

Detecting Leaks in Water-Distribution Pipes

by *Osama Hunaidi*

This Update gives an overview of techniques and equipment used to detect leaks in water-distribution systems. The information is based on recent research conducted by IRC.

In most water-distribution systems, a large percentage of the water is lost in transit from treatment plants to consumers. The amount of water that is lost or unaccounted for is typically 20-30 percent of production.¹ Some systems, especially older ones, may lose as much as 50 percent. Water loss can be attributed to several causes, including leakage, metering errors, public usage such as fire-fighting and pipe flushing, and theft. Leakage is usually the major cause.

Leakage occurs in different components of the distribution system: transmission pipes, distribution pipes, service connection pipes, joints, valves, and fire hydrants. Causes of leaks include corrosion, material defects, faulty installation, excessive water pressure, water hammer, ground movement due to drought or freezing, and excessive loads and vibration from road traffic.

Leaks waste both money and a precious natural resource, and they create a public health risk. The primary economic loss is the cost of raw water, its treatment, and its transportation. Leakage leads to additional economic loss in the form of damage to the pipe network itself, e.g., erosion of pipe bedding and pipe breaks, and to the foundations of roads and buildings (Figure 1). Risk to public health can be caused by contaminants entering the pipe through leak openings if water pressure in the distribution system is lost.



Figure 1. Leakage leads to damage to the pipe network, e.g., erosion of pipe bedding and pipe breaks, and to foundations of roads and buildings.

Economic constraints, concern over public health risk and the need to conserve water all motivate water system operators to implement leakage-control programs. Systematic leakage-control programs have two main components: water audits and leak-detection surveys. In recent years, significant efforts have been made to develop water audit procedures and leak-detection methods. As a result, water system operators now have several well-established procedures² and modern equipment to help them control water loss.

Water Audits

Water audits determine the amount of water loss in the distribution system. They can be performed on a network-wide basis or district by district. Network-wide audits provide an overall picture of water losses in the distribution system as a whole. These audits require detailed accounting of water flow into and out of the distribution system, usually based on past meter records and flow meter accuracy checks. The comprehensive nature of network-wide audits entails significant effort, especially for large systems.

For district audits, the distribution system is divided into small districts or zones having approximately 20 to 30 km of water main. Districts are isolated individually by turning off the appropriate valves except at control points where portable flow meters are installed to measure water flow over a 24-hour period. To determine if excessive leakage exists, the ratio between the nighttime minimum rate and the average daily rate of water flow is compared to “normal” ratios or to previously measured ratios of the same district. Flow rates from any 24-hour commercial use should be subtracted from the measured flow rates. Alternatively, if all service connections in the water system are metered, more accurate information about leakage can be obtained by monitoring water flow and usage in the isolated district over an extended time period.

Areas of excessive leakage in a district can be bracketed by “step testing.” This is done by subdividing the district itself and then measuring flow rates while turning off valves to cut off different subdivisions in succession. A significantly lower flow rate indicates excessive leakage in the last subdivision that is shut off.

District audits are labour-intensive and costly, since they are performed at night. A trend that has emerged in recent years is to install permanent flow meters that are connected telemetrically to a SCADA system. The transmitted flow rate data are automatically analyzed to detect unusual increases in flow patterns. Based on experience with the water system, it can

then be determined whether an increase in flow rate is due to new leaks.

District audits and step testing help identify areas of the distribution system that have excessive leakage. However, they do not provide the information needed by repair crews on the exact location of leaks; that requires leak-detection surveys.

Leak-Detection Surveys

In areas that have been identified as having excessive leakage, leaks are commonly pinpointed using acoustic devices. These devices detect the sound or vibration induced by water leaking from pressurized pipes. Leak sounds are transmitted through the pipe itself over significant distances (depending on pipe size and type), and through the surrounding soil in the immediate area of the leak.

Initially, leak detection crews roughly bracket leaks in water-distribution systems by listening on all accessible contact points with the distribution system such as fire hydrants and valves. Suspected leaks are then pinpointed by listening on the ground surface directly above the pipe at very close intervals (about 1 m). Alternatively, suspected leaks can be pinpointed automatically by using modern leak noise correlators, which have become popular in recent years. Normally, leak noise correlators are more efficient and more accurate than listening devices.

Leaks could also be detected using several non-acoustic techniques such as tracer gas, infrared imaging, and ground-penetrating radar. The use of these techniques for this purpose, however, is still very limited and their effectiveness is not as well established as that of acoustic methods.

Detection Equipment and Techniques

Listening Devices

These devices include listening rods, aquaphones, and geophones or ground microphones (Figure 2), and may be either mechanical or electronic. They use sensitive mechanisms or materials such as piezoelectric elements to sense leak-induced sound or vibration. Modern electronic devices have signal amplifiers and noise filters to



Figure 2. Typical listening devices include listening rods (left) and ground microphones (right). Photos courtesy of Palmer Environmental Ltd.

