Water Leakage Control and Sonic Detection

G. Wayne Hennigar[1]

Abstract:
Public health officials, environmentalists, municipal engineers and the general public are now convinced that the abundance of pure fresh water in North America is becoming scarce. Problems of supply, pollution, contamination and waste water are only a few of the complexities faced by present day water managers. An emphasis must therefore be placed on conservation and the reduction of "unaccounted-for" water. The greatest economic loss to the water utility industry normally occurs in the distribution system. Even today surveys indicate unaccounted-for figures as high as 50 percent in some water distribution systems in North America.

This paper underscores the urgent need to conserve our potable water resources by the reduction of waste water through effective leakage control programs. A brief history of instrumentation associated with the sonic principal of leak detection is reviewed. The factors contributing to waste water, the distribution network, as well as the factors affecting sonic leak detection, are discussed. The paper addresses both the advantages and disadvantages of sonic leak detectors and how electronic technology has overcome some of the disadvantages. Various types of leakage control programs applicable to a variety of system requirements are outlined.

Résumé:
Les fonctionnaires de la santé publique, les spéclialistes de l'environnement, les ingénieurs municipaux et de nombreux citoyens sont maintenant convaincus que les abondantes réserves d'eau douce en Amérique du Nord commencent à diminuer. Les problèmes d'approvisionnement, de pollution et de contamination ne sont que quelques-uns de ceux auxquels doivent actuellement faire face nos gestionnaires. Il faut donc insister sur la réduction des pertes inutiles de ce précieux liquide, que ce soit à la maison ou dans l'industrie. Les plus grandes pertes au point de vue économique se produisent normalement dans le processus de distribution. De nos jours encore, des études révèlent que les pertes considérées comme plus ou moins normales comptent pour environ 50 % dans certains réseaux de distribution en Amérique du Nord.

Cet article souligne le besoin pressant de contrôler nos réserves d'eau potable en réduisant le volume de pertes inutiles, grâce à des programmes efficaces. Un bref historique de l'instrumentation associé au principe de détection des fuites par vibration est ici présenté. On aborde ensuite divers facteurs relatifs aux eaux usées, aux réseaux de distribution, ainsi que divers aspects de la détection des fuites. L'article présente les avantages et les désavantages des détecteurs de fuites par vibration et montre de quelle façon l'électronique en a corrigé les désavantages. On décrit plusieurs types de programmes de contôle des fuites qui peuvent être appliqués avec succès aux réseaux d'aqueduc.

Introduction

Problems of supply, pollution, contamination and waste water are only a few of the complexities faced by present day water managers. Water is perhaps our most valuable natural resource in terms of life, health and general well-being. To economically preserve and conserve this resource is becoming increasingly difficult in the shadow of rising cost. Water has long been recognized as a prime resource in the development of industry and in the growth of our nation. If we care for the growing need of the population we must be objective in conserving our present supplies and developing new sources. Costs of the latter are often prohibitive, if not impossible, in many areas.

[1] Vice President and General Manager, Heath Consultants Limited, London, Ontario.

The Importance of Leakage Control Programs

An emphasis must therefore be placed on conservation and the reduction of "unaccounted-for" water. For definition purposes, unaccounted-for water is that differential between what is put into the system and what is measured coming out of the system. There are a number of factors contributing to unaccounted-for water and the most important of these are as follows:

1. Meter error
2. Main cleaning
3. Plant operation
4. Fire protection
5. Authorized unmetered usage
6. Unauthorized unmetered usage (theft)
7. Lag time in meter reading
8. Leakage

The greatest economic loss to the water utility industry normally occurs in the distribution system. Even today, surveys indicate unaccounted-for figures as high as 50 percent in some water distribution systems in North America. For guideline purposes the American Water Works Association indicates that unaccounted for percentages between 10 percent and 15 percent are acceptable. This complacent acceptance of 10 percent to 15 percent in North America may have to change. European nations, faced with the same situation long ago, took steps to remedy it. By using sonic instruments and developing leak detection methods supported by prompt repair programs, they have reduced waste water well below North American acceptance levels. An unaccounted-for figure of 5 percent is considered high in Europe today. In comparison to other allied utilities our standards for waste water in North America are somewhat lax. Natural gas distributors normally experience unaccounted-for gas figures in the range of one-tenth of one percent to about two percent. Based on these attainable levels the water works industry may have to significantly improve its standards and performance.

