

# From Easy to Elusive:

## The Journey of Leakage Detection and Active Leakage Control (ALC)

*A practical perspective on why leakage becomes harder to find,  
why experience and technology are essential,  
and how to achieve sustainable water savings.*



The objective is not simply to find more leaks.  
The objective is to keep the network under control.

## Abstract

Active Leakage Control (ALC) is often judged by the number of leaks found, the length of network surveyed, or the immediate volume of water recovered. These measures are useful, but they can create an unrealistic expectation that leak-finding productivity should remain constant throughout a leakage reduction program. Successful ALC changes the population of leaks that remains. Leaks that are noisier or otherwise more readily detectable tend to be identified and removed first, leaving fewer and often more difficult targets. Detectability is not simply a function of leak size: a large leak may generate a weak acoustic signal depending on pipe material, pressure, leak path and ground conditions.

This paper uses the fishbowl analogy, together with the practical progression of leakage detection, to explain why mature ALC must move from broad activity-led searching toward information-led control. District metering, pressure and flow analysis, continuous monitoring, experienced interpretation, and appropriately selected technology become increasingly important as the readily detectable leak population is reduced.

The objective is not to sustain a high leak count. The objective is to reduce physical losses and keep the network under control. A declining leak-finding rate should not, however, be accepted as evidence of success on its own. It indicates progress only where verified leakage trends, normalized operating conditions, repair quality and surveillance coverage confirm that the network remains under control.

**The easier leaks are removed first. Success changes the problem.**

## 1 Introduction

Leakage reduction programs change as they succeed. Initial surveys may produce rapid results because a relatively large population of readily detectable leaks is present. Those early finding rates should not automatically become the permanent benchmark for a mature program.

Performance should instead be judged by whether physical losses are reducing or remaining controlled, whether new leakage is identified quickly, and whether intervention remains justified by the value of the water saved. The practical challenge therefore changes from finding many leaks to maintaining control of a progressively smaller and more difficult residual population.

Throughout this paper, a network is described as under control when physical losses remain within an established operational and economically justified range, when abnormal increases are detected promptly, and when significant new leakage is localized, located, pinpointed and repaired within defined response periods. Control does not imply the elimination of all leakage, which is neither technically achievable nor economically justified.

## 2 The Blind Man and the Fishbowl: A Metaphor for Leakage Detection

The fishbowl model provides a simple visual explanation of how the probability of finding a target changes as the target population falls. Early in the process, many fish are available and almost any scoop can succeed. Later, the same unguided action becomes progressively less productive. The final targets require better information, greater precision, and more experience.

### The Blind Man and the Fish Bowl: A Metaphor for Leakage Detection

|                                                                                   |                                                                                   |                                                                                   |                                                                                      |                                                                                                   |
|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| <b>1 Easy to Find</b><br>Many fish near the surface.<br>Anyone can scoop them.    | <b>2 Getting Harder</b><br>Fewer fish, moving deeper.<br>Needs more effort.       | <b>3 Quite Difficult</b><br>Very few fish.<br>Hard to locate.                     | <b>4 Extremely Hard</b><br>One or two fish left.<br>Almost impossible without skill. | <b>5 Needs an Expert</b><br>Only an expert with experience and technology can find the last fish. |
|  |  |  |    |                |
| Like finding visual leaks – obvious and easy.                                     | Like non-visual leaks – not obvious, harder to find.                              | Like small/background leaks – require experience.                                 | Like hidden leaks – need advanced tools.                                             | Like technology and expertise finding the last leaks.                                             |

As targets become fewer, random searching gives way to informed and precise searching.

**The fish have not disappeared; they are simply harder to find. The same is true with leaks.**

#### 2.1 Stage 1: Many targets, the easy wins

When leakage levels are high, there may be a large population of readily detectable leaks. Strong leak noise and clear indications of leakage mean that routine sounding, and basic leak detection techniques can produce a high finding rate.

#### 2.2 Stage 2: Fewer obvious targets

As the more readily detectable leaks are removed, the finding rate begins to fall. Systematic survey becomes increasingly important, supported by reliable network information with pressure and flow data to help identify where leakage is most likely to remain.

#### 2.3 Stage 3: A different residual population

As the readily detectable leaks are removed, the remaining population becomes progressively more difficult to find. Leak signals may be weaker or more difficult to distinguish because of pipe material, pressure, background noise, and other network operating conditions.

