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## Abstract

In France, the law on national commitment to the environment of July 10, 2010 encourages water services to reduce losses in distribution networks in order to preserve water resources. To support the implementation of this policy, the National Water and Aquatic Environments Office (ONEMA) asked Cemagref to develop a methodology and technical and financial indicators to define and evaluate the actions against water losses (Renaud *et al.* 2011).

Indicators of water losses commonly used in France do not take into account the pressure even though this factor is now recognised as an important parameter to consider for reducing water loss (Renaud, 2010). Very often, those responsible for water utilities consider that the average pressure of a network is a parameter poorly defined and difficult to obtain. To overcome this obstacle, Cemagref decided to study the practicality of defining and measuring pressure indicators, representative of a service zone, in the French context (Sissoko, 2010). This article presents the main results obtained in this study.

### *The link between leakage and pressure*

A leak can be seen as a flow of water through a hole. The rules of hydraulics state that the flow velocity of a fluid through an orifice depends on the head ($v = \sqrt{2gh}$ , the Torricelli formula) or, in other words, the flow rate depends on the pressure.

A commonly accepted formulation of the relationship between leakage and pressure is:

$$\frac{L_1}{L_0} = \left(\frac{P_1}{P_0}\right)^{N1}$$

With:

$L_1$, the leakage rate at pressure $P_1$, $L_0$, the leakage rate at pressure $P_0$ and $N_1$, an exponent whose value depends on the characteristics of the pipes involved. $N_1$ is usually between 0.5 (rigid material) and 2.5 (deformable materials for which the pressure increase is followed by an increase in the size of the hole).

In connection with this formulation, assuming that generally across a network $N_1$ is close to 1, the formula for Unavoidable Annual Real Losses (UARL) proposed by (Lambert, 1999) and adopted by the International Water Association (IWA), assumes a direct proportionality with pressure:

$$UARL\ (liter\ / day) = (18 \times Lm + 0{,}8 \times Nc + 25 \times Lp) \times P$$

With:

*Lm,* network length (without service pipes) in km

*Nc,* number of service connections

*Lp,* distance between street and water meter in km

*P,* average service pressure in m head

Usually, the assessment of losses is carried out at network level (annual indicators) or zonal level (in the case of segmented networks). In order to establish a relationship between pressure and leakage, the pressure must be estimated at these scales while pressure is a parameter that is variable in both space (relation to elevation) and time (head losses are related to flow rate). Therefore, it is necessary to firstly define what is meant by the concept of 'average zone pressure' and also to clarify the ways to evaluate it.

### *Concepts and methods developed by IWA*

Taking pressure into account for the evaluation of leakage reduction in a District Metered Area (DMA) has led to numerous studies. Two methodology references can be cited: "District Metered Areas Guidance Notes (Draft)" (Morrison et al., 2007) and "Leakage management and control – a best practice training manual" (Farley, 2001). The main concepts that were developed for the assessment of a pressure zone or network are:

- Current Average System Pressure (CASP): This is the indicator used to evaluate UARL. It is also known as Average operating pressure in the reference book "Performance Indicators for Water Supply Services" (Alegre *et al.,* 2006).
- Average Zone Night Pressure (AZNP): This indicator is used to manage water losses in DMA with monitoring of night flows.
- Average Zone Point (AZP): Refers to a point where the pressure variations are supposed to be representative of the zone average.

The Water Services Association of Australia (WSAA) has developed a guide for estimating the average pressure of service zones and networks (WSAA, 2009). This method involves the systematic identification of a representative point for each zone (AZP) and offers an approach that includes four steps:

- <u>Step 1: Calculation of weighted average elevation of each zone</u>

From topographic data, the area bounded by two contour lines is considered and the average elevation of the two curves assigned. A weight is then assigned to each band representing the network and the weighted average height is calculated. The weights proposed are:

• The length of pipes or the number of fire hydrants if the density of connections in the area is less than 20 connections / km;

• The number of individual connections if the connection density of the zone is more than 20 connections / km.

- <u>Step 2: Identification of a hydrant AZP representative of each zone</u>

For each zone, a hydrant is selected. It is ideally located near the centre of the zone and its ground level should be close to the weighted average ground level of the zone. If such a point does not exist, a hydrant where ground level is not far from average should be chosen and then the pressure values are adjusted by the difference in elevation.