Not only should water system management strive to prevent depletion of our most valuable natural resource, but also to increase efficiency of conservation efforts which can result in limited operational expenses. By reducing unaccounted-for water in a distribution system, we can often defer, or even eliminate, plant expansion expenditures. Water managers should give serious consideration to water leakage control programs when unaccounted-for figures exceed 10 percent of treated water.

Any overall unaccounted-for water control program must take all the contributing factors into consideration. However, this paper is largely concerned with leakage.

In addition to the economic factors discussed previously there are other reasons which should encourage water leakage control programs. These should be considered in terms of their necessity, their economics and their intrinsic value to the water distributor.

1. Water saved on both the system side and the customer side of the meter aids in conservation. Saving in lost revenues by locating and repairing leaks on the system side is obvious. However,leakage control on the customer side would indicate lost revenue to the water utility system. The prime objective of a water utility is to provide optimum service to the community at the lowest cost. Locating leaks on the customer side is the right thing to do, and, in the long run, saves money for all rate payers.
2. A continuous up-to-date report can be maintained on system condition for scheduled replacement and repair programs as well as for budget purposes. The water superintendent literally can keep ahead of problems caused by leakage. This greatly reduces the burden and responsibility of system operation as the water superintendent can plan both daily operations and longer term maintenance programs more effectively. Also, a thorough knowledge of system condition can greatly assist the municipality in refuting unsubstantiated damage claims and law suits.
3. A tight system results in fewer or smaller capacity pumps and a lower fuel charge to move water. Also, the costs associated with purification and treatment can be kept to a minimum. This can be coupled to lower maintenance costs on pumping and treatment equipment with longer life of such equipment a natural result. It is normal practice to develop the most economic sources of water supply first. When these are exhausted, the more expensive sources are utilized. Thus, by maintaining a tight system, we can limit wasteful use of the more economic sources and avoid the need to tap new and expensive supply sources.
4. A well co-ordinated leak control program

will result in savings associated with overtime costs by being able to direct a maintenance and repair program during regular working hours. By finding and repairing existing leaks less call-out time during bad weather or frost conditions can be achieved. Large municipal systems can support leak survey crews whose full time job is investigating and locating leaks using sonic water leak detectors. These crews become very adept at using the equipment as they are not involved in other activities. This experience leads to pinpointing efficiency resulting in a reduction of the number of costly dry holes. Also, such crews can quickly determine if the leak is on customer piping which nullifies the need to call out repair crews.

5. Improved underground safety and prevention of property damage are natural benefits derived from water leakage control programs. As these are intrinsic benefits it is difficult to credit them with a monetary value. By locating leaks in their early stages, cave-ins, wash outs, slides and flooding can be reduced which means less litigation and disruption to other underground utilities. Flooding, caused by surfacing water in sub-freezing temperatures, creates dangerous icing conditions on streets and highways. Numerous traffic accidents have resulted in northern climates due to loss of vehicle control on flooded streets. Considerable damage to automobiles and injuries to drivers have occurred because of washouts under street surfaces also caused by leaking or broken water mains.
6. A water leakage control program can be the vehicle to foster better public relations with customers and the community as a whole. Such a program can form the base for water conservation within the community as it does show homeowners that something is being done to conserve water resources. By setting an example, water system employees encourage customers to make water conservation a way of life. Water leakage detection programs can be co-ordinated with the municipalities' streets department. Any upgrading and resurfacing of city streets can be preceded by a water leak detection and repair program. Nothing is more annoying to residents than having a newly surfaced street excavated by the municipal water department.

Because this paper is concerned not just with leakage control but also with detection of leakage by the use of selective sonics, it is appropriate to review the priniciple of sonic water leak detection and the various types of instruments available.

Principles and Instrumentation of Sonic Leak Detection

In defense of sonic leak detection, we should first refer to the European situation. European countries had their water systems under control from a leakage standpoint well before the problem became of paramount concern in North America. The Europeans had developed instruments and procedures for leak detection and were actively conducting leak detection surveys as a maintenance program before we got started. Most of the instruments used were amplified sonic type devices and the results are evident.

In North America, several instruments such as the Globe Geophone, the Metrotech 200L and others were developed mainly to assist in pinpointing known or suspected leak locations. These worked fairly well for this application but were slow and cumbersome for leak search activities. In recent years, more emphasis has been placed on leak search activities, and, consequently, a wide range of instrumentation has been developed. Prior to a discussion of sonic water leak detection, a review of the development of instrumentation and methodology is appropriate. However, an analysis and understanding of water leak frequency characteristics should first be outlined.

