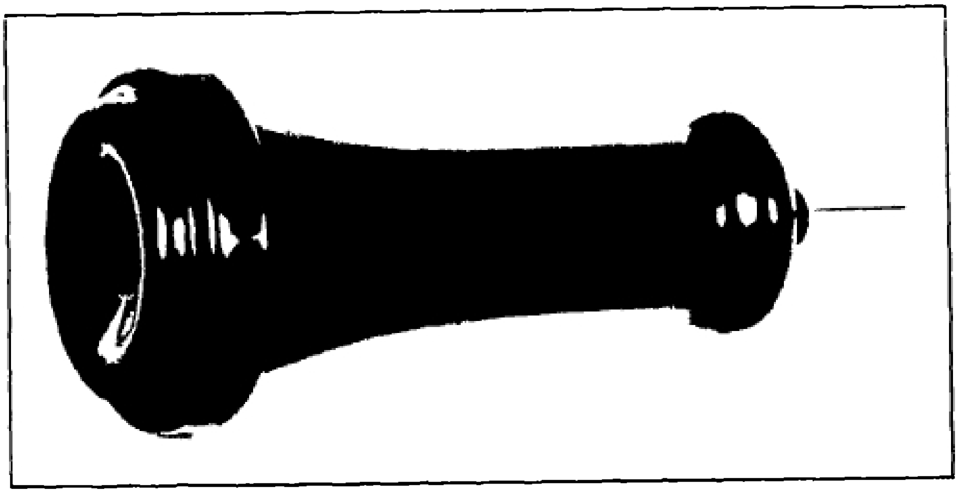


Figure 2. Aquaphone

Electronic aquaphones (such as the Stethophone made by Heath shown below) have a metal probe, electronic amplification and volume control, and earphones for direct listening. They cost about $350.

Figure 3. Electronic Aquaphone

Geophones are the simplest devices for surface or indirect listening. They consist of two metal diaphragms and ear pieces like those of a stethoscope. They are highly sensitive, and the user can pinpoint leaks by moving along the line to find the loudest noise. They are ineffective on non-paved surfaces without the use of flat metal resonance plates. They cost $250-$300.

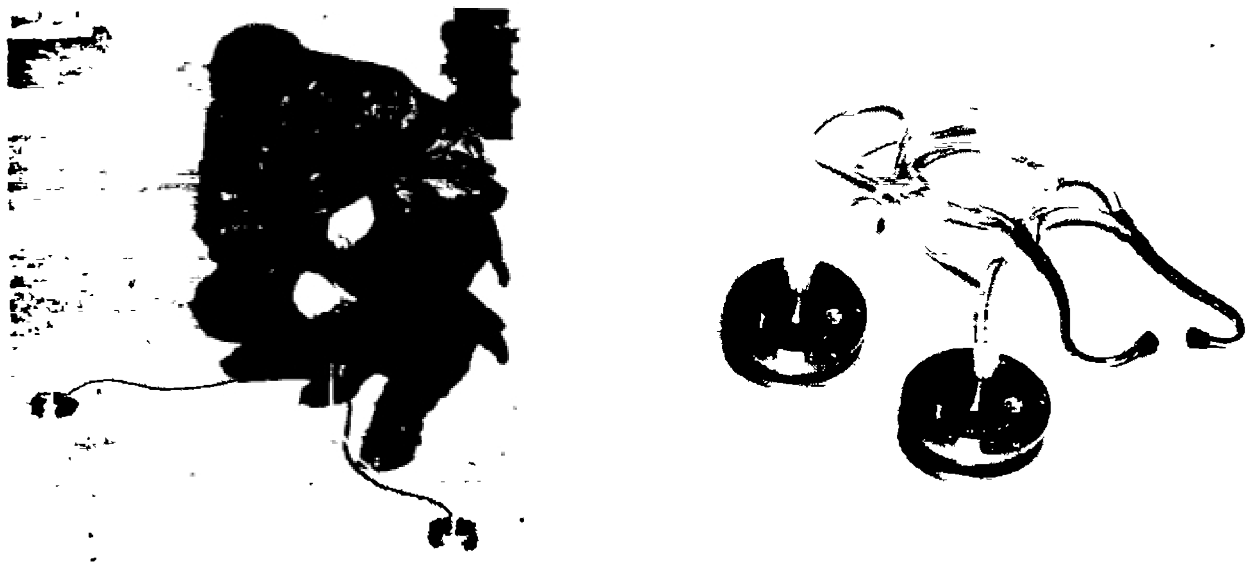


Figure 4. Geophone

Advanced electronic devices (such as the Aqua-Scope made by Heath shown here) combine a ground or direct contact microphone, electronic amplification of key leak frequencies, and earphones. Some also include an analog meter display and most can be obtained with metal resonance plates without which they are ineffective on non-paved surfaces They are more powerful than a geophone and also relatively expensive—$1,300-$1,500.

