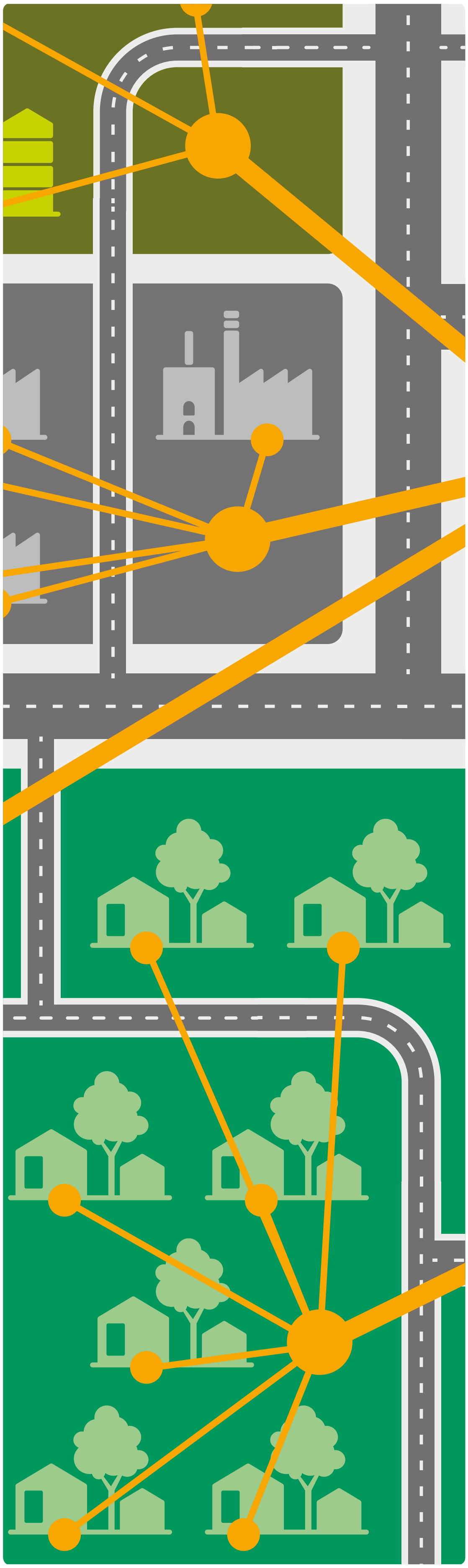
Monitoring pressure in the distribution network

How to safeguard your distribution network and your consumers

Monitoring pressure is the foundation for the utility's proactive efforts to optimise the pressure in the distribution network



Many areas of the world struggle with water shortages, urban centres are growing as a consequence of urbanisation and energy prices continue to rise. The impact of these factors are intensified by the fact that globally, 30-35% of the drinking water that utilities pump to consumers is lost as a consequence of, for instance, leaks caused by excessive operating pressure,and other factors [1].

Distributing water at too high a pressure increases the risk of bursts and leakages. At the same time, energy is wasted unnecessarily, which means it costs more to operate the utility. Conversely, if the pressure is too low at the point of supply, the consumers' expectations for the supply quality are not met. It will also lead to an increased risk of water ingress from the surrounding environment, which can result in pollution of the drinking water. Therefore, it is important that the utility optimises the distribution of water, so that the optimal pressure is present at all times, regardless of how many consumers need water.

For the utility, introducing continuous monitoring of the pressure in the distribution network is the basis for being able to optimise it. Among other things, pressure management is a concrete, effective and recognised way of reducing water loss.

In this white paper, we describe the importance of water pressure as an operating parameter. We then look at the options that pressure monitoring provides for the utility in the work to optimise pressure in the distribution network, and how it can be used as a basis for pressure management. Finally, we look in more detail at the potential for utilities using pressure management as a proactive tool.

The utility can transform knowledge about the pressure into concrete optimisations and financial results.