Instruments and procedures developed over the years were keyed to the fact that water leaks create vibrations or frequencies on the pipe wall as the water escapes through the leak orifice. These vibrations tend to travel laterally along the pipe wall and concentrate or amplify at hydrants, main line valves, service connections and other connections where greater mass is present. Metallic type pipes such as cast and ductile iron are much better conductors than plastic and asbestos cement type pipes. Therefore, greater sensitivities and closer test intervals are required during leak search programs on non-metallic systems. Vibrations from the leak source also radiate through the soil in a concentric pattern. These sounds or vibrations can be detected at the surface directly over the leak by the use of special ground microphone attachments available with most instruments. The type of soil greatly influences the frequency strength being transmitted to the surface. Sand is normally a good conductor of sound whereas organic soil and clay tend to be poor conductors.

Another factor influencing leak vibration or sound transmission detection at the surface is the type of surface itself. Asphalt and concrete surfaces act as sounding boards, thus providing good resonation and a uniform surface for microphone contact. Sod, including soil, gravel and grass cover, tends to insulate and muffle leak frequencies making leak pinpointing activities difficult for inexperienced operators. The size (volume loss) and shape of the leak orifice will influence the frequency and intensity or amplification of the sounds emitted. A corrosion pit on a high pressure steel main will often create a high level of sound in the upper frequency ranges. Conversely, a broken plastic pipe with a much larger orifice will often create a low level of sound in the lower frequency ranges. Background noise is a problem in some areas, and, if of a greater volume and in the same frequency range as water leaks, may limit sonic leak detection to specific periods. Leak survey activities on mains adjacent to busy highways and city streets may have to be scheduled to night shifts when traffic flow is at a minimum.

When discussing vibrations, frequencies and sound we are actually referring to the same parameter, namely, the sonic characteristic of a leak. It is necessary to be specific as to the sonic characteristics, and define the frequency ranges for the majority of water leaks. Each leak will normally emit three frequency ranges or sounds. The first sound, referred to as the "vibration sound", is created as the high pressure water escapes through the leak orifice thus causing a vibration on the pipe wall. Depending on the factors outlined above, this sound is normally in the frequency range of 500 to 800 cycles per second. This sound is often referred to as the search sound as it tends to travel laterally along the pipe wall, and can be heard some distance from the leak by direct contact listening on a hydrant, valve or other direct contact point. By direct contact listening for this frequency range on the system, sections of potential leakage can be readily identified.

The second sound is often referred to as the "impact sound" and is so created as the high pressure water from the leak orifice strikes or impacts with the soil around the pipe. This sound is normally in a lower frequency range of about 50 to 250 cycles per second. A third sound, best described as the "fountain sound", is water circulating in water at the leak source and is in the some frequency range as the impact sound. This sound is particularly evident at main line breaks or at large volume loss leaks where water filled cavities are created in the soil at the leak location. Both the impact sound and the fountain sound are normally restricted to the immediate area of the leak and are considered as the pinpointing sounds.

The human ear was the first sonic water leak detector. By placing an ear on a pressurized water pipe, early day water system operators were able to hear and identify nearby water leaks on the system. The same basic principle applied to the railway industry. Approaching trains could be heard long before they came into sight by listening on the rails. These early operators were innovative and soon learned to use hickory or listening sticks. The sound of leakage on the mains was transferred through this solid medium directly to the ear, and allowed direct contact to a valve stem through a valve box. Weighted diaphrams came into existence during the early 1900's. Various types, such as early telephone receivers and the Globe Geophone, were employed and are still in wide use today. These weighted diaphrams were often coupled to the ear by a tube, and, with practice, were effective and accurate for pinpointing water leaks, particularly under hard surface cover.

During this early period new procedures coupled with new instrumentation developed. Several organizations offered surveys to determine flow patterns throughout the distribution systems, and isolated those sections with abnormally high flows for follow-up leakage detection. Leakage detection in these high flow sections was normally accomplished by using a variety of acoustic type listening devices.

Old style instruments are still commonly used in present operations and operate on either mechanical or electronic modes. These are basically sound intensifying or amplification instruments which permit the operator to hear leak sound otherwise unattainable to the human ear. Both the Aquaphone and Geophone are still in wide use and are strictly mechanical devices. The Aquaphone is similar in appearance to the old style telephone receiver with a metal spike protruding several inches on the cord end. This spike makes a direct contact with the pipe and transfers pipe vibrations into the earphone where they are intensified to the audible level. The geophone resembles two hockey pucks connected to a doctor's stethoscope by clear plastic listening tubes. The hockey puck like geophones actually contain diaphrams which are sensitive to leak vibrations. By placing the two geophones over the leak area a stereo effect is obtained which permits the operator to determine the direction to the leak sound. These rugged and low maintenance mechanical devices have been in wide use for a number of years.