#### 2.4 Stage 4: Repetition gives diminishing returns

As the leak population reduces, repeated surveys will continue to find leaks, but the finding rate from each pass should generally be expected to fall. Surveying more kilometers can therefore find additional leaks, but it is not simply a matter of increasing survey coverage. As the remaining leaks become fewer and more difficult to detect, results depend increasingly on where the survey is directed, the information used to target it, and the experience and techniques applied.

#### 2.5 Stage 5: Expertise and technology become increasingly important

As the remaining leaks become more difficult to find, greater use of network data, monitoring, experienced personnel, and appropriately selected technologies are required. Field activity becomes increasingly targeted, with information used to identify where investigation should be concentrated and specialist techniques used where conventional methods are no longer sufficient.

### 3 The Leakage Detection Journey: from Obvious to Hidden

As leakage is progressively reduced, the characteristics of the remaining leak population change. The challenge is no longer simply to survey the network and find readily detectable leaks. Increasingly, the process requires the utility to identify where abnormal leakage occurs and then progress through three stages.

#### 3.1 The Life of a Leak: Weep, Leak, Burst, Catastrophic Failure

A leak is not a fixed condition. Hamilton and Charalambous (2013) described the “Life of a Leak” as a four-stage progression through Weep, Leak, Burst and Catastrophic Failure. These stages are a conceptual aid to understanding how detectability changes over time rather than a formal classification, and in practice they overlap. The sequence is simple; the timing is not. A defect may remain at one stage for months or years, or it may move through the stages very quickly. In some cases, the progression from a small defect to catastrophic failure can be almost instantaneous.

- Weep: the earliest stage, where an exceedingly small amount of water escapes through a developing defect. The acoustic signal may be weak, inconsistent or below the practical detection threshold.
- Leak: the defect has developed into a more established loss of water. An acoustic signal is more likely to be present, although its detectability still depends on pressure, pipe material, leak path, ground conditions, and background noise.
- Burst: the defect has enlarged and the discharge is more substantial. The leak will often create a stronger indication, but it may still remain non-visible depending on the surrounding ground and network conditions.
- Catastrophic Failure: a complete rupture of the pipeline. The event is normally obvious or disruptive and requires immediate operational response.

This progression is important to leakage detection because acoustic noise is partly a reflection of where the defect is in its life at the time of the survey. A leak that is difficult or impossible to hear today may become detectable later as the defect develops. Equally, a leak may progress rapidly between survey cycles. This is another reason a single survey cannot be treated as proof that an area is leak free.

The Life of the Leak therefore complements the fishbowl analogy. The fishbowl describes how the remaining population becomes harder to find as the easier targets are removed. The Life of the Leak explains why the detectability of an individual leak can also change over time. Together, they reinforce the need for continuous monitoring, repeat investigation, and the appropriate escalation of experience and technology.

The practical task is then to move from evidence that abnormal leakage exists to the precise point where excavation should take place.

This progression can be described as Localizing, Locating and Pinpointing (LLP). The LLP approach was introduced by Hamilton (2009) as a structured progression for active leak detection and was subsequently recognized in the wider academic literature by El-Zahab and Zayed (2019):

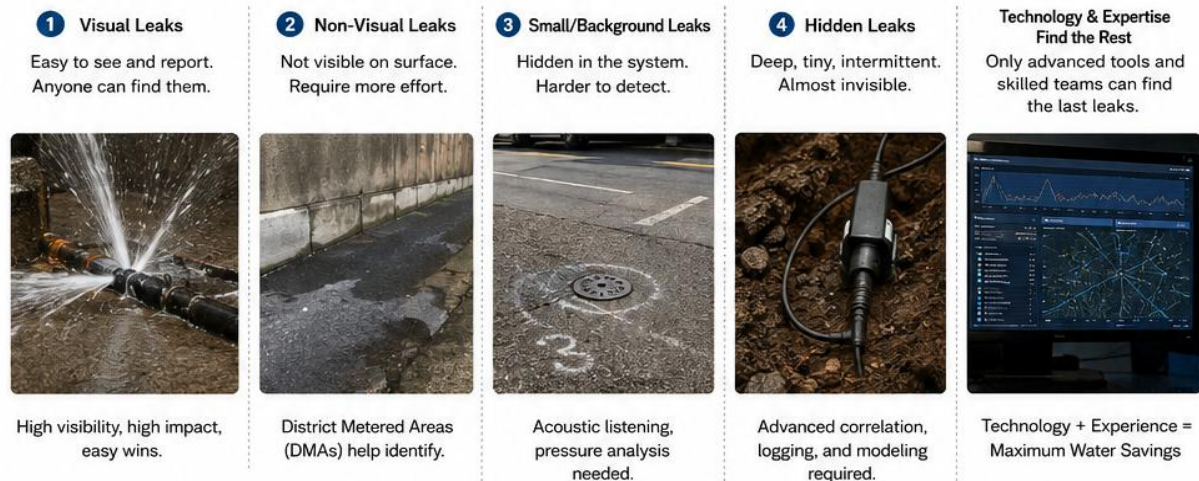
- Localizing identifies the part of the network where abnormal leakage is most likely to be occurring.
- Locating progressively narrows the investigation to the likely position of the leak.
- Pinpointing establishes the precise position for excavation and repair.