– Step 3: Evaluate the pressure at the AZP for each zone

- By direct measurement at the AZP;
- By evaluation from measurements at other points located, then estimating the head losses;
- By calculating the pressure with a hydraulic model.

– Step 4: Calculate the average pressure of the network from these zones

The average pressure of the network will be considered equal to the weighted average pressure of all zones. The proposed weights are the same as in step 1 and use the same criteria.

## Methods implemented in the study framework

The methodology proposed by WSAA is designed for sectored networks and systematically applies the definition of an AZP. It is not always applicable, especially in France. Therefore, variants applicable without DMAs or without recourse to the notion of AZP need to be studied.

As part of this study, different methods of assessing the pressure characterising a service zone have been tested. They are partly based on the WSAA method and have been adapted to the available data from water utilities in general and, in particular, from our study areas.

Two real cases have been studied, “RMMS de La Réole” and part of the “SIAEP de Coulounieix Razac”. Both water utilities have remote flow metering, with 4 and 7 DMAs respectively. For each service, hydraulic model and GIS (Geographic Information System) capabilities exist, but information about individual connections is not available.

**Table 1** Principal characteristics of the studied DMAs

| Utility | DMA | Type of supply | Particular nature | Length (km) |
|---|---|---|---|---|
| **RMSS de La Réole** | S1 | Pumping - distribution | Low service | 12 |
| | S2 | Distribution | High service | 27 |
| | S3 | Distribution | Fed by S2 | 12 |
| | S4 | Distribution | Fed by S3 | 20 |
| | **Network** | | | **71** |
| **SIAEP DE COULOUNIEIX RAZAC** | S033 | Distribution | High service | 19 |
| | S118 | Distribution | Low service | 12 |
| | S121 | Pumping - distribution | Two PRV | 25 |
| | S122 | Distribution | High service | 11 |
| | S124 | Distribution | Medium service | 09 |
| | S125 | Distribution | Medium service | 11 |
| | S126 | PRV | Stabilised | 11 |
| | **Network** | | | **98** |

Given the available data, hydraulic modelling nodes were chosen as basic entity for weights and three weighting schemes were considered, if $w$ is the weight assigned to a node:

– $w_i = u_i = 1$:uniform weight

– $w_i = c_i$ :daily average consumption at node i

– $w_i = l_i$ :pipe length of the node $i$ (length = ½ sum of the length of the pipes attached to the node).

In the absence of information on the number of service connections, it is assumed that the average daily consumption is representative of the number of connections. For the topography, in the absence of more precise information, the elevations of the nodes mentioned in the hydraulic models were used.

Three methods were tested to evaluate CASP (Current Average System Pressure) and AZNP (Average Zone Night Pressure):

- "Topographic" method
- "Hydraulic model" method
- "Measurement" method.

### *"Topographic" method*

This method is based on a topographic approach and neglects the pressure variations due to head losses. The average static pressure, $PS_{wz}$ of a zone, *z,* with weights, *w*, is obtained by the difference between the head of the tank overflow $HS_z$ of the reservoir supplying zone z or, where applicable, the total head of the device feeding the zone (pump, pressure reducing valve, etc.) and the weighted average ground level $WAGL_{wz}$.

In this method, we consider that *PSwz* is both an evaluation of CASP and AZNP.

$$PS_{wz} = HS_z - WAGL_{wz}$$

With:

$$WAGL_{wz} = \frac{\sum_{i=1}^{n} GL_i \times w_i}{\sum_{i=1}^{n} w_i}$$

$GL_i$ : Ground level (elevation) of node i.

### *"Hydraulic model" method*

This method relies on the hydraulic model and considers the hourly variations of pressure during a typical day; the head losses being evaluated by the model. The dynamic pressure, $PD_{hi}$, is calculated for each node, *i* ,at each hour, *h*, allowing the calculation of the weighted hourly average dynamic pressure of the zone, *z*, using the following formula:

$$PD_{wz}^{h} = \frac{\sum_{i=1}^{n} PD_i^h \times w_i}{\sum_{i=1}^{n} w_i}$$

The estimation of CASP is then the weighted daily average dynamic pressure of the zone, *z*, defined as:

$$PD_{wz}^{j} = \frac{\sum_{h=0}^{23} PD_{wz}^{h}}{24}$$

The estimation of AZNP is defined as the maximum hourly average dynamic pressure of the zone between 02:00 and 05:00.

$$PDN_{wz}^{j} = Max_{h=2}^{5}\left(PD_{wz}^{h}\right)$$

### *"Measurement" method*

This method is based on pressure measurements taken at one point representing the average for the zone, AZP. A measurement of the pressure is made at a point, k, considered to represent the zone, *z*, and whose ground level $GL_k$ is close to the weighted average ground level *WAGLwz*.