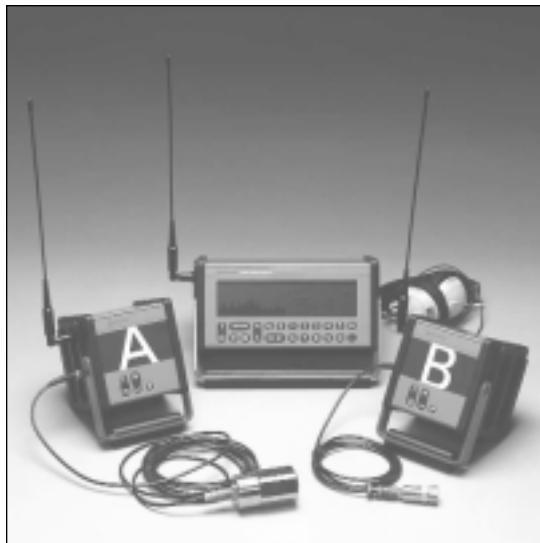


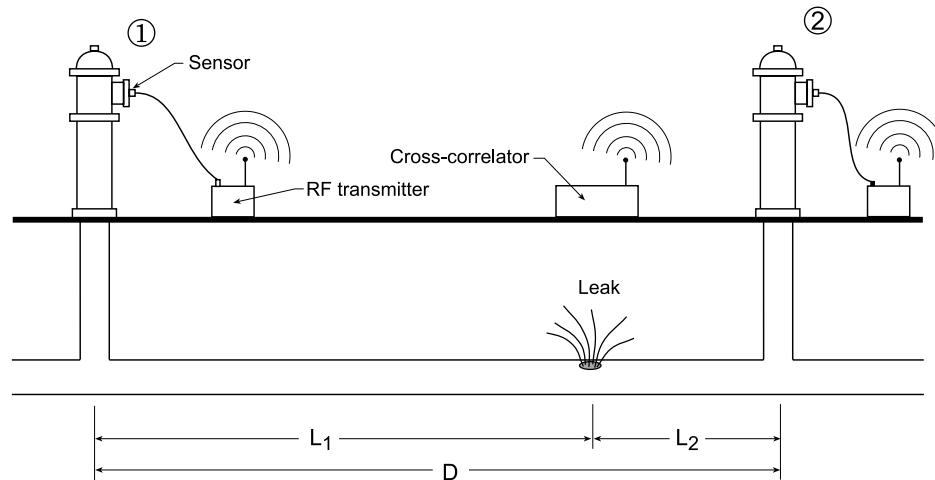
Figure 3. A leak noise correlator is a portable microprocessor-based device that pinpoints leaks automatically.

Courtesy Dantec Measurement Technology.

make the leak signal stand out. The operation of listening devices is usually straightforward, but their effectiveness depends on the experience of the user.

Leak Noise Correlators

These are portable microprocessor-based devices that pinpoint leaks automatically based on the cross-correlation method (Figure 3). In this method, acoustic leak signals are measured with vibration sensors or hydrophones at two pipe contact points (usually fire hydrants or valves) that bracket the location of a suspected leak. Leak signals are transmitted from the sensors to the correlator wirelessly. The leak is in most cases located asymmetrically between measurement points and consequently there is a time lag between the measured leak signals. The time lag is found from the cross-correlation function of the leak signals. In the presence of a leak, the cross-correlation function has a distinct peak at the time shift between leak signals. The location of the leak is calculated based on



Arrival time of signal ① = $T_1 = L_1 / V$, where V is sound propagation velocity in pipe
 Arrival time of signal ② = $T_2 = L_2 / V$
 Time lag between signals ① and ② = $\Delta T = T_2 - T_1 = (L_2 - L_1) / V$
 $L_2 = D - L_1 \rightarrow \Delta T = (D - 2L_1) / V \rightarrow L_1 = (D - V\Delta T) / 2$

Figure 4. Schematic illustration of the cross-correlation method for pinpointing leaks in water pipes

an algebraic relationship between the time lag, the sensor-to-sensor distance, and the propagation velocity of sound waves in the pipe (Figure 4). The distance between sensors is measured on site or read from distribution system maps. Propagation velocities for various pipe types and sizes are usually available in most commercial devices, or they can be measured easily on site.

Tracer Gas Technique

With this technique, a non-toxic, water-insoluble and lighter-than-air gas, such as helium or hydrogen, is injected into an isolated segment of a water pipe. The gas escapes at a leak opening and then, being lighter than air, permeates to the surface through the soil and pavement. The leak is located by scanning the ground surface directly above the pipe with a highly sensitive gas detector.

Thermography

The principle behind the use of thermography for leak detection is that water leaking from an underground pipe changes the thermal characteristics of the adjacent soil, for example, making it a more effective heat sink than the surrounding dry soil.

The resulting thermal anomalies above pipes are detected with handheld, or vehicle- or airplane-mounted infrared cameras.

Ground-penetrating Radar

Radar can be used to locate leaks in buried water pipes either by detecting voids in the soil created by leaking water as it circulates near the pipe, or by detecting segments of pipe which appear deeper than they are because of the increase in the dielectric constant of adjacent soil saturated by leaking water. Ground-penetrating radar waves are partially reflected back to the ground surface when they encounter an anomaly in dielectric properties, for example, a void or pipe. An image of the size and shape of the object is formed by radar time-traces obtained by scanning the ground surface. The time lag between transmitted and reflected radar waves determines the depth of the reflecting object.