Monitoring pressure has two overall purposes:

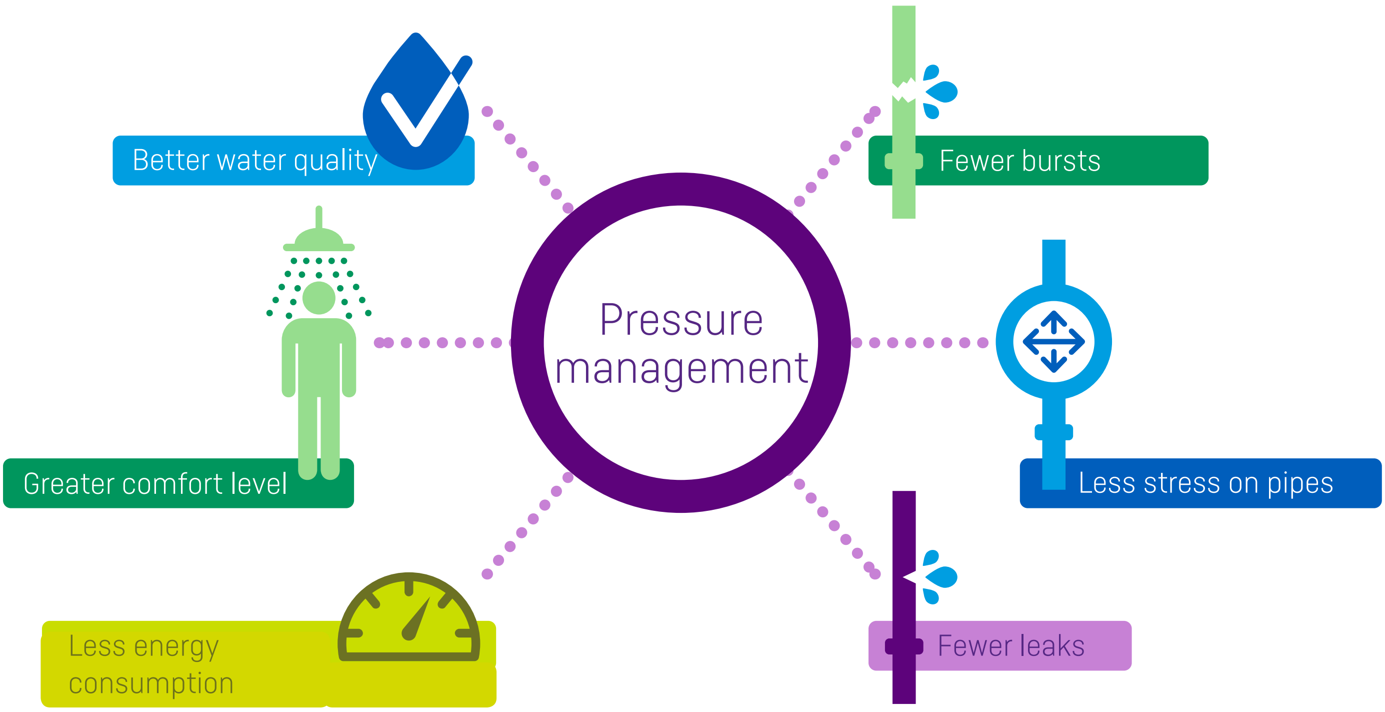
- To assess whether the correct pressure is present at all of the critical points in the distribution network. This allows for the pressure to be adjusted more precisely, thus preventing unnecessary energy costs.
- To map out pressure surges in the distribution network. Pressure surges can lead to bursts, water loss and can shorten the lifetime of the distribution network.

Continuous monitoring of the pressure is a prerequisite for the utility to reduce the water loss through pressure management.

Pressure management can be defined as:

The work to achieve the pressure level in the distribution network which satisfies the needs of the consumers but which does not reach a level where it causes unnecessary bursts and leakages.

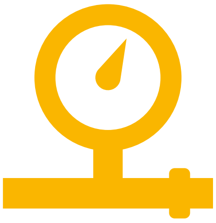
Pressure management is relevant for all utilities because of the results it produces:



* *The pressure-critical points are often the supply points that are located either at the topographically highest points or furthest away from the utility. It can also be points that are pressure sensitive for other reasons.*

What is water pressure and how is it determined?

The pressure in the distribution network is one of the most important operating parameters for a utility.



The utility needs to maintain a sufficient water pressure to ensure that consumers - even at the critical points – feel that there is sufficient water coming from the tap. If the utility maintains a too high pressure, too much energy is used pumping water which leads to a greater water loss. In addition, it stresses pipes unnecessarily, which increases the risk of bursts and leakages.