As technology advanced, electro-acoustical water leak detectors were developed. These instruments consisted of a receiver or amplifier coupled to a microphone with the output signal from the amplifier transferred to head phones worn by the operator. Many of the earlier types operated on a wide band frequency range of 20 to 4000 cycles per second. These had the disadvantage of picking up many extraneous sounds which were often confused with water leaks by inexperienced operators. Advancements in the electronics field soon led to amplifiers equipped-with electronic filtering capabilities to allow only those frequencies within the water leak band to be outputted to the meter and head phones. The filters eliminate unwanted frequencies and background noise caused by traffic and other sources. The microamp meter on the amplifier assists the operator to visually compare sound intensity levels at the various contact points. Several good quality instruments are available and are field proven. These are normally portable instruments operating on standard DC batteries, and provide advantages of portability, low cost and rapid system coverage combined with accurate results. The accuracy of sonic leak detection instruments and techniques has been well documented by water utility operators over the years.

Portable electronic instruments with electrical sound amplification are now commonly used. These are available with or without frequency filtering capabilities. In addition to leak sound amplification and measurement, new instruments have advanced state of the art features to assist in leak location. The new Metrotech HL2000, for example, has incorporated an LED display that is used in conjunction with a solid state memory for storage of up to eight leak sound intensity measurements. The LED readout is also used to display a frequency analysis of the leak sounds at any location. This portable instrument has a frequency selection filter that can be tuned such that only the predominant leak sound frequency is amplified and all other frequencies generally attenuated to aid in pinpointing and locating leaks in areas with noisy ambient conditions. These instruments are normally portable and easily carried by an operator.

Sonic water leak detection with portable electronic instruments is probably the least expensive method currently available as an effective and practical tool for predicting leak location and size. Although there are other leak detection methods in use which may be more accurate, they may often be prohibitively expensive. In this category is Leak Sound Correlation, a relatively new arrival in the sonic water leak detection field.

Leak Sound Correlation

Leak sound correlation is a computer-based detection system applying computer sonic detection technology to pinpoint and evaluate difficult leaks in pipeline networks. Correlation instruments provide a practical and reliable system to detect and locate leaks in pipeline networks based upon the "Cross Correlation" technique. This new method gives the exact position of leaks while showing complete insensitivity to other noises and multipath transmission of sound through the ground. By simply placing two accelerometers, one on each side of the leak sound, the Correlator will determine the exact location of the leak or leaks. Although expensive, leak sound correlators can save labour and time while pinpointing difficult leaks and can reduce the need for night shift work. For large water distribution systems, leak sound correlators, used in conjunction with an effective water leak detection program, can pinpoint leaks in noisy background areas as well as leaks previously uneconomical to pinpoint.

Leak sound correlators operate differently from other types of sonic water leak detectors. They do not attempt to determine the position of maximum sound intensity as do other types of sonic water leak detectors. Correlators measure the difference in time taken for the leak noise to travel to two hydrophones or transducers placed on hydrants or valves on either side of the leak location. Depending upon the instrument used, and the type of distribution system being checked, transducers can be placed as much as 800 meters apart. The signals from the transducers are fed to pre-amplifiers and from the pre-amplifiers to the Correlator. Units are available with cable drums containing cable connections between the pre-amplifier and the Correlator.

Stringing cables, particularly in heavy traffic areas, can be cumbersome and slow. Several units are available with radio-links between the pre-amplifier and the Correlator. Although adding considerable capital cost to a correlation system, the use of radio-links eliminates the problems of stringing cables thus reducing field time and operating costs.

The difference in time for the leak noise to travel to the two transducers coupled with the velocity of sound and the distance between the transducers enables the instrument to compute the position of the leak. As with all types of sonic water leak detectors the type of system influences the effectiveness of the correlator. Metallic pipes such as steel, cast and ductile iron followed by asbestos cement are relatively good conductors and are effective for methods of cross correlation leak detection. Plastic type systems are least effective, and the distance between the transducers must be greatly reduced. As mentioned earlier, background sounds such as compressors, pumps and traffic noises in the distribution system will not affect correlators.