With $PM^h_k$ being the measured pressure at the point, *k*, at time, *h*, the time-weighted average pressure of the zone, z, is calculated as follows:

$$PMwz^h_{azpk} = PM^h_k + GL_k - WAGL_{wz}$$

CASP evaluations and the resulting AZNP are then respectively:

$$PMwz^j_{azpk} = \frac{\sum_{h=0}^{23} PMwz^h_{azpk}}{24}$$

and $PMNwz^j_{azpk} = Max^5_{h=2}\left(PMwz^h_{azpk}\right)$

## Results obtained

The three previously defined methods were applied to the two studied water utilities at the DMA level and at the network level (the whole network in the case of RMMS de la Réole and the combined seven DMAs for the SIAEP de Coulounieix Razac). The results allow several observations to be made.

### *Impact of weighting system*

The weighting system used has a strong impact on the results, as shown in the table below displaying the results of the CASP calculation performed using the "hydraulic model" method for the RMMS de La Réole.

**Table 2** RMMS de La Réole. CASP calculated by the “hydraulic model” method. Impact of the weighting

| DMA | *PDju* | *PDjc* | *PDjl* | Average | SD | CV |
|---|---|---|---|---|---|---|
| | m | m | m | m | m | % |
| **S1** | 41.7 | 42.9 | 48.8 | 44.5 | 3.8 | 8.6% |
| **S2** | 66.4 | 64.6 | 64.1 | 65.0 | 1.2 | 1.9% |
| **S3** | 98.0 | 107.0 | 95.3 | 100.1 | 6.1 | 6.1% |
| **S4** | 93.6 | 99.9 | 90.8 | 94.8 | 4.7 | 5.0% |
| **Network** | 64.6 | 69.9 | 74.4 | 69.6 | 4.9 | 7.0% |

The coefficient of variation CV (standard deviation, SD, divided by the average) according to the weighting system reaches significant values: 8.6% for S1 and 7% for the network as a whole. It is also notable that the hierarchy of CASP values based on weighting schemes depends on the DMA. For example, the weighting according to pipe length results in a higher value than that based on consumption for DMA S1 and the network, while the reverse is true for other DMAs.

The weighting system is not neutral; it is necessary to make recommendations in order to obtain comparable results from one water utility to another. To the extent that the pressure assessment is performed with the aim of tackling leakage, it makes sense to focus on weighting that is related to the possible causes of leakage. In the present state of our knowledge we can propose the following weight ranking system according to the available information:

- Number of service connections
- Daily consumption
- Network length
- Uniform

### *Impact of the method*

The table below shows the results for the DMAs studied in the SIAEP de Coulounieix Razac network. The results of the “Measurement” method were obtained following a series of measurements, detailed in the (Sissoko, 2010) report.

**Table 3** SIAEP de Coulounieix Razac – Calculation of CASP – Impact of the method

| DMA | Topographical | Hydraulic model | Measurement | Average | SD | CV |
|---|---|---|---|---|---|---|
| | m | m | m | m | m | % |
| **S033** | 47.9 | 46.6 | 45.6 | 46.7 | 1.2 | 2.5% |
| **S118** | 37.9 | 36.2 | 41.1 | 38.4 | 2.5 | 6.6% |
| **S121** | 73.9 | 56.8 | 53.7 | 61.5 | 10.9 | 17.7% |
| **S122** | 60.3 | 58.9 | 46.3 | 55.1 | 7.7 | 14.0% |
| **S124** | 46.0 | 45.7 | 46.8 | 46.2 | 0.6 | 1.2% |
| **S125** | 56.5 | 55.0 | 67.8 | 59.8 | 7.0 | 11.7% |
| **S126** | 44.6 | 44.5 | 45.9 | 45.0 | 0.8 | 1.7% |

It appears that the coefficient of variation according to the method is very different from one DMA to another. It is small (less than 3%) for DMAs S033, S124 and S126 while it is more important for other DMAs, especially in the case of DMA S121 (17.7%). The technical review of the operating modes of the different DMAs helps to understand these differences:

- When the DMA is fully served by a pure distribution reservoir and has no regulatory system, the three methods lead to very similar results. The same situation is observed when the DMA is powered by a Pressure Reducing Valve (PRV), set at constant;
- When the DMA is supplied by Pumping-distribution, the topographical method, applied without correction leads to very different results from the other methods;
- When the DMA has several pressure zones, which is the case when part of the DMA is supplied via PRV, the three methods lead to results that can be very different due to the impossibility of determining a representative AZP to apply the “measurement” method.