Utilities often manage the pressure in the distribution network based on a single point – the "Exit from the waterworks", i.e. from the exit side of the pressure booster system that is installed at the waterworks.

In addition, there are often also pressure booster systems in pumping stations throughout the distribution network. These maintain the pressure in the network after the pumping system. However, often the utility does not know the actual water pressure in the critical points of the distribution network – and this is where it matters most to the consumer.

The pressure in the distribution network depends on several factors:

- How big is the distribution network?
- How does consumption change over time?
- What is the area's topography?
- How is the utility's distribution network dimensioned?
- What options does the utility have for supplying an area (waterworks, elevated tanks and similar)?
- What are the customers' requirements?

In London in 1989, a decision in principle was made to distribute water at a pressure of 0.7 bar to protect the existing distribution network, limit the leakage levels and to consider the area's topography. This has resulted in a negative customer experience as people felt they had insufficient access to water.
Plumbers have therefore found a completely new market, where they sell and install pressure boosting systems that increase the pressure in people's private installations and thus ensure they get the comfort level they expect.

(Source: Under pressure, Report by the Health and Public Services Committee into water pressure management in London, March 2005)

What does water pressure mean for the utility?

Ensuring the correct water pressure affects the efficiency, the customer experience and the quality of the drinking water.

The pressure in the distribution network has an effect on:

- **The waterworks' energy consumption for water distribution (OPEX*)**
  The energy consumption of the pumps that maintain the water pressure largely depends on the pressure. For example, a Grundfos Hydro MPC pressure booster with three CR64-5 pumps, uses 60,769 kWh/year at a pressure of 7 bars. If the pressure is reduced by 1 bar, the energy consumption falls to 52,939 kWh/year, which is an energy saving of 13 %[2].

- **Costs associated with the maintenance of the distribution network and repairs of bursts (OPEX*)**
  There is a direct correlation between the pressure level and the total number of bursts. A study has shown that reducing the maximum operational pressure by 38 % leads to a 53 % reduction in the total number of bursts[3].

- **Customer satisfaction**
  If the consumers experience an insufficient water pressure in their homes, they will often contact the utility and expect that something is done to improve this.

- **Lifetime of components in the distribution network (CAPEX**)**
  High pressure stresses the pipes in the distribution network, which means the lifetime of pipes and other components is reduced.

- **The risk of water penetration and pollution**
  When the pressure is too low, water from the surrounding soil will penetrate and pollute the pipeline and lead to increased health risks.

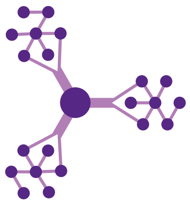
- **Leakage volume**
  When the pressure is increased, so is the water loss because more water is forced out through bursts in the distribution network. The correlation between the leakage volume and the pressure depends on the pipe material. For example, a burst in a plastic pipe will expand at higher pressure, which means the amount of water loss increases exponentially with the pressure, while water loss from iron pipes has a more linear relationship.

A pipe in a waterworks with a round 5 mm hole and 5 bars pressure will result in 11,520 m^3 of annual water loss. If the pressure is reduced by 1 bar, the utility will automatically reduce the annual loss with 11%, equivalent to 1,267 m^3. It is therefore important for the utility to pump at the correct pressure, so that it can reduce the water loss and save energy.

(Source: http://166138.buildyourownpublisher.com/documents/00044.pdf)

***OPEX** stands for 'Operational expenses', which are the ongoing expenses that are necessary to operate a company (e.g. wages, electrical consumption and automatic operation).
****CAPEX** stands for 'Capital expenditure', which is the expenditure used for all of the business' physical activities (e.g.purchase of water meters, new pipelines, improvement or purchase of new waterworks).

What are pressure zones and what is sectioning?



By dividing the distribution network into smaller zones, the utility is able to manage and regulate the pressure in individual zones.

The pressure in the utility's distribution network can vary according to topography and the network's design. And, it can be a complex task to maintain the correct pressure in all areas of the distribution network. In large towns and cities, it is necessary for the utilities to have several supply points in the form of waterworks, pump stations and elevated tanks to maintain the optimal pressure. The network is therefore often divided into pressure zones that reflect a correlation between topography or geography.