The advantage of correlators lies in the fact that they can operate with high background noise levels and can discriminate between leak sounds and other ambient frequencies. They can quickly and accurately determine actual leak locations thus reducing the number of dry holes. Due to their amplification, they are effective on low-level leak sounds and will normally indicate if two leaks are present at a given set-up. The disadvantages are associated with their high capital cost and the need for technical training to be an effective operator. For leak search activities, they are somewhat slower than using conventional portable sonic leak detectors.

Implementing a Sonic Leakage Detection Program

Once a municipality has decided to embark upon a sonic water leakage detection program several decisions have to be made. First, the type of instrumentation as well as the type of inspection program should be established. Objectives for the program as well as a budget should be set down and full involvement encouraged from all levels of management. The program can be flexible, general, intensive or optional depending on the utilities' perceived requirements. A general sonic water leak detection program may take the following procedure based on comprehensive coverage of the system.

1. A starting point on the system is established, normally either at a pump house or reservoir.
2. The system is then sectioned into smaller working units using specific boundaries such as streams, railroad tracks, and main arteries. Progress of the inspection is recorded on a master system map which becomes a leakage progression map with each leak plotted on acetate layovers, color coded by year and shaped according to classification for ready follow-up repairs.
3. With the starting point determined, the technician begins inspection, carrying specialized sonic instruments, equipment and reports for making notes and conducting selected tests where necessary. A systematic "listening" procedure is used. The technician "listens" for sound on all direct contact points such as fire hydrants, main line gate valves, open piping on bridges, and when necessary, sillcocks on houses and water curb-valves. The technician uses the ground microphone and listens directly over the main at intervals of six to ten feet, paying special attention to cover service taps. With this method, comprehensive coverage of the system is attained and all leak sounds are investigated and pinpointed immediately.
4. Where direct ground microphoning over the main is not practical,such as where the main is under sod, care is taken to establish apattern of direct listening points to insure complete coverage of the system with specialized equipment used for pinpointing theleaks.
5. In addition to a comprehensive coverage, the program should be flexible enough to provide optional coverage as required. At times a rapid hydrant and valve search inspection may be required to locate a sudden major loss or suspected break. This is often referred to as a "Quick Search Inspection" and is required to alleviate a critical condition. As in the comprehensive coverage the leak indication should be pinpointed, classified and recorded.

One of the major objectives of any inspection program is to provide repair crews with the actual leak location. This results in economical, effective and rapid excavation for repair of the leak. It is not always possible, even with present technology, to pinpoint 100 percent of the leaks detected so that repairs can be made through the initial excavation. Every effort should be made to attain a very high level of efficiency in this area to fully realize the dollar savings possible as a result of accurate pinpointing of the leak source. Accurate pinpointing from the surface is not only possible but an accomplished fact with experienced staff and good sonic instruments.

Once leakage is detected in an area, it is important that the location of all mains and services be established. This information can be obtained from maps or cards, or through the use of a pipe locator. An intensified pattern of sonic tests is then made directly over mains and services. Proper interpretation of the results of these tests enables leak inspectors to accurately determine the source of leakage. Many variable factors must be considered and properly evaluated when pinpointing leaks. Past experience, training and knowledge of system construction play a major role in an inspectors pinpointing success.

Each leak should be classified according to size and hazard. Often the extent of leakage indication will provide a clue as to the potential hazard that such a leak could cause. Surfacing leaks often resemble an iceberg in size because they are most often large below the surface in spread. Of specific concern are underground wash-outs and encroachment upon other utilities as well as damage to the water line itself. These lead to damage claims and insurance expenses. Often leaks from services or mains are first detected by seepage into basements or conduits which creates customer relations problems and can be detrimental to the public image. Thus inspectors must be very careful in their analysis of conditions and make the most accurate classification possible. Leaks classified as Type 1 are leaks which are hazardous or those leaking a significant amount of water to warrant immediate repair. Type II leaks are losing a sufficient amount to be placed in a repair schedule. Type III leaks are small and can be repaired as crew time permits. Follow-up maintenance and repairs can then be concentrated on the urgent conditions.

At one time in the history of North America the Passenger Pigeon and the Plains Buffalo were an abundant and inexhaustible resource. Until recently, the supply of pure fresh water in North America was considered in the same light. Indications are surfacing that our supply of potable water may be limited, so let us not repeat the mistakes of our past. Water conservation now is critical to ensure a healthy heritage for future generations. Sonic water leak detection is a valid and effective means of water conservation. Leakage control programs, practiced and promoted by utilities, will encourage individuals to make individual efforts to conserve water. Our commitment to sound water management practices today will dictate our life style in the future.