A Primer on Investigating and Reducing Water Loss in Water Systems in Developing Countries

1. Purpose and Focus

Information for Decision-Making

The purpose of this technical note is to help development officials working with rural water systems in developing countries understand the issues of leak detection and water loss reduction and to give them the information to make wise decisions in this area. The note is not intended to be a technical "how-to" manual; rather, it tries to impart an understanding of investigating water loss and the factors to consider when deciding what to do about leaks. (WASH Field Report No. 341 is an expanded version of this Technical Note.)

Focus on Small Rural Systems

The focus is on small rural water supply systems in developing countries. These are systems designed for 500-2500 people, with water distribution via standposts, yard taps, or, in some cases, direct house connections. Most systems use groundwater or spring catchments, although some use surface water. Typically, these systems entail minimal water treatment, plastic (PVC or polyethylene) or asbestos-cement piping, and, in most cases, no metering to simplify maintenance and repair. Most systems with wells and pumps have elevated storage tanks, but spring-fed systems generally have only minimal storage. Distribution networks range from a "water yard" standpost to many kilometers of buried piping leading to standposts or household connections.

These design decisions are usually made to keep investment costs down and simplify maintenance. They also have implications for the volume of water loss and the work required to investigate and reduce losses. The smaller number of pipes, taps, meters, and valves, and the smaller pipe diameters, create fewer locations for leaks to start, and lower pressures help keep losses down. On the other hand, low pressures, non-metallic piping, and lack of valving and metering make it more difficult to investigate and control loss. Also, rural systems are rarely designed and built to the same standards as urban systems, and sometimes not to any standards at all. The latter is especially likely if systems are conceived or built by non-governmental organizations (NGOs) or other groups whose staffs have little or no engineering experience or training. Cost constraints are often tighter in rural areas, hence poorer quality materials are used.

Rural systems are commonly operated by a local caretaker, with some backup from technicians in a regional, district, or even national office. The caretakers usually have only a small amount of training and focus on day-to-day operational tasks and minor maintenance. Major problems and maintenance activities are usually handled by mobile crews, most of whom are overworked, lack parts and tools, have limited budgets, keep inadequate records, and have logistical, bureaucratic, and transportation difficulties. Overall these isolated rural systems receive poor or sporadic maintenance, leading to premature deterioration and higher leakage.

Overview

Following this introductory section, the note discusses the benefits of reducing water loss, the factors involved in it, procedures for investigating water loss, and methods of preventing it.

2. Benefits of Investigating and Reducing Water Loss

Investigating and correcting water loss is not an easy matter in most small rural systems. In fact, it may be very complicated and quite expensive. It is important that the benefits of undertaking a detection and repair

WASH

1611 N. Kent Street, Room 1001
Arlington, Virginia 22209-2111 USA
TEL: (703) 243-8200 FAX: (703) 525-9137

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program 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. Which of these benefits is realized, and how important they are, depends on the particular situation.

Identifying the Magnitude of the Problem
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. For example, a site visit to assess leakage may show that a diesel engine needs overhauling or a storage tank re-painting.

Evaluating Performance and Service
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. (A new, well-constructed system should not leak beyond five or ten percent.) In older systems, leakage is an indicator of the degree of system deterioration and of the effectiveness of maintenance programs.

Determining the amount of water loss can also provide important data about water use. By deducting the amount lost from the amount produced, one can find out how much water users are consuming. This data is helpful in evaluating current service levels, planning expansions, and designing future systems.

Improving Water Quality
Leaking pipes may be a source of contamination, especially if system pressure falls very low. With fewer leaks and higher water pressure, contamination of the distribution system decreases. Also, leakage or wastage around taps, standposts, or connections can lead to stagnant water and related health risks.

Conserving Water
Reducing water loss can also conserve water, since it should lead to decreased production and withdrawal from the water source. Reducing the amount of water lost makes more water available for all users and helps restore aquifers and augment streamflow.

Water Loss in Gallons

Leak this Size	Loss per Day	Loss per Month
●	120	3,600
●	360	10,800
●	693	20,790
●	1,200	36,000
●	1,920	57,600
●	3,096	92,880
●	4,296	128,880
●	6,640	199,200
●	6,984	209,520
●	8,424	252,720
●	9,888	296,640
●	11,324	339,720
●	12,720	381,600
●	14,952	448,560

Unrepaired leaks can be costly. (Courtesy Health Consultants, Inc.)