A pressure zone is a defined section of the utility's distribution network. The pressure zone is typically defined by the height differences and pumping options available in the section. The connection between different pressure zones is managed by either a pressure booster station or by pressure reduction. This means the utility can manage the pressure in individual zones independently of each other.

Pressure zoning makes it possible to consider the individual zones' topographic location and achieve uniform pressure in the entire supply area.

This means the utility can optimise the pressure for a smaller group of consumers at a time.

In addition to being divided into pressure zones, the distribution network is often also divided into sections. Sectioning makes it possible to carry out a detailed water loss analysis for defined areas of the distribution network. Sectioning is not used as such with pressure management. However, a pressure zone can also be a section or consist of several sections.

In addition, sectioning provides a way of containing any water pollution that occurs, so that it does not affect the whole supply area. In relation to finding leaks, sectioning provides the option for splitting up the work, so that it can be carried out in a gradual but structured way. This is done by targeted leak searches in the sections where the greatest loss is expected, e.g. in the section with the highest pressure.

What is a pressure surge and what effect does it have?

Pressure surges are caused by powerful changes in the pressure and can lead to both bursts and further stress on the pipes.

A pressure surge is also known as a water hammer, and it is caused by a rapid change in water speed in the pipe system. They are seen for example, when a valve closes too quickly or when a pump stops quickly. A pressure surge often occurs in areas with many industrial companies, where water use, for example for process equipment, can vary a great deal. A pressure surge is often accompanied by a sound similar to that of a hammer hitting a pipe.

If the network's structure cannot absorb the energy, the pressure wave will oscillate and stress the pipes. In the worst cases, friction in the pipelines will be the only only thing to absorb the energy from the pressure surge, until the pressure returns to normal.

A pressure surge creates both overpressure and underpressure. Where overpressure stresses the pipes and can lead to bursts, underpressure can cause the pipes to collapse, allowing water to penetrate the pipes and possibly pollute the water. Where a high pressure in general leads to high leakage levels, a pressure surge is the main cause of sudden bursts.

Bursts which are caused by pressure surges lead to greater consequences in the form of water loss, water damage and inconvenience to consumers.

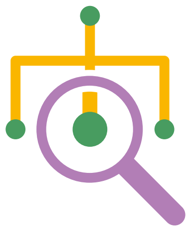
Bamburgh, Northumberland, UK
Private homes and companies were flooded when a sudden increase in water pressure caused a number of burst pipes. In several town properties, residents saw the effect of the increased water pressure when pipes blew out of walls, electrical systems short-circuited and the back of toilets blew out. The problem was cause by faulty equipment that was used while the utility was carrying out infrastructure work.

(Source: https://www.questia.com/newspaper/1G1-220109363/businesses-flooded-as-pipes-burst-pressure-surge)

Pekin, Illinois, USA
When testing a newly installed pumping station, the pressure increased dramatically, which lead to a pressure surge that caused the main water supply pipeline to burst.
At the start of the incident, 20-25 consumers were without water, but that number rose to 2,500 when the utility started repairs and had to switch off the water.
After the repairs were completed and the water supply was restored, water had to be boiled for household use in the supply area until tests showed that the water quality was once again safe.

(Source: http://www.pjstar.com/article/20150811/NEWS/150819870)

What is the optimal pressure?

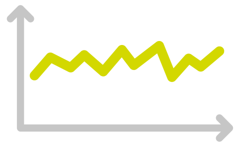


Pressure monitoring enables the utility to manage water pressure proactively rather than reactively.

The majority of utilities have regulations that give them the freedom to regulate the pressure to the level that they think is optimal. Despite the many parameters that affect the pressure, many utilities end up managing the pressure based on personal reports made directly by the consumers. For example, if a consumer calls the utility to complain that the pressure is too high or too low, the utility reacts to that feedback. Often the consumers who call the utility live in a critical location, where the pressure is difficult to predict because of all of the factors that affect it.

As stated earlier, the pressure is often regulated at 'Exit from the waterworks'. This actually means that the waterworks does not have optimal conditions for managing the pressure because reactively rather than proactively. By introducing continuous pressure monitoring in the distribution network, the waterworks will be able to continuously optimise the water pressure in consideration of both consumers and the distribution network.