Figure 5. Advanced Electronic Device

Other devices. The leak correlator is an extremely sensitive direct listening device that can pinpoint a leak on a long pipe. It is a complex instrument and costs thousands of dollars.

There are magnetic devices that can locate ferrous objects underground and are useful in tracing pipes and valve boxes. They can be used on non-ferrous pipe if a steel wire or special metallic tape is placed on the pipe during installation. They cost $500-$1,000.

Chapter 7

ESTABLISHING A CONTROL PROGRAM

There are no rigid guidelines on how a leakage control program should be structured and what it should do. Technical, economic, financial, managerial, and institutional factors will influence the shape and scale of each program. This chapter offers some general ideas.

7.1 Program Development

The best program is one that evolves as the experience and knowledge of the staff increase and as needs dictate.

If a regional O&M office is beginning to work with communities and operators and nothing is known about the magnitude of losses, the program should have a modest beginning. A leakage team should be formed and trained by an engineer. Water audits such as those described in Chapter 4 should be conducted on several systems, starting with those likely to gain the greatest benefits, or those where water is scarce or pumping or treatment costs are high. The costs and benefits of correcting leaks should be evaluated, and repairs should be carried out where warranted. These pilot projects will serve as a training ground for the staff, and provide information on the nature of the problem.

If leakage control proves to be beneficial, the leakage team should be made permanent and its responsibilities expanded. It should be given its own vehicle and tools and the authority to follow its own schedule. It should begin to train operators and the community and to sensitize people to the issues. The team should apply the Step 1 audit procedures to all systems in the region and rank them in order of priority, taking into account the amount of loss, the cost of water, and other factors. Then Step 2 and Step 3 should be carried out for a few systems at first and, if the results are favorable, extended to the rest of the region.

The financial return from a leak control program can be determined once the program gets underway if good records are maintained on the progress to date. Persuading agency management to fund the program may be difficult when other activities such as repairs or new installations may appear more pressing. The office and field work to investigate and reduce water loss can be time consuming, and results will be slow in coming at first. Nonetheless, if the team perseveres, it can produce evidence to justify the program.

7.2 Program Components

Water Loss Work

- Conduct regular annual desk audits of water loss
- Conduct regular annual line surveys, listening, pressure tests, loss measurements
- Establish regional leakage teams to move from system to system investigating water loss, pinpointing and repairing leaks, and training caretakers/operators in regular leak detection
- Develop good distribution system maps, including updates when changes or repairs are made
- Initiate meter testing, repair and replacement programs
- Establish records on pipe breaks by location, and analyze results by pipe material, location and pressure
- Establish records on cost of leakage repairs and volume savings
- Develop detailed O&M cost estimating procedures

Training

- Train operators in basic leak checking (line surveys, spot listening, night tests)
- Train maintenance personnel—leakage team(s)
- Train engineers in good design practice

Incentives

- Create incentives such as reduced bills for community members to get involved in leakage work
- Offer salary bonuses to operators/caretakers
- Offer salary bonuses based on savings made to leakage teams

Community Involvement and Water Conservation

- Sensitize users to the need to combat wastage and leakage
- Provide pamphlets and videos on methods and benefits of water conservation
- Train villagers to identify leaks and alert operators or caretakers
- Initiate education programs in schools about local water systems, conservation methods, and resulting benefits
- Involve school groups or youth groups in leak detection as science education (line surveys, for example)

Detailed Measurements

- Conduct more detailed measurements if water audits indicate uncertainty in the magnitude and variations in water production, water demand, and water loss
- Install master production metering in selected areas, perhaps on a temporary basis around valves
- Install distribution metering to measure overall demand and the magnitude of night flows to assess leakage
- Install zonal distribution metering in house connections, to assess per capita or per connection demands
- Conduct water use surveys at standposts—people/day, number of buckets, etc.

Chapter 8

PREVENTING HIGH WATER LOSS

The best way to keep water loss at a minimum is to prevent it in the first place through good design and construction, regular maintenance, and strong community involvement in water conservation.

