ZCorr: Multi-Sensor Overnight Leak Survey and Pinpointing In One Step

The ZCorr system is a new, systematic approach to pipeline surveying. ZCorr digital correlating loggers offer significant advantages over listening loggers by detecting and pinpointing multiple leaks in a zone overnight. ZCorr's technical advances make efficient leak surveying viable for water utilities.

The ZCorr Concept

ZCorr is a software-driven approach that allows a distribution system leak survey to be efficiently directed from the office, integrating leak detection data, maps, and database tools to:

1. Plan the survey and print deployment orders
2. Pinpoint leaks and print repair reports
3. Track survey progress and performance

The ZCorr survey has 3 steps: DEPLOY, RETRIEVE and ANALYZE. Each step can be performed either in the office or in the field.

1. Deploy

Eight ZCorr loggers are held in a compact *Docking Station*, which is connected to a PC. The docking station communicates with the ZCorr loggers electronically, without cables.

The PC software user:

- Sets the synchronized recording times (by default, 3 AM, 3:30 AM, and 4 AM)
- Places the loggers on a map image
- Optionally prints a deployment work order

The ZCorr loggers are then deployed in the field in readiness for the nighttime recording.

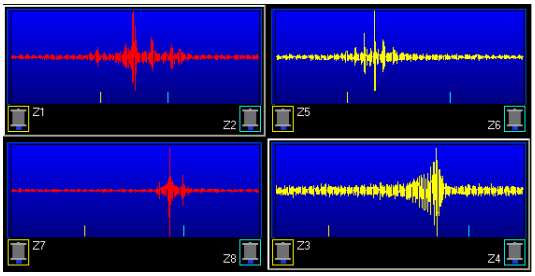
Deployment is typically in underground valve chambers, on fire hydrants, or other pipe fittings.

2. Retrieve

During the night the synchronized ZCorr loggers record at the user-programmed times. Recorded vibration samples are saved in memory. The loggers then enter low-power mode until they are reconnected with the docking station.

3. Analyze

The recorded data is downloaded from the ZCorr loggers, via the docking station, using the PC software. Eight loggers produce 28 distinct pairs for correlation analysis. ZCorr analysis finds all significant leak noise correlations automatically. Results are ranked by *Correlation Score* (0 – 100), scored by the determination of leakage versus usage, correlation signal quality, and the smallest estimated error in pinpointed location of any leak(s).



How ZCorr Loggers Work

The ZCorr system has several patented[1] innovations, described in the next sections, in the areas of synchronization (timing), data recording, processing, and PC software analysis.

[1] U.S. Patent #: 6,567,006

Real-Time Clock

At the heart of the ZCorr logger is an ultra low-power, temperature-compensated Real-Time Clock (RTC). The RTC is used to synchronize ZCorr loggers via the docking station. Over an 18-hour period, between deployment and retrieval for an overnight recording, an ordinary wrist watch would drift in time by up to 50 parts per million (ppm), i.e. about 3 seconds. In a correlation analysis this could lead to errors of 10,000 feet or more in the pinpointed location of a leak. Using a combination of ultra-low power electronic and software techniques, timing drifts are reduced by a factor of 2,500 times. The patented method of timing compensation restricts errors in leak location to typically less than 3 feet.

Recording

The ZCorr logger is fitted with a low-noise piezo-ceramic acceleration sensor, known as an accelerometer. Accelerometers sense vibration and convert it to a tiny electrical charge. Sensitive conditioning electronics amplify and filter this electrical response. As with audio and other amplifiers, the accuracy, precision, and intrinsic noise level of the amplifier is more important to the recording quality than the gain or volume level, *per se*. In an accelerometer, intrinsic noise is often defined by *resolution* and gain is referred to as *sensitivity*. The ZCorr sensor has a sensitivity of 1V/*g* at a resolution of 0.025 μ*g* / √Hz. Additional electronic gain gives a pre-digitizing sensitivity of 200 V/*g*.

The earth's gravitational field is defined as having a constant acceleration of 1 *g*. In contrast, leak signals are sensed from pipes as a varying pattern of acceleration as small as micro*g*'s, i.e. millionths of *g*'s. These are imperceptible levels of vibration to humans and require very low-noise, precise electronic amplification and filtering to preserve the leak signal. In addition, in a correlating logger the sensor is positioned very close to the logger's electronics. Most real-time correlators can advantageously separate the sensor and recording electronics by a long cable. To overcome this potential interference problem, the ZCorr logger uses a custom-designed discrete amplifier and filter circuit, integrated very closely with the sensor.