How is the pressure in the distribution network measured?



By placing the meters out in the distribution network, the utility gains valuable knowledge about the condition of the network.

When measuring the pressure in the network, the utility must take several factors into consideration to ensure it gets useful measurements. The most important thing is where the utility measures the pressure.

If the pressure sensor is located inside the individual household, the utility loses important information. Due to the difference in dimensions between the distribution network and the service connection, pressure surges are significantly reduced meaning that the sensor cannot properly register them. In addition, the pressure and flow changes that occur locally in the household have a tendency to interfere with the measurements and make them unsuitable for managing and regulating the pressure.

It is therefore much more appropriate to perform the measurements directly in the distribution pipes. In certain cases, it is possible to access these via fire hydrants, but often it is best to establish fixed measuring points using measuring wells and tapping saddles.

In order to attain useful results, it is also important to consider the type of pressure sensor that it used. To be able to register rapid pressure surges, which are the cause of many bursts, it is necessary to have a measurement frequency of at least 10 Hz. This means that the sensor must measure the pressure at the sensor site 10 times every second. Only at this frequency can the utility gain a complete picture of the state of the network.

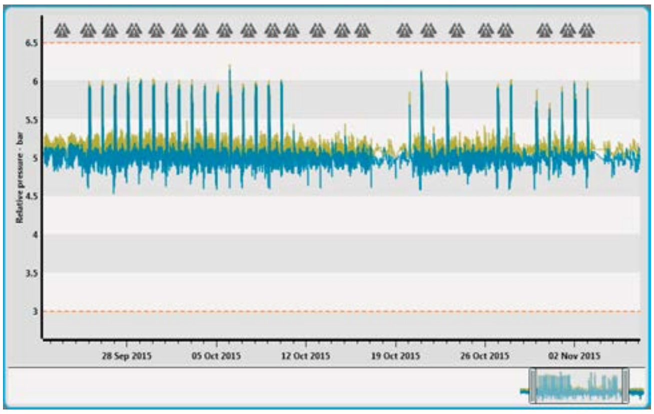
What is the optimum location for the pressure sensor?

The pressure sensor's location can be determined based on an assessment of the critical points, the areas' sensitivity and their burst history.

Pressure critical points

The first factor is the most critical pressure points. In other words, the locations in the distribution network where, due to topography or pipe dimensions, the pressure is either at its highest or lowest. This is not necessarily limited to a location in the distribution network or the given pressure zone, but it is often dependent on the consumption pattern in the zone. For example, an area with holiday homes may be the most critical point during the weekends, where the pressure loss in the pipes is high because of a high flow, while during the week, an industrial area might be the most pressure critical area. The pressure critical points can be calculated using hydraulic models but often, the utility is able to locate them through experience.

Pressure measurements made by the utility Skanderborg Forsyningsvirksomhed A/S.



The areas' sensitivity

Another factor to consider when positioning the pressure sensors is how 'sensitive' the individual areas are. The sensitivity often results from the type of consumers in the area, for example a hospital or industrial customers (e.g. dairies and abattoirs), that require a specific water pressure to be able to carry out the daily cleaning or maintain their production.

Burst history

Finally, the utility often has sections of the distribution network where it sees frequent bursts or pressure related consumer complaints. Installing pressure sensors that can identify and determine the reason for the changing water pressure and any pressure surges that cause bursts can be a good choice. The image shows the pressure measurements made by the utility Skanderborg Forsyningsvirksomhed in a zone supplied by two waterworks and a storage tank where there had been a number of bursts. The pressure measurements showed a series of minor pressure surges and further investigations indicated that they were caused by an automatic closure of the storage tank. The tank was shut down for one hour every night when the night consumption for the zone was measured from one of the waterworks, as it was not possible to install a flow meter on the pipe to the storage tank. It was therefore highly likely that the leaks in the area were provoked by the pressure surges.

Management based on pressure in the distribution network

Knowledge of the pressure in the distribution network enables the utility to find the optimal pressure.

As stated earlier, the pressure in the distribution network is often managed based on a pressure sensor placed on the exit side of the pump or pressure booster system. This is unsuitable as the pressure is kept constant at the pump, but it might not be constant at the critical points or with all of the consumers. This is due to the fact that the pressure present at the consumer depends on the pressure loss in the pipeline leading to the consumer.