8.1 Engineering Design

- Install master meters for water production
- Install isolation valves or bypasses for uninterrupted service during repairs or maintenance of storage tanks
- Install distribution zone meters
- Install meters on bypasses to allow easy removal for recalibration, repair, or replacement
- Install valves at frequent intervals to facilitate zone measurements and repairs
- Design for moderate pressures
- Provide washouts for regular line flushing
- Lay tracer cable for future location of non-metallic piping if records are lost
- Specify pipe carefully, taking into account water characteristics, soil conditions, pressures, and operational experience with different materials and classes of pipe used locally
- Specify and select meters carefully
- Ensure adequate trench depth, correct bedding, and cover materials, especially at road crossings
- Establish and enforce clear standards and specifications on trench depth, bedding materials, cover materials, jointing, backfilling, and testing

8.2 Construction

- Exercise care in selection, storage, and installation of piping materials, valves, fittings, etc.
- Supervise construction to ensure adherence to specifications for pipe installation, especially trench depth, and bedding materials
- Supervise pressure testing before acceptance
- Lay tracer cable for future location of non-metallic piping if records are lost

Appendix A

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Appendix B

SOURCES OF INFORMATION, PRODUCTS, AND SERVICES

Sources of Information and Publications

1. **American Water Works Association**
   6666 West Quincy Avenue, Denver, CO 80235, USA
   Tel: (303) 794-7711

2. **International Reference Centre for Community Water Supply and Sanitation**
   P.O. Box 93190, 2509 AD The Hague, The Netherlands
   Tel: (31)-70-33 141 33

3. **National Rural Water Association**
   P.O. Box 1428, 2915 S. 13th., Duncan, OK 73534, USA
   Tel: (405) 252-0629

4. **Water and Sanitation for Health Project**
   WASH Operations Center, 1611 N. Kent St., Room 1001, Arlington, VA 22209, USA
   Tel: (703) 243-8200

5. **World Bank**
   Publications Department, 1818 H. St, N.W., Washington, D.C. 20433, USA
   Tel: (202) 473-1234

Private U.S. Companies Providing Leak Detection Equipment and Services

1. **Camp Dresser & McKee International Inc.** 1 Cambridge Center, Cambridge, MA, 02142. Tel: (617) 621-8181.
   Provides general water supply engineering services, including distribution studies, leak detection and related studies.

2. **EnTech Engineering**, 111 Marine Lane, St Louis, MO 63146. Tel: (314) 434-5255
   Provides specialized services in pipe location and leak detection

3. **Fisher Research Laboratory**, 1005 I Street, Los Banos, CA 93635. Tel: (209) 826 3292

Provides equipment for pipe location and leak detection.

4. **Forestry Suppliers**, Inc, P.O. Box 8397, Jackson, MS 39284. Tel: (800) 752-8460
Provides equipment for pipe location, leak detection, soil moisture testing, surveying, and other relevant purposes.

5. **Heath Consultants Incorporated**, P.O. Box CS-200, Stoughton, MA 02072. Tel: (617) 344-1000
Provides specialized services in pipe location and leak detection, and provides equipment and training.

6. **Metcalf & Eddy**, 10 Harvard Mill Square, Wakefield, MA 01880. Tel: (617) 246-5200
Provides general water supply engineering sevices, including distribution studies, leak detection and related studies.

7. **James M. Montgomery Consulting Engineers, Inc.** 250 North Madison Avenue, Pasadena, CA 91101 Tel: (818) 796-9141
Provides general water supply engineering sevices, including distribution studies, leak detection and related studies.

8. **Pitometer Associates Consulting Engineers**, 2 North Riverside Plaza, Chicago, IL 60606. Tel: (312) 236-5655
Provides specialized services in leak detection and distribution analysis and training.

9. **Joseph G. Pollard Co, Inc.**, 200 Atlantic Avenue, P.O. Box 5438, New Hyde Park, NY 11042. Tel: (516) 746-0842
Provides equipment for pipe location, leak detection, and other pipeline and water supply operations and maintenance activities.

The Environmental Health Project (EHP) provides technical assistance to USAID missions and bureaus and other development organizations in nine areas: tropical diseases, water and sanitation, wastewater, solid waste, air pollution, hazardous waste, food hygiene, occupational health, and injury. It is part of the Office of Health and Nutrition's response to requests from USAID missions and bureaus for an integrated approach to addressing environment-related health problems. In addition to EHP, this effort includes an Environmental Health Requirements Contract and a PASA (Participating Agency Support Agreement) with the U.S. Centers for Disease Control and Prevention. A wide range of expertise is made available by EHP through a consortium of specialized organizations (see list below). In addition to reports on its technical assistance, EHP publishes guidelines, concept papers, lessons learned documents, and capsule reports on topics of vital interest to the environmental health sector. For information on the reports available, contact EHP headquarters.

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