Saving Money
If consumer demands are already met, reduced water loss will lead to a lower volume of water production and to savings in costs for items such as chemicals, electricity, or fuel. Indirect costs such as chemical or fuel transport will also be lowered. And the operating period for pumps and engines will be reduced, increasing system life and delaying or avoiding costly maintenance or repairs.

Extending Coverage
If consumer demands are not fully satisfied and water loss is subsequently reduced, more people can be given water service. Coverage may be extended to unserved sections of a town or village, or to another community. Adding new customers is the principal means of increasing revenue in unmetered systems.

Other Benefits
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.

3. Understanding Water Loss

Physical and Non-Physical Losses

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 most small rural systems, the most important water losses are in the "physical" category.

Type of Water Loss

The most important types of water loss in small rural systems are leakage, wastage, and illegal use.

Leakage includes water that drains out of cracks, gaps, holes or other openings in transmission or distribution pipes, and their fittings, joints, and valves, standposts, yard taps, house connections, and other water distribution points. Leakage is a physical loss with financial implications.

Wastage refers to water delivered but not used at standposts, connections, livestock troughs, or other distribution points. This is a physical loss and a financial loss in the case of unmetered uses, and a physical but *not* a financial loss for metered uses. Another source of wastage in rural water systems is overflow of elevated storage tanks due to careless operating procedures.

Illegal use of water via illegal connections, bypassing meters, or unauthorized uses at unmetered locations is also an important type of loss in some situations. Such illegal uses represent a non-physical loss with financial implications.

Water can also be "lost" when used for activities such as line flushing, storage tank draining and/or cleaning, and repairs or other maintenance. Water used for fire-fighting, unmetered government or public buildings (clinics, schools, or post offices), street washing, and construction may also be considered lost because revenue is not collected.

Meter under-reading can be an important non-physical water loss. The type of water meters commonly used tend to lose accuracy over time. This occurs with master meters, zone meters, and individual connection meters, but it may not affect each of these equally. Meter under-reading can represent a significant financial loss, even though there is no physical loss.

The Role of Technology

A number of technical factors affect leakage from pipes. The pipe itself may play a role. The pipe material, diameter, and wall thickness are important factors in leakage. In most urban areas, where ductile iron pipe is used, pipe corrosion is a prime concern in leakage. But in rural systems where plastic or asbestos-cement are much more common, corrosion is less of a concern. PVC and other plastic pipes can lose strength, however, if exposed to strong sunlight for extended periods. Another concern in developing countries is the quality of materials and fabrication of the pipe. Pipe quality control can be poor, leading to a product with variable wall thickness and lower strength, which is prone to breakage at high pressure.

The environment into which the pipe is placed can affect leakage. The chemistry of the water and the soil can, in some cases, lead to reduced pipe strength, especially for ductile iron or galvanized steel pipe. In addition, stresses imposed on the pipe from vehicle traffic overhead, or from soil or ground movement, may lead to pipe fracture. If proper depth, bedding, and coverage requirements are not adhered to, breaks will be more frequent.

The quality of construction work may be poor, even if good design standards are used. Poor construction can lead to misalignment, settling, and unexpected stresses, promoting leakage. Careful supervision and pressure testing are essential to minimize leaks.

An important factor in the amount of leakage is system pressure, since higher pressure increases leakage. Poor design can lead to water hammer, which can aggravate leakage. Maintenance is also an important factor. A pipe network that is neglected will deteriorate much faster than one that is well maintained. Leaking pipes can create cavities in the ground, which produce additional stress and can increase leakage or cause more extensive rupture of the pipe. Valves that are never used or checked are more likely to leak. Maintenance policies that rarely replace old pipes lead to leakier networks.

Ways of Expressing Water Loss

Losses are commonly expressed as a percentage of volume "produced" (put into the distribution system). There is little data on the percentage of losses in rural areas in developing countries. In developing country cities loss rates of 40-50% are common.

Another way to look at losses is in terms of the volume of water lost per year. A typical small pinhole leak, 2 millimeters in diameter, leaks at about 1 to 4 liters per minute, which translates into 600-1800 cubic meters per year. A big leak could be many times that value.

In rough terms, a system with leakage of about 1000 cubic meters per kilometer of piping per year is suffering low losses, but one at 10,000 cubic meters per kilometer per year has a substantial leakage problem.

4. Investigating Water Loss

This section provides an overview of the process of investigating water loss and suggests considerations in deciding whether to go forward with an investigation. There are three main steps in investigating water loss: an initial audit, a field investigation, and a refined audit. These steps tell the investigator about how much water is being lost and roughly where leaks are located.