As leakage levels reduce, this progression becomes increasingly important. Field teams should not simply search in larger areas hoping to find increasingly difficult leaks. Network information,

monitoring, and analysis should progressively reduce the area of investigation before detailed leak detection and pinpointing are undertaken.

These concepts describe different but complementary aspects of leakage management. The Life of a Leak describes how an individual defect can develop over time. LLP describes the progressive process used to identify where leakage exists and establish its precise position. The Fishbowl analogy describes how the overall population available to be found changes as successful ALC progressively removes the more readily detectable leaks. Together, they provide a practical framework for understanding why leakage detection becomes more demanding as a network moves toward lower levels of physical loss.

#### Leakage Detection Journey: From Obvious to Hidden



*The methods required therefore evolve as the remaining leaks become more difficult to find.*

As the readily detectable leaks are removed, the utility increasingly depends on network information, flow and pressure data, established baselines and changes in network behavior to determine where leakage is most likely to occur. This information supports the LLP process (Hamilton, 2009; El-Zahab and Zayed, 2019) by progressively focusing field investigation on the areas where it is most likely to be productive. This is why mature ALC is as much an analytical and management function as a field survey activity.

## 4 Why Leak Counts Alone Become a Poor KPI

A leak count measures the number of leaks found or repaired, but it does not necessarily measure the volume of water saved. One large trunk main leak can represent more recoverable water than dozens of small service leaks. Equally, a team maintaining a repeatedly surveyed, well-controlled DMA should not be judged against a team entering a high leakage area for the first time.

| KPI / measure                                                                                                       | Why it matters                                        | How to interpret it in mature ALC                                                                                                       |
|---------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| Physical loss volume and estimated water saved (m <sup>3</sup> /day, m <sup>3</sup> /month or m <sup>3</sup> /year) | Measures the outcome that ALC is intended to deliver. | The primary test is whether physical losses are being reduced or being held at the required level, not whether leak counts remain high. |

| KPI / measure                                                                  | Why it matters                                                    | How to interpret it in mature ALC                                                                                                             |
|--------------------------------------------------------------------------------|-------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Leak run time and repair response time                                         | Shows how long identified leakage is allowed to continue.         | Shorter run times protect savings and become increasingly important when the remaining leak population is small.                              |
| Trends in DMA, operational area, and system leakage                            | Shows whether an area remains under control between surveys.      | A stable or falling trend may be a stronger sign of success than a high monthly leak finding total.                                           |
| Pressure and supply conditions                                                 | Operating conditions influence leak flow and detectability.       | Interpret leakage performance alongside pressure and hours of supply so that changes are not attributed to ALC alone.                         |
| Repeat failures and repair quality                                             | Poor repairs can recreate losses and increase future workload.    | A mature program should reduce repeat interventions and protect the benefit of each repair.                                                   |
| Survey coverage and the proportion of the network under active leakage control | Confirms that the utility is maintaining systematic surveillance. | Coverage remains important, but repeated coverage should be increasingly targeted by evidence rather than judged only by kilometers surveyed. |
| Cost per unit of water saved, where appropriate                                | Links technical effort to the value of the outcome.               | As leakage falls, higher investigation effort may still be justified where the value of saved water remains high.                             |

**Good leakage management is not about producing a high number of leak tickets. It is about reducing losses and keeping them down.**