As a result, each method has a scope beyond which it can not be used without precautions and corrections.

### *Representativeness of the average day*

The "Hydraulic model" and "Measurement" methods calculate an average pressure over 24 hours, for a day supposed to be representative. It appears that sometimes the pressure of a DMA does not follow a cycle of 24 hours; that case was found in the DMA S1 of the RMMS de la Réole network (Figure 1). This phenomenon is explained by the automatic pumping controlled by the water level in the tank which leads to a drain/fill cycle of about 29 hours.

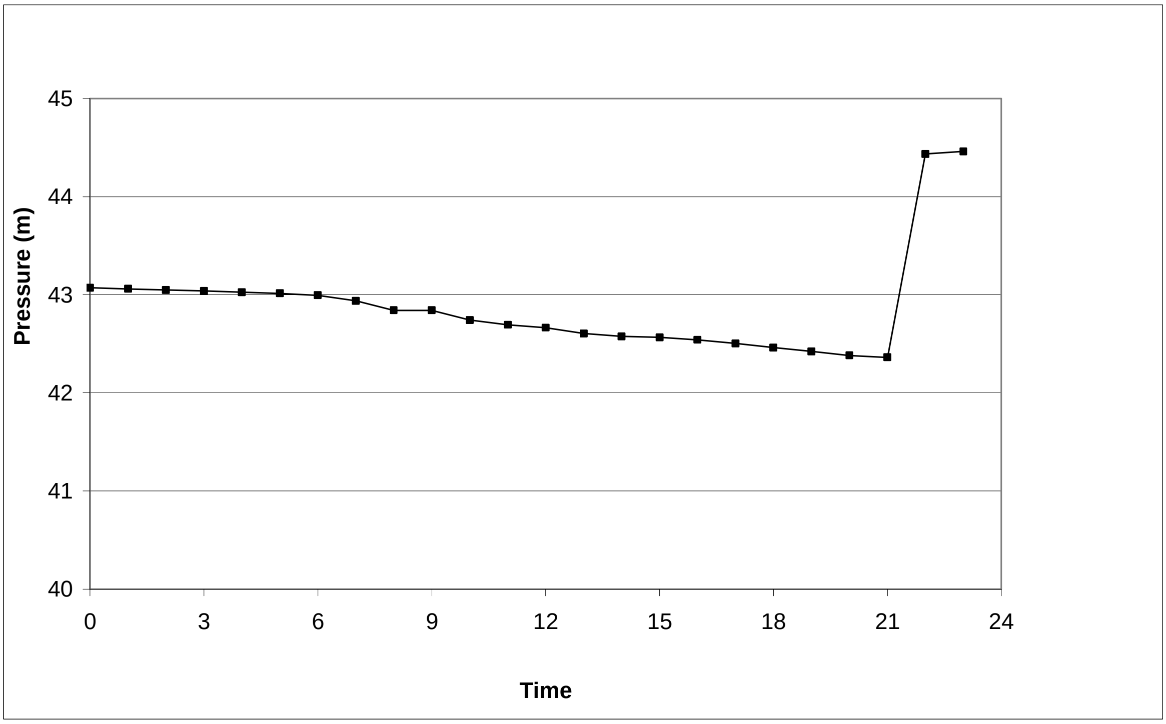


**Figure 1** RMMS De la Réole. "Hydraulic model" method. Dynamic hourly pressure of DMA S1 over 24 hours

In such cases, it is necessary to calculate the pressure over a longer time step. Figure 2 shows the calculation over a week of daily average pressures and combined average pressures of the previous days.