The pressure varies with consumption, and this means that the pressure at the consumer's address varies. In some cases, the utility compensates for this by setting the pump pressure in accordance with the highest conceivable flow. This ensures that the consumer has the desired minimum pressure at all times. On the other hand, in periods with a low flow, the pressure will be unsuitably high, which will lead to increased leakages, bursts, energy consumption, etc.

In other cases, pressure variations are compensated for by varying the pump pressure during a 24 hour cycle. This is based on the assumption that the consumption - and thus the flow - follows a specific M-shaped pattern, and that by increasing and decreasing the pump pressure in relation to the historical patterns, the utility can better compensate for flow changes. As a consequence of the lower average pressure, the utility reduces leakages, bursts and energy consumption. However, because of the uncertainty about the historical patterns, the utility must still work with a significantly higher pressure to ensure that all of its consumers are satisfied.

Knowing the pressure in the distribution network and utilising this as a part of the pumping management, the utility can get much closer to the optimal pressure compared to the previous methods.

One option is to let the pumps for the individual pressure zones be controlled directly in accordance with the pressure at the critical points. However, this leads to irregularities: firstly, it requires continuous communication from the pressure sensors and secondly, in terms of regulation, it must take into consideration the long reaction times and the fact that the regulation parameters change if the pressure critical point vary.

An alternative method for using the known pressure for regulating the pump pressure is to continuously use it to adjust the historical consumption pattern – and thus the pump's setpoint - with real pressure data.
Using this method, management becomes more robust in relation to breakdowns in communication from the pressure sensors, and the utility can still manage in accordance with the locally positioned pressure sensors. At the same time, it achieves pressure management that is able to maintain a pressure that is very close to the optimal pressure at all times during any 24 hour cycle.

Pressure Management Index (PMI)

The utility can use PMI as a strategic calculation tool in connection with fighting water loss.

In recent years, the focus on minimising water loss has meant that pressure management has become more and more relevant as an active tool. This has come about because of the increased knowledge of the relationship between size and water loss, the risk of bursts/frequency and the pressure relationship in the distribution network.

Calculating the Pressure Management Index (PMI) has become part of this discussion in recent years.

Pressure Management Index (PMI) is not considered a definite performance indicator, in line with for example, the infrastructure Leakage Index (ILI), but considered more as a way to indicate which water loss strategy provides the best value for the utility to implement.

PMI is expressed as:

PMI = Current average system pressure (CASP)/Annual minimum reference pressure (MARP)

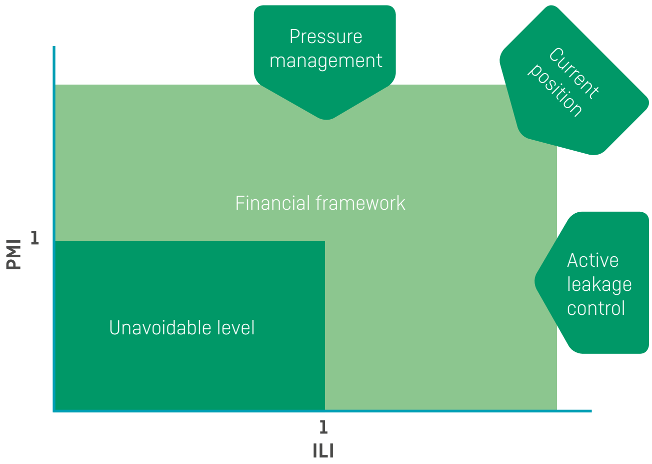
Water balance and ILI are methods, which the utilities can use to calculate and compare their water loss and divide it into smaller portions, so that it can be tackled appropriately. Learn more about water balance and ILI in our white paper *Non-revenue water – Understanding and working proactively with non-revenue water*.