Digitizing of the analog signal is performed with a 23-bit ADC. Most acoustic loggers use between 8 and 12 bits, allowing a digitizing resolution of between 1 part in 256 and 4096. Vibration signals on pipes have a useful dynamic range of up to 80 dB, i.e. one part in 10,000. A 23-bit ADC, with a resolution of 1 part in over 500,000, is therefore adequate and necessary to preserve the fine detail of pipe vibrations and the leak signal.

Data Processing

After digitizing, the pipe vibration signal is encoded and saved in low-power memory. The ZCorr data processor is programmed to employ special encoding techniques in different situations. For example, different pipe materials (plastic, cement or metal), large-diameter pipes, and long distances between loggers (with the presumption of very small leak signals), are all situations where the encoding is set to enhance the anticipated leak acoustic signature.

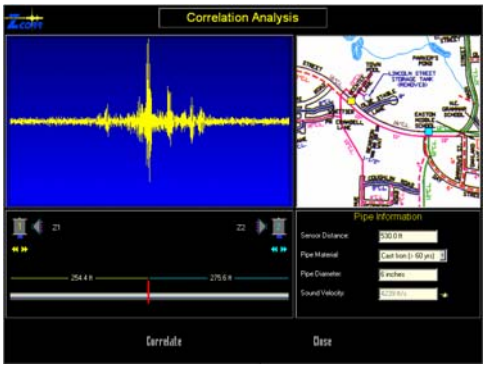
Data Downloading

Data is downloaded to a PC via the ZCorr docking station. A waterproof connector facilitates a high-speed data link between the logger, docking station, and PC. This is the final link in the chain of high resolution recording, processing, and data transfer for correlation analysis.

ZCorr Data Analysis

ALFA Optimal Correlation

Flow Metrix has developed an advanced leak noise correlation method called *ALFA*, or Automatic Leak Frequency Analysis.
ALFA works by identifying a leak acoustic signature in 2-logger recordings. The leak sound may be very different between the 2 loggers, both in sound level and frequency pattern, and is often not audible or otherwise discernible to a human user. The ALFA process identifies the acoustic signature of the leak sound at each logger and designs an optimal correlation filter that is unique for that 2-logger recording. The ALFA filter concentrates on the leak sounds and ignores other vibrations, for example those due to normal flow, transient usage, and environmental sounds such as traffic.

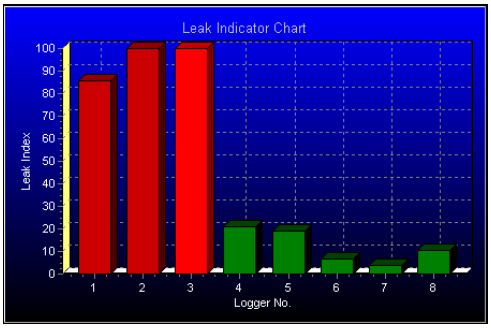


ALFA is particularly useful with large-diameter pipes, multiple leaks, and noisy environments. The graphic above shows a ZCorr correlation result with 6 correlation peaks, identifying 6 leaks in and outside a 530-foot recording span.

Another benefit of ALFA is enhanced productivity. Recordings in a zone with one or more leaks may readily produce a total of 28 correlations, one for every possible pair of loggers. ALFA produces 28 optimal correlations, each ranked by Correlation Score, without the need for time-consuming experimentation with manual filter settings.

Enhanced Listening Analysis

Unlike listening loggers, which only store statistics, ZCorr stores actual CD quality recorded nighttime sound.



A *Leak Index* (a 0 – 100 ranking) for each logger shows the sound levels present at the quietest time of the night. Each logger is represented by a bar (red = abnormal leak index; green = normal). The listening and sound analysis provide additional capabilities that can supplement the correlation information.