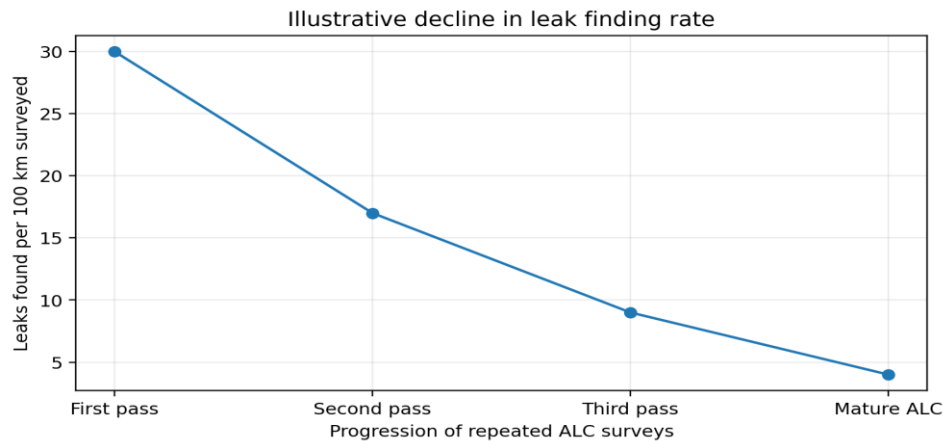
As the readily detectable leak population is reduced, finding rates should be interpreted alongside physical loss, survey coverage and the effort required to locate each additional leak.

## 5 The Changing Productivity Curve: From Easy Wins to Elusive Leaks

The decline in leak-finding rate can be illustrated by considering repeated surveys of the same network. The figures below are schematic and are included only to show the direction of travel. They are not utility data and should not be read as a productivity benchmark. The illustration assumes that surveyed length remains constant while the readily detectable leak population is progressively removed. Effort per leak is shown as an indicative trend only: actual effort depends on labor hours, analysis and technology inputs, which do not remain constant between survey passes.

| Survey cycle | Network surveyed (km) | Leaks found | Leaks per 100 km | Relative effort per leak |
|--------------|-----------------------|-------------|------------------|--------------------------|
| First pass   | 500                   | 150         | 30               | 1.0                      |
| Second pass  | 500                   | 85          | 17               | 1.8                      |

| Survey cycle | Network surveyed (km) | Leaks found | Leaks per 100 km | Relative effort per leak |
|--------------|-----------------------|-------------|------------------|--------------------------|
| Third pass   | 500                   | 45          | 9                | 3.3                      |
| Mature ALC   | 500                   | 20          | 4                | 7.5                      |



The numbers are not intended as a universal productivity curve. Actual results depend on network condition, pressure, pipe material, survey frequency, repair quality, and the rate at which new leaks occur. The principle is that a constant survey effort can produce a lower leak count as the residual population is reduced. At the same time, the investigation effort required for each additional leak may increase.

This is why mature ALC should not be managed against the first pass finding rate. A falling strike rate can be entirely consistent with successful leakage reduction when physical losses are also falling or being maintained at the required level.

**Leak-finding rates surveyed per kilometer or per team should generally be expected to fall as the readily detectable leak population is reduced. This can be a sign of success rather than failure, but only where verified leakage trends, operating conditions, repair quality and survey coverage confirm that the network remains under control. Otherwise, a falling rate may instead indicate poor targeting, inadequate survey quality or declining operational performance.**

## 6 ALC Maturity and the Changing Detection Requirement

| Network condition                   | Typical situation                            | LLP requirement                                                                                     | Main approach                            | People and technology                                           |
|-------------------------------------|----------------------------------------------|-----------------------------------------------------------------------------------------------------|------------------------------------------|-----------------------------------------------------------------|
| High leakage / initial intervention | Large population of readily detectable leaks | Localization remains valuable from the outset, although broad survey may find many leaks without it | Broad systematic survey and rapid repair | Trained field teams using established leak detection techniques |

| Network condition    | Typical situation                              | LLP requirement                                                              | Main approach                                                     | People and technology                                            |
|----------------------|------------------------------------------------|------------------------------------------------------------------------------|-------------------------------------------------------------------|------------------------------------------------------------------|
| Improving            | Readily detectable leak population reducing    | Greater localization and targeting before detailed investigation             | DMA analysis, flow and pressure information and systematic survey | Experienced technicians supported by appropriate instrumentation |
| Controlled           | Fewer leaks and lower finding rates            | Stronger LLP process required to focus field activity                        | Monitoring, targeted investigation and selective escalation       | Experienced personnel using a combination of techniques          |
| Low residual leakage | Remaining leaks increasingly difficult to find | Information-led localization followed by specialist locating and pinpointing | Continuous monitoring and targeted intervention                   | Expert interpretation and appropriately selected technologies    |

## 7 Experience Becomes Critical

Technology provides data, but experience turns data into decisions. Experienced leakage personnel can distinguish between genuine leak indications and other sources of noise, recognize when changes in flow may be caused by demand rather than leakage, challenge a suspected leak location, and determine when a different investigation technique is required. These judgments become increasingly important as the readily detectable leak population is reduced.