Factors Influencing the Effectiveness of Acoustic Methods

The effectiveness of acoustic leak-detection methods depends on several factors including pipe size, type, and depth; soil type and water table level; leak type and size; system pressure; interfering noise; and sensitivity and frequency range of the equipment.

The pipe material and diameter have a significant effect on the attenuation of leak signals in the pipe. For example, leak signals travel farthest in metal pipes and are attenuated greatly in plastic ones. The larger the diameter of the pipe the greater the attenuation, and the harder it is to detect the leak. The pipe material and diameter also affect the predominant frequencies of leak signals — the larger the diameter and the less rigid the pipe material, the lower the predominant frequencies. This effect makes leak signals susceptible to interference from low-frequency vibrations, e.g., from pumps and road traffic.

The strength of leak signals at the ground surface is influenced significantly by the soil type and the water table level. Experience has shown that leak sounds are more audible on sandy soils than on clayey ones, and on an asphalt or concrete surface than on grass. Leak signals are “muffled” if the pipe is below the water table level.

The characteristics of leak sounds vary with the leak type and size. Splits and corrosion pits in pipe walls induce stronger leak signals and higher frequencies than leaks in joints or valves. Generally, the larger the leak the stronger the leak signal, but this may not be true for very large leaks. The higher the pipe pressure, the stronger the leak signals; it is difficult to detect leaks in pipes having pressures less than 1.05 kgf/cm² (15 psi).

There is significant variation in the sensitivity, frequency range, and signal-conditioning and processing features of different acoustic leak-detection devices. The more sensitive the leak sensors and the higher the signal-to-noise ratio of the equipment, the smaller the leaks that can be detected. Modern acoustic equipment incorporates signal-conditioning components such as filters and amplifiers to make leak signals stand out. Filters remove interfering noise occurring outside the predominant frequency range of leak signals. Amplifiers improve the signal-to-noise ratio and make weak leak signals audible.

Difficulties with Plastic Pipes

Most professional users consider acoustic methods to be effective for finding leaks in metal pipes but problematic when used for plastic pipes. Acoustic leak-detection equipment was developed mainly for metal pipes. Leak signals in plastic and metal pipes, however, have substantially different acoustical characteristics. Plastic pipes are “quieter” and do not transmit sound as efficiently as metal pipes. Also, leak sounds in plastic pipes are dominated by low-frequency components, unlike leak sounds in metal pipes.

A recent study³ by IRC funded by the American Water Works Association Research Foundation showed that leaks in plastic pipes can be located using acoustic techniques; however, there are several difficulties with these techniques. Leak noise correlators operated in automatic mode rarely succeeded in locating leaks, because the frequency range selected by the correlator was usually too high. Operators using the correlators in manual mode also tended to select a high frequency range and therefore missed leaks. It was also found that accelerometers (a type of vibration sensor) were effective only for large leaks. For small leaks, hydrophones were necessary.

It was also found that leak-detection professionals were not able to hear leak sounds in plastic pipes using headphones attached to leak noise correlators. According to popular wisdom, if no noise is heard then no leak exists. The professionals were therefore surprised when they succeeded in locating leaks that they could not hear. Leak signals in plastic pipes were found to be dominated by frequency components lower than 50 Hz. The human ear is not sensitive to sounds in this low frequency range. For the same reason, listening rods and aquaphones were not effective unless they were attached at access points that were very close to leaks (within about 5 m). In practice, these results imply that detecting leaks in plastic pipes may have to rely solely on leak noise correlators.

High-resolution surveys using ground microphones at intervals of, say, 1 m or less can still be used but these surveys are time-consuming and therefore impractical.

The IRC study revealed several modifications that can improve the effectiveness of leak noise correlators in locating leaks in plastic pipes: revision of automatic mode algorithms, higher sensitivity sensors (especially accelerometers), low-frequency capability, and finely tunable high- and low-pass filters. Several changes to practice in the field can also improve the equipment's effectiveness: use of low-frequency components of leak signals, on-site measurement of sound propagation velocity in pipes, verification of the proper functioning of leak sensors (especially hydrophones), and use of hydrophones or sensitive vibration accelerometers attached to pressurized fire hydrants.

Summary

Leakage is usually the major cause of water loss in water-distribution systems. To minimize public health risk and economic loss and to conserve water, utilities regularly audit their distribution systems and conduct leak-detection surveys. Water audits provide an overall view of water losses and identify areas of the distribution system having excessive leakage. Leak-detection surveys determine the exact location of leaks by using acoustic listening devices and modern leak noise correlators. Acoustic equipment is effective for metal pipes but could be problematic for plastic. Modifications were recommended in IRC's leak detection study to improve the effectiveness of leak noise correlators as well as field procedures for plastic pipe. Leaks in both metal and plastic pipes could also be located with non-acoustic techniques such as tracer gas, infrared imaging, and ground-penetrating radar. The use of these techniques is still very limited and their effectiveness is not as well established as that of acoustic methods.

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