Initial Water Audit

The first step is to collect and analyze basic data to get a sense of whether there is serious water loss. Such "audits" can be performed on a single water system or on a whole region. Systems with high losses can be identified and given top priority. This first step is usually done in the office by an engineer. It involves the following activities.

1) Collecting system design documents. If they exist, it is essential to locate system design studies, drawings, diagrams, or maps, especially of the distribution system. If only initial design sketches are available, investigation will be much more difficult, since the "as-built" configuration may be different. If no drawings can be found, then new ones should be made.

Listening for leaks with a geophone. (Courtesy Health Consultants, Inc.)

2) Determining design water demand. The designers estimated demand, usually based on estimated population, daily per capita consumption, seasonal variation, and population growth over time. System design documents should be collected and the design water consumption for different times of the year (dry season/wet season) should be determined.

3) Estimating current water demand. If the system is several years old, estimated current demand can be found using estimates of current population and per capita demand. Current population is commonly multiplied by the original estimate of per capita (or per household) consumption. This is a simple approach, but water users may be using more or less water than the design estimate. If recent survey results from other systems are available, they may provide a useful comparison.

4) Collecting and analyzing existing records on current water production. The next step is to find detailed information on current water production. Common sources include master production meter readings, initial design flow measurements at springs or other gravity sources, and pumping records (hours per day of pump operation derived from operator logs, if available). For this calculation an estimate of the pumping rate will be needed.

5) Comparing water production and demand and estimating losses. The difference between annual production and annual consumption will be a first estimate of losses. Losses can be estimated as follows:

- Subtract total water consumption in cubic meters per year or per day (m^3/yr or m^3/day) or liters per person per day (lpcd) from
- total water production in m^3/yr, m^3/day, or lcpd to get the total loss, which may be expressed as
- percentage of loss (loss/production) or
- loss per kilometer per year.

6) Looking for trends in repair records, if any. A review of system maintenance records may provide valuable insights before field work begins. Frequent pipe breaks may indicate corrosive soils or pressure problems. Rapid repairs indicate that leakage has been controlled, and that people are sensitive to the importance of losses.

Site Follow-Up Visits
The second part of the audit includes field work to verify the information developed above, and collecting more precise data on key parameters. This requires a team of two persons with the local operator/caretaker, water user association representative, or village chief. The team should spend one or two days at the site and should be equipped with basic hand tools. The following activities are part of the on-site work.

1) Interviewing caretaker-operator. This person should have system records and know if there have been any recent significant changes in system operating performance (e.g., operating hours per day, water pressure, flow rate, color).

2) Interviewing local leaders/water users. Community members can provide information on any recent significant changes in water pressure, flow, or color, or any increased incidence of water-related diseases, all of which may indicate significant leakage. It is also important to find out if a count of the people or families using the system has been made recently.

3) Inspecting standpost taps, livestock troughs, fountains, and kiosks. This permits visual identification of leaks and/or wastage.

4) Inspecting transmission lines, storage, and distribution network. The team should walk the pipelines to locate leaks; look for wet spots, uncharacteristic vegetation near lines, and depression or slumps in the soil; check valve boxes for moisture or wetness; check for wet subsoil; check air release valves; examine gullies, roads, or stream crossings or other points where pipes are subjected to loads; and look for signs of illegal taps or connections.

5) Looking for leaks by listening on transmission or distribution lines. There are two basic methods to check quickly for leaks on portions of transmission or distribution zones. Both depend on the presence of some valving. The first is listening on valves along the line, and the second is pressure tests. Both should be done when all authorized uses are shut down, usually at night.

A zone or length of line should be selected for study and the following procedures used. Close all valves controlling flow into or out of that zone. After waiting an hour or so, open the valve that controls water flow into the zone. Listen on each valve by placing one end of a simple device, such as a flashlight, long wrench, or valve key, on the valve and the other on the ear. If water can be heard rushing, there is a leak somewhere in the zone.

6) Looking for leaks using pressure tests on transmission or distribution lines. Another way to find if there is leakage is to do a pressure test. A simple pressure gauge is mounted on a fitting somewhere in the zone. Once the gauge is installed, all valves are closed and the gauge is monitored. If the pressure falls faster than a few meters per minute (5-10 pounds per square inch), there is probably a leak. A leak will produce a steady drop.

7) Measuring water loss on transmission lines, storage tanks, and distribution systems. If there is an elevated storage tank in the system, a simple method can be used to measure the amount of leakage. This involves closing the valves to all zones of the distribution system, measuring the storage-tank level, waiting an hour or two, and remeasuring the storage tank level. Any drop in level indicates a leak in the tank. While all the valves are closed, listen on each valve. If water is seeping past, the valve should be repaired.