A tiered approach is therefore appropriate. Routine teams can undertake systematic field investigation and pinpointing, experienced personnel can investigate more difficult cases, and senior specialists can be used selectively where conventional approaches have repeatedly failed or where additional interpretation is required. The level of expertise applied should increase as the difficulty of localizing, locating and pinpointing the remaining leakage increases.

## 8 Technology as an Escalation Tool

Technology does not replace good leakage detection fundamentals or experienced personnel. It supports them. The appropriate technology should be selected according to what the utility is trying to achieve within the Localizing, Locating and Pinpointing process. Selection will also depend on pipe material, pressure, supply conditions, background noise, access, and the quality of available network information. No single technology is appropriate for every network or every leak.

The boundaries between Localizing, Locating and Pinpointing are not absolute. Some technologies can contribute at more than one stage. The important principle is that technology should be selected according to the investigation requirement and network conditions, rather than expecting a single technology to provide the complete solution.

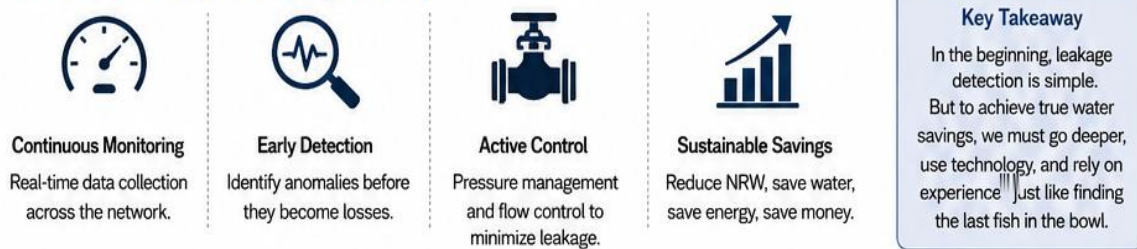
| LLP stage   | Purpose                                                                                     | Examples of methods and technology                                                                                                                       |
|-------------|---------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| Localizing  | Identify the area of the network where abnormal leakage is likely to exist                  | DMA flow analysis, pressure and flow monitoring, minimum night flow analysis, permanent monitoring, remote sensing, and other broad screening techniques |
| Locating    | Progressively reduce the area of investigation and identify the likely position of the leak | Systematic sounding, noise logging, step testing, correlation, and targeted acoustic investigation                                                       |
| Pinpointing | Establish the precise leak position before excavation                                       | Electronic listening, ground microphones, correlation where appropriate, tracer gas, and other specialist techniques selected for the network conditions |

**Technology gives the utility better information. Experience determines where to look, which technique to use and what the evidence means.**

## 9 Active Leakage Control is a Continuous Cycle

ALC is not a one-time leak-finding project. It is a continuous management cycle: establish the baseline, monitor, identify change, prioritize, localize, locate, pinpoint, repair, verify the saving and return the area to monitoring. Without this continuous cycle, new leaks will occur and leakage levels will begin to rise again.

### The Role of ALC (Active Leakage Control)



*Mature ALC combines monitoring, early detection, intervention, and verification.*

Pressure management and network calming are also important because they can influence both leakage flow and the rate at which new leaks occur. Reducing unnecessary pressure fluctuations and hydraulic stress can help reduce new failures and protect the benefits achieved through leak detection and repair. Network calming refers to operating the network in a way that minimizes unnecessary pressure fluctuations and hydraulic shocks.

## 10 Intermittent Supply Creates an Additional Challenge

In intermittently supplied networks, the opportunity for leak detection may be limited to the periods when the network is pressurized. Pressure can change rapidly and customer demand can make leakage more difficult to distinguish from legitimate consumption. Leakage discharge is also limited to the period during which pressure is present. Extending supply hours without first reducing the leak population can therefore significantly increase the volume of water lost from existing leaks.