Data Management

The ZCorr PC software includes:

1. Electronic maps converted from the utility's Geographic Information System (GIS) and integrated into the ZCorr user interface
2. An integrated Data Manager that:
   - Stores an unlimited number of ZCorr recordings in a database
   - Provides typical database functions, such as searching and sorting
   - Can export recording information and results to other database and GIS software programs

Financial Benefits of a Leak Survey Program

The following Financial Benefit Analysis is typical for a small town (population 20,000 – 50,000) or a network region. The example distribution system has:

- 100 miles of mains pipe
- 10,000 service connections
- Daily production of 4 million gallons
- Unaccounted for water of 15%

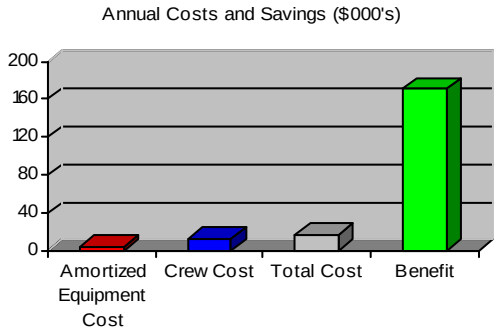
Using the Flow Metrix *Water Loss Calculator* software program[2], approximately half of the unaccounted for water is likely to be recoverable leakage (the remainder is due to meter error and un-metered or unauthorized usage). Recoverable leakage is expected to be 312,000 gallons per day, with 4 mains leaks at 30 gallons per minute (gpm) and 15 service line leaks at 6.5 gpm.

Eight ZCorr loggers deployed overnight at spacings of 1,000 feet will survey an estimated 2 ½ miles of pipe. This pipe mileage includes lateral mains and services that convey leak sounds to the loggers. The operational expense is calculated for one leak detection crew for 3 hours, at a total cost of $100 per hour. The entire distribution system is surveyed in 44 nights. The value of lost water is taken to be $1.50 per thousand gallons.

The chart below shows a benefit of over $170,000 per year, with a total cost of $17,700, i.e. an annual crew cost of $13,200 plus the ZCorr equipment cost amortized over 5 years ($4,500). The operational expense outweighs the capital expense, despite the fact that ZCorr is significantly more productive than other leak detection methods. The financial benefit of recovered leakage pays for the entire leak

[2] www.flowmetrix.com

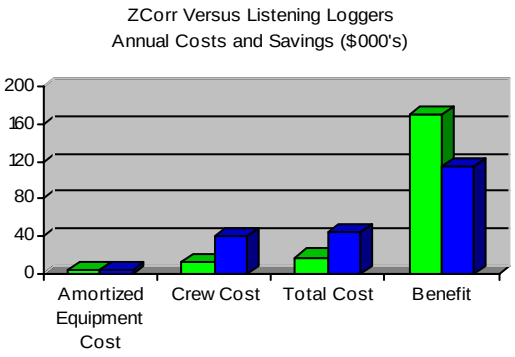
detection program and generates a considerable surplus to invest in other operations and maintenance activities.



Productivity Comparison: ZCorr Versus Other Logger Technologies

Correlating loggers such as ZCorr offer significant advantages over listening loggers:

1. A single overnight correlation study of 3 recordings almost completely eliminates any false positive detection of leak noise.
2. A listening logger can only register leak noise that is close to or louder than background vibration levels. In contrast, the ZCorr correlation process is capable of detecting and pinpointing leak noise that is inaudible and over a hundred times quieter than background noise.
3. The ZCorr correlation process simultaneously detects and pinpoints multiple leaks between any 2 loggers.



The bar graph above compares the capital and operational expense of ZCorr (green bars) and listening logger (blue bars) survey programs. The following assumptions were made:

1. The listening loggers are used for 3 nights at each location
2. Three times as many listening loggers are needed at 1/3 the cost of ZCorr loggers
3. Listening loggers lead to recovery of two thirds of leakage, using real-time correlation to investigate true (30%) and false (70%) positive detections.
4. Listening loggers miss one third of recoverable leakage; typically very quiet long-running service line leaks.

The correlative domain is more sensitive and more specific for leak noise. This advantage translates into finding more leakage with less operational effort and less equipment cost. The table below shows a comparison of ZCorr correlating loggers and simple listening loggers:

Parameter	*ZCorr*	*Listening Logger*	*Comments*
Inter-logger spacing	800 – 1,500 feet	Up to 500 feet	ZCorr loggers have wider coverage
Duration of deployment	Overnight	1 – 7 nights	ZCorr loggers work overnight
False positive rate of leak detection	Less than 5%	67 – 90%	Listening loggers cannot distinguish leakage from continuous usage
Sensitivity to leak noise	Very high	Moderate	Correlation detects & pinpoints inaudible leak sounds
Operational effort	About 20 minutes per logger	20 minutes per logger + leak verification + leak pinpointing effort	It is time-consuming to rule out leakage when the majority of indications are false positives

Summary

The ZCorr correlating logger system is operationally viable for most water utilities with over 2,000 service connections. It has superior performance and is cost-effective compared to other leak survey methods.