If valving permits branches of the system to be isolated, the distribution system can be studied zone by zone. Select a zone for study, measure the level of the storage tank, open the valve to the zone under study, wait one to two hours, remeasure the storage tank level, and subtract any storage tank loss to get the distribution loss in the zone.

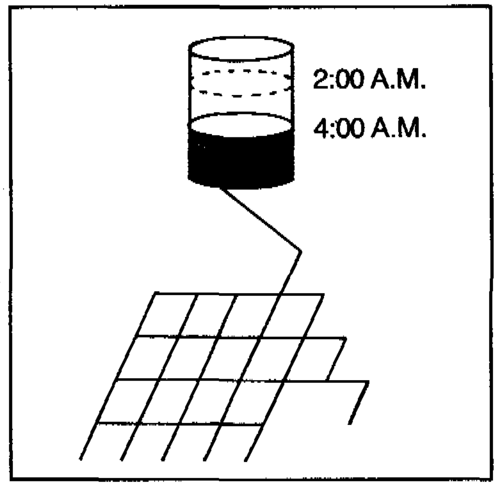
If there is metering at the water source and a storage tank, a similar process can be used to measure losses in a transmission line to the tank. The flow of water should be stopped or diverted, the tank level measured, outlets from the tank closed, and the tank filled for a known period of time. Next the tank level is rechecked and the volume arriving at the tank is calculated and compared to the volume put into the transmission line. Then the loss can be found directly.

It is obvious from the above discussion that valves play a crucial role in detecting leaks and measuring losses. The procedures described here would be virtually impossible in a system without any valves. The more valves there are, the more zones that can be created, and the easier it is to determine where leakage is occurring.

If there is no storage tank, the only way to measure losses is to install a meter and measure the flow with all authorized water uses shut down.

8) Measuring water production rate. If there is no meter, the amount of water produced can be estimated by watching the rise in water level in a storage tank. As described above, the outlet valve of the tank must be closed, the water level in the tank measured or marked, the pump run for an hour, the level rechecked, and the volume pumped computed. If there is a long pipe from the pump to the tank, there may be leakage in the line, which will go undetected. In this situation, a meter must be installed to measure the pump output.

Analyze Results
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 that oversees the system. If community members are not familiar with engineering reports, other means, perhaps a meeting, should be used to communicate the results.



Storage tank levels can measure use within a zone. (Courtesy National Rural Water Association.)

5. Corrective Action

Balancing Costs and Benefits
If there is significant leakage, corrective action must be considered. 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.

Costs of Locating a Leak
The costs of repairing a leak include the expense of locating the exact spot of the leak and repairing it.

Locating a leak can be quite easy or quite difficult. If investigations have shown a leak in a section several kilometers long, and there are no obvious signs on the ground surface, locating the leak will be difficult and time-consuming.

Specialized equipment permitting sonic leak detection may be needed. Such equipment ranges from aquaphones to geophones to advanced electronic devices. Other devices may be needed to help locate pipes or valve boxes. Magnetic tracing or locating devices can locate ferrous objects underground. They, of course, will be of little help on non-ferrous pipe unless a tracer wire is used or special metallic tape can be placed along the pipe during installation. (Information on purchasing this equipment may be obtained from Fisher Research Laboratory, 1005 I St., Los Banos, CA 93635; Forestry Suppliers, Inc., P.O. Box 8397, Jackson, MS 39284; Health Consultants, Inc., P.O. Box CS-200, Stoughton, MA 02072; and Joseph G. Pollard Co., Inc. 200 Atlantic Ave., P.O. Box 5438, New Hyde Park, NY 11042.)

Costs of Making Repairs
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 estimator should collect information, interview repair personnel, and make an estimate.

Financial Benefits
As noted earlier, there are numerous potential benefits from reducing water losses. In any given case, only some of these will accrue. Many of the benefits are difficult to assess, either because their extent is unknown, or their value in financial or economic terms is hard to determine. This discussion focuses on the financial benefits as they are the easiest to estimate.

Financial benefits may consist of reduced operation and maintenance costs or increased revenue. Where local demands are well satisfied, reduced water loss will mean reduced water production, and reduced operation and maintenance cost.

Where local demands are not fully satisfied, which will be common, financial benefits can accrue from supplying water for new uses or to users willing to pay for the water. A portion of a village previously unserved with yard taps could have such connections made, new accounts set up, water delivered, and revenue collected. Water could be sold to vendors to haul to other communities, or sold to farmers for small-scale irrigation.