**Every leak repaired before supply hours increase is one less leak that will remain continuously pressurized.**

## 11 Implications for Utilities, Managers and Funding Agencies

- Do not use first-pass leak-finding rates as the permanent benchmark for mature ALC.
- Measure outcomes in water and network performance, not only the number of leaks located.
- Expect leak-finding rates to reduce as the readily detectable leak population is removed.
- Increase the level of experience, information, and appropriately selected technology as the remaining leaks become more difficult to find.
- Use DMA, flow, pressure, and other network information to localize leakage and direct field investigation to where it is most likely to be productive.
- Protect early savings through repair quality, pressure management, network calming, and continuous monitoring.
- Recognize that sustaining low leakage is a permanent operational function rather than a temporary project.

## 12 ALC Progression: From Recovery to Maintenance

| Phase            | Dominant objective                            | Expected finding rate | Management response                                                               |
|------------------|-----------------------------------------------|-----------------------|-----------------------------------------------------------------------------------|
| Initial recovery | Reduce the readily detectable leak population | High                  | Survey broadly and repair quickly                                                 |
| Stabilization    | Continuing reducing the leak population       | Reducing              | Improve targeting, LLP and quality assurance                                      |
| Optimization     | Find increasingly difficult leaks             | Lower                 | Increase the use of information, experience and appropriately selected technology |
| Maintenance      | Identify and repair new leakage quickly       | Variable              | Monitor continuously and intervene rapidly                                        |

**The mature question is not "How many leaks did we find this month?" but "Is the network remaining under control?"**

## 13 Conclusion

The fishbowl analogy provides a simple explanation of a practical ALC reality: success changes the problem. Early intervention removes many of the readily detectable leaks. The residual population is smaller, more variable, and often more difficult to localize, locate and pinpoint. The Fishbowl analogy extends this established leakage-management thinking by considering not only the

development and location of individual leaks, but how the detectability of the remaining leak population changes as an ALC program succeeds.

Effective ALC must therefore evolve from broad systematic survey toward targeted, information led control. Network monitoring, the LLP process, experienced personnel, appropriate technology, pressure management, network calming, and repair quality have all become increasingly important in protecting the reductions already achieved.

A declining leak-finding rate is not, in itself, evidence of declining performance. Success should be judged by whether physical losses remain controlled and whether new leakage is identified and repaired quickly.

**The objective is not to keep finding large numbers of leaks. The objective is to create a network in which there are fewer leaks to find and to find new ones quickly when they occur.**

## References

Hamilton, S. (2009). ALC in Low Pressure Areas – It Can Be Done. Proceedings of the 5th IWA Water Loss Reduction Specialist Conference, Cape Town, South Africa, pp. 131–137.

Hamilton, S. and Charalambous, B. (2013). Leak Detection: Technology and Implementation. IWA Publishing, London. ISBN: 9781780404714. <https://doi.org/10.2166/9781780404714>

El-Zahab, S. and Zayed, T. (2019). Leak detection in water distribution networks: an introductory overview. Smart Water, 4, Article 5. <https://doi.org/10.1186/s40713-019-0017-x>

Hamilton, S., Charalambous, B. and Wyeth, G. (2021). Improving Water Supply Networks. IWA Publishing, London. ISBN: 9781780409191.

Hamilton, S. and Charalambous, B. (2020). Leak Detection: Technology and Implementation, 2nd ed. IWA Publishing. ISBN: 9781789060843. <https://doi.org/10.2166/9781789060850>

## Authors and Affiliations

Stuart Hamilton

[shamilton@hydrotec.ltd.uk](mailto:shamilton@hydrotec.ltd.uk)

Raid Al-Zraikat

[rzraikat@engicon.com](mailto:rzraikat@engicon.com)

Naem Saleh

[nsaleh@engicon.com](mailto:nsaleh@engicon.com)

Danial Warq

[dwarq@engicon.com](mailto:dwarq@engicon.com)

## Editor

Layla Al-Zraikat

[lzraikat@engicon.com](mailto:lzraikat@engicon.com)



## Note on the Illustration

The fishbowl illustration is used only as a metaphor to demonstrate how the probability of finding a target changes as the number of available targets reduces, and how better information, targeting, technique, and experience become increasingly important. It is not intended to characterize the capability of people with visual impairments.