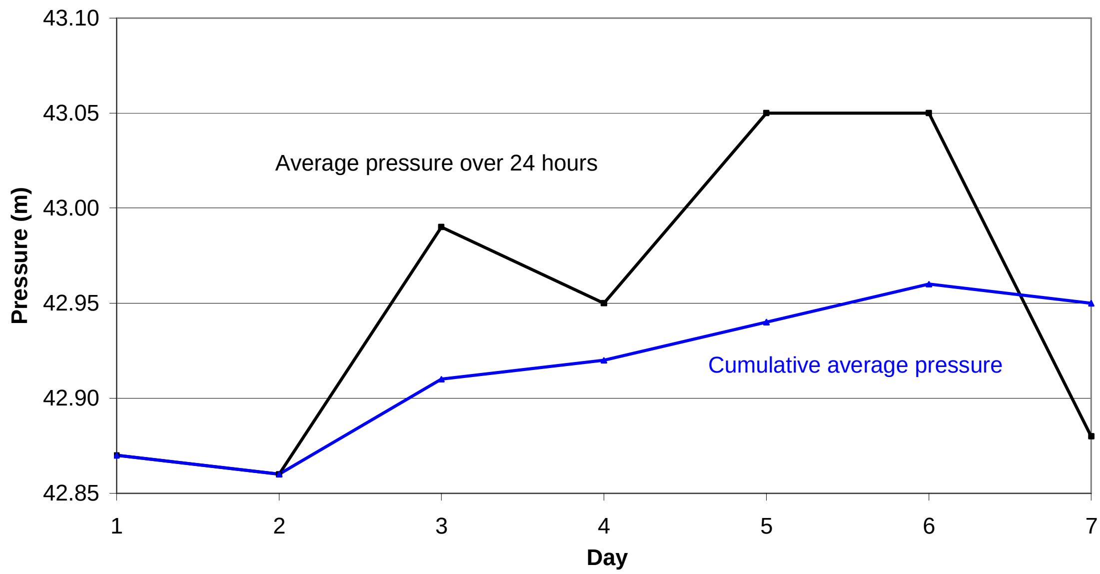


**Figure 2** RMMS De la Réole. "Hydraulic model" method. Average pressures of DMA S1 over a week

In this particular case, the pressure varies little and stabilises at the end of the week. However, care must be taken in the case of areas where the pressure at the end of a cycle of 24 hours is significantly different from that found at the beginning of the cycle.

# Conclusion

After conducting the investigations, it appears that the three methods of assessing the pressure that were considered are generally applicable and that they each have advantages and disadvantages, so that, no method should be discounted. This is summarised in the table below.

**Table 4** Comparison of the three pressure evaluation methods

| | **"Topographic" method** | **"Hydraulic model" method** | **"Measurement" method** |
|---|---|---|---|
| **Basic principles** | The mean pressure is assumed to be similar to the static pressure which can be estimated from the elevation of the system components. | The mean pressure is calculated from a hydraulic model assumed to be reliable for mean daily demand. | The mean pressure is deduced from measurements taken at a point that is assumed to be representative of the whole DMA. |
| **Necessary information** | Plan of the network with background topography (contour lines). | Existence of a calibrated hydraulic model with recent reliable demand information. | Topographic information and a measurement point with ground elevation known precisely. |
| **Application scope** | Well adapted to pure distribution DMAs. To be applied with caution in other cases. | Applicable for all types of DMA so long as the operation conditions and demands are well known. | Only applicable to DMAs where all consumers are subjected to the same pressure regime. |
| **Advantages** | Easy to implement even for networks for which knowledge is limited. | Applicable for all types of DMA. Easy to simulate different configurations. | Quite simple to implement and allows adaptation to changes in operation or demand. |
| **Disadvantages** | Not suitable for complicated networks | Does not permit a simple and realistic adaptation to the possible changes in demand. | Not suitable when there are many pressure regimes and requires installation of measuring equipment. |
| **Precautions** | Besides simple distribution networks, precautions must be taken and corrections implemented. | The quality of the model is paramount; it is useful to test for coherence with other methods. | The elevation of the measurement point must be known precisely; the representativeness of the point should be checked. |

It was also shown that the weighting system used to calculate the average pressure has a strong impact on the results which leads us to advocate using the weighting by the number of connections, whenever this information is available.

Some zones might experience different operating conditions during the year, this is often particularly true of certain tourist areas where facilities operate only during peak season. In such cases, it is necessary to evaluate the pressure for each plan of operation and then to deduce the pressure by making an average, weighted by the length of periods.

From a general point of view, it seems that for the vast majority of water utilities, including small rural ones with limited resources, one or other of the methods considered are applicable without major difficulties. Thus, with the appropriate recommendations, the current average system pressure (CASP) is an indicator that could be widespread in France and included in the annual report on price and service quality.

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