With leaks reduced, and pressures and availability higher, people may use more water, especially if there is no cost recovery, or a flat-rate tariff. Given such a "non-volumetric" tariff, the extra water provided to these users will *not* translate into revenue gains.

Potential revenue gains will not translate into actual revenue if collections are poorly organized and run. If a water system collects only 50% of what it is due, selling more water is pointless unless efforts are made to improve the collection rate.

Making a Decision

Given estimates of the cost of locating and repairing a leak and the annual benefits derived, the attractiveness of making a repair can be assessed. The cost of making a repair is a "one-time" event, but the benefits go on for a considerable period of time. The actual benefits of repairing a leak are hard to pin down. If there is another leak six months later in the same area, the benefits of the first repair were only felt for six months. In other cases, benefits might go on for years. Most studies, when faced with this problem, assume that the benefits from a particular repair last for just one year.

Practical Considerations

Aside from basic cost-benefit considerations, in many cases there will be other, more practical concerns that will influence the decision as to whether or not to take action. Financial or institutional factors may outweigh the balance of benefits and costs.

In some cases the people (or budgets) who pay for operating costs (fuel, etc), are not the same as those who would pay for replacement of a long run of leaking pipe. Thus one budget foots the bill and the other reaps the benefit. In such a situation it may be difficult to get authorization for a repair. There are also instances where the capital funds are simply not available to make a sizable repair, but operating funds are. Political pressure is often much stronger to spend money to keep something running than to spend a considerable sum fixing an underground pipe, which no one sees.

6. Preventing Water Loss

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.

Engineering Design Practice

The following rules of thumb will make leaks more unlikely and easier to locate when they do occur.

- Design for moderate pressures.
- Provide washouts for regular line flushing.
- Specify pipe carefully, taking into account water characteristics, soil conditions, pressures, and operational experience with different materials and classes of pipe used locally.
- Select and specify meters carefully.
- Provide clear standards and specifications on trench depth, bedding materials, cover materials, jointing, backfilling, and testing.
- Include a master meter that measures total water production.
- Include isolation valves to allow continued service when repairing or maintaining storage tanks.
- Install all meters on bypasses to facilitate removal for recalibration, repair, or replacement.
- Use frequent valving to facilitate zone measurements and repairs.
- Include tracer cable for future location of non-metallic piping if records are lost.

Construction Practice

Good construction practice includes careful selection, storage, and installation of piping materials, valves, and fittings; careful construction supervision to assure adherence to pipe installation specifications, especially trench depth, and selection and installation of bedding materials; and careful supervision of pressure testing before accepting the system.

Leakage Control Programs

The best leakage control programs are those that evolve as the experience of the staff increases, as information about leakage grows, and as needs dictate. If a regional operation and maintenance office is beginning to work with communities and nothing is known about the magnitude of loss, then the program should begin modestly. A provisional leakage team should be formed and trained under the supervision of an engineer. These teams would move from system to system investigating water loss, pinpointing and repairing leaks, and training local caretakers to carry out regular leak detection. Audits such as those described in Section 4 should be conducted on several systems, starting with ones where the benefits may be highest. If leakage control is shown to be beneficial, the leakage team should be made permanent and its work expanded.

It is often difficult to convince management to put resources into leak detection. Program proponents must be able to show that the program is cost effective. If the leakage team proceeds steadily, evaluating its results, and changing course when necessary, the program should be successful.

The following actions are necessary for an effective program.

- Regularize water-loss monitoring activities: Carry out "desk" audits, line surveys, listening and pressure tests, and loss measurements annually; maintain good system distribution maps (including updates) and records on pipe breaks, cost of leakage repairs, and savings; set up meter testing, repair, and replacement programs; and use detailed operation and maintenance cost-estimating procedures.
- Set up training programs for operators (basic leak checking), maintenance personnel, and engineers (on good design practice).
- Create incentives for community members (reduced bills, for example), operators or caretakers (salary bonuses), and leakage teams (salary bonuses based on savings realized).
- Involve the community in water conservation: Sensitize users to the need to combat wastage and leakage; provide pamphlets and videos on methods and benefits of water conservation; train and encourage villagers to notice leaks and to alert operators; and initiate education programs in schools about water systems, conservation methods, and benefits.
- If water audits do not clearly show the magnitude and variation in water production, water demand, and water loss, use more detailed measurement programs such as master production metering in selected areas, distribution metering to measure overall demand, and actual surveys at standposts.

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This Technical Note was prepared by Alan Wyatt.