...Pressure Management Index (PMI)

Identification of the most appropriate strategic activity based on PMI and ILI

By mapping the relationship between PMI and ILI for the individual system and its zones, the utility can evaluate the potential with a strategy that is built on:

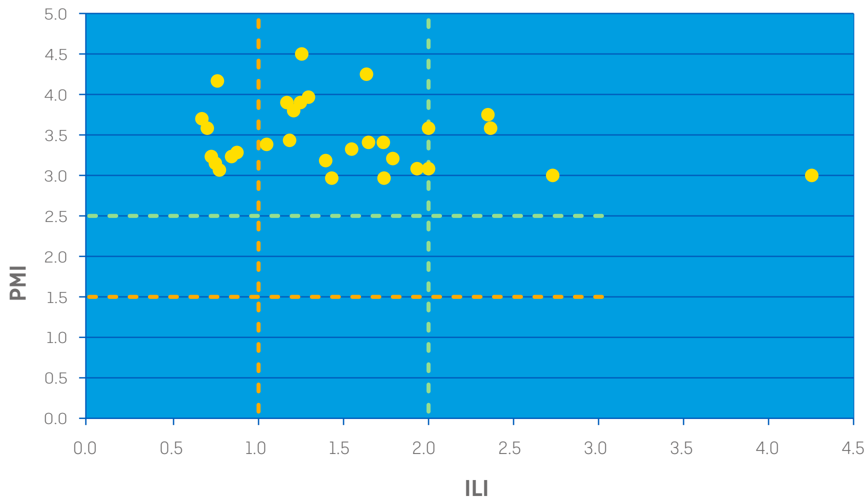
- Pressure management (vertical arrow)
- Active leakage control (horizontal arrow)
- A combination of pressure management and active leakage control (tilted arrow).



(Source: Trow, 2009)

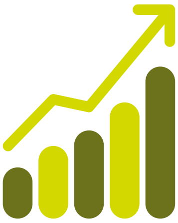
The figure below shows the relationships between PMI and ILI for a large English utility, divided into different pressure zones. It shows that even though some pressure zones are thought to be associated with a moderate to high ILI category (perhaps as a consequence of them still being financially profitable), the operational pressure in several zones indicates that it should be reduced as part of a financial re-assessment.

PMI and ILI for zones in a large English utility



(Source: EU Reference document Good Practices on Leakage Management WFD CIS WG PoM, 2015)

The potential of pressure management



With pressure management, the utility can work proactively with optimising operations and consumer comfort, as well as reducing water loss.

It is relevant to consider pressure management as an active management tool, used to, among other things, lower the amount of water loss – regardless of the level at which the utility lies.

By measuring the pressure relationship at strategic locations in the distribution network and comparing these values with measurement values from the water meters, the utility can generate the optimal "need/ pressure" balance.

Continuous management of the water pressure in the distribution network gives both utilities and the consumers a number of financial and comfort benefits. For the utility, the improvement also includes better asset management and risk management.

By delivering a water pressure at the consumer that does not vary significantly despite changes in consumption over time, the utility can proactively optimise several central parts of the utility:

- Share of non-revenue water (NRW)
- Utility's efficiency
- Operational and Maintenance costs
- Customer satisfaction

…The potential of pressure management

The table below shows some of the benefits the utility can gain related to the distribution system, operations and customers.

Effects and benefits of pressure optimisation								
System benefits			Operational benefits				Customer benefits	
Reduced flow speed			Reduced frequency of leakages and bursts					
Reduced surplus or undesired consumption	Fewer leakages and bursts	Reduced and more effective energy consumption	Less need for repairs, restoration and servicing of pipes	Lower costs related to exposure to liability and wrongful coverage in the media	Delayed re-newal of the distribution network and increased lifetime of assets	Fewer problems related to active leakage control	Fewer problems with customers' branch connections and equipment	Greater level of comfort
Examples of the effect								
Less water loss	Longer lifetimes for pipes and fittings	Lower operating costs	Lower maintenance costs	More positive media coverage	Proactive renovation	Lower costs with pipe leakages	Fewer calls out to branch connection bursts	Greater customer satisfaction

(Source: Multiple Benefits of Pressure Management, WSAA, 2011. See also GRUNDFOS WHITE PAPER Pressure management: http://www.studiomarcofantozzi.it/w/wp-content/uploads/2015/03/Whitepaper_English.pdf)

Source references:

1 IBNET; GWI; Frost & Sullivan

2 https://product-selection.grundfos.com/front-page.html?custid=GMA&=&time=1447740926017&qcid=53629151

3 Thornton & Lambert, water21, Dec 2006

